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Biofuel & biorefinery portfolios of petroleum companies–Policy & nomenclature implications

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ABSTRACT

This research investigated the biofuel and biorefinery portfolios of several prominent petroleum companies. The results show that they invested in biofuel research, and produced, not only conventional but also, innovative biofuels, such as crude, bio oil, green naphtha, hydrogenated vegetable oil, renewable natural gas, renewable compressed natural gas, sustainable aviation fuel, sustainable liquefied petroleum gas, bio-liquefied natural gas, bio-butanol, bioethanol and alcohol-to-jet fuels. They are also converting petroleum refineries to biorefineries. However, their current efforts remain insufficient for net zero target attainment. Four petroleum companies divested from some biofuel portfolios because of inconsistent energy policies' impacts on profitability. These biofuels and their diverse feedstock and production processes highlight the great need for the establishment of international biofuel and biorefinery product nomenclatures, standardization and policy upgrades to ensure net zero attainment.

Keywords: biofuels, biodiesel, biorefineries, nomenclature, policy

INTRODUCTION

Bioethanol and biodiesel (hydrogenated vegetable oil [HVO]) are conventional sustainable transportation fuels produced by many companies and countries. According to the IPCC (2022), "biofuel is a fuel, generally in liquid form, produced from biomass." It includes ethanol made from sugarcane, sugar beet or maize, and biodiesel made from canola or soybeans. Biomass is also an "organic material excluding the material that is fossilized or embedded in geological formations." To avoid competition with food sources (primary feedstock), current efforts target secondary and tertiary production feedstocks.

Primary biofuels utilize food sources as feedstocks for biofuel production, whereas secondary biofuels use dry woody wastes, including agricultural and forest residues, as feedstocks. Tertiary biofuel production occurs by the action of microbial algae. The net zero emissions envisage a significant increase in bioenergy use by 2050, and the displacement of fossil fuels by 2030. While Brazil is the global leader in bioethanol production, the European Union is the leader in biodiesel production. The impact of the transition from petroleum fuels to biofuels is more significant among the largest global fuel consumers, such as those in the aviation and petrochemical industries.

The aviation industry has adopted sustainable aviation fuel (SAF), including alcohol-to-jet (ATJ) family processes, which use bioethanol or biobutanol as feedstocks to produce SAF. Currently, biofuels are the only known alternatives to hydrocarbon liquid energy carriers, and this will likely remain the case for propulsion technologies (ICAO, 2021).

Biofuels are not just transportation fuels. In addition to hydrogen and its derivatives, they are the requisite fuels for the harder-to-abate sectors. The aviation net-zero low-carbon targets require a combination of biofuels, as they are vehicle-ready fuels. Although biofuel production can occur in stand-alone facilities, they enjoy economies of scale if produced within biorefineries.

Petrochemical production, on the other hand, employs oil and gas as feedstocks and it is the largest consumer of industrial hydrocarbons worldwide. Their product demand growth projects to more than a third of the world's oil demand growth in 2030 and approximately half by 2050. They will utilize an additional 56 billion cubic meters of natural gas by 2030 as feedstock, to produce a large number of diverse chemical products (Energy Education, 2020; Gikunda, 2019). Petrochemical products are not biodegradable, as they are environmentally recalcitrant. The global demand for petrochemical plastics will increase their carbon emissions to 2 Gt yearly by 2050 through their production processes and 4.2 Gt from their product end-of-life emissions. The plastic production process emits 2.5 tons of CO_2 per ton of plastics on average, whereas their end-of-life decomposition emits approximately 2.7 tons of CO_2 per ton of plastics. The production of bioenergy, bioplastics and green chemicals, which are alternatives to petrochemicals, can occur within a biorefinery.

The International Energy Agency (IEA) bioenergy task 42 (IEA Bioenergy Task 42, n. d.) defines "biorefining as the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, and materials) and bioenergy (biofuels, power, and heat)." It is, therefore, a strategic conversion of biomass, into a portfolio of bioproducts, green chemicals and bioenergy, as biorefineries combine bioethanol, biogas, biodiesel, bioplastics, heat, biopower, and green chemical production (instead of petrochemical production) into a single integrated production facility, in efforts toward carbon neutrality, biodegradability and sustainability. Biorefineries are sustainable replacements for petrochemical plants and refineries because they use biomass feedstock as raw materials to produce sustainable alternatives to petrochemical and refinery products and capture the emitted carbon dioxide. Their products, including bioplastics, contribute to net zero attainment, and, unlike petrochemicals, they are environmentally biodegradable. Effective policies are therefore required to transform petrochemicals into biorefineries.

The goal of energy policy is to ensure energy security and reduce global carbon emissions. While this is commendable, green fuels find it challenging to compete with hydrocarbon fuels, as the latter is less expensive, primarily because their price fails to account for carbon emission costs in their production. Currently, energy policies provide subsidies for biofuel production, and, at the same time, tax carbon emissions from hydrocarbon fuels in many countries. While the efficiency of these policies in ensuring net zero attainment requires improvement, nomenclature ambiguity or absence further complicates it.

Nomenclature is a naming system or classification based on rules, principles, or terms that regulate both the formation and use of specialist terms, as agreed upon by international scientific conventions. It is part of, but distinct from, taxonomy. The latter entails classification system study, including principles, rules, and procedures, while classification orders 'taxa' or classification objects by exploiting their differences or similarities. As a branch of taxonomy, nomenclature focuses on the application of scientific names to taxa, using particular classification schemes agreed upon by global rules and conventions. The scientific precision required often results in the adoption and use of codes (IUPAC, 1998; Panico et al., 1994).

Several workers in the fields of biofuel and biorefinery classification and nomenclature reported the systematic classification of biorefineries through their feedstock, platform process, and product knowledge (Cherubini et al., 2009). The classification of biofuels makes use of their feedstock generation, physical state, product generation, and technology maturity (Awogbemi et al., 2008).

According to DeTar (2007), industrial growth and increasing global biofuel production have resulted in multiple feedstock conversion technologies, the use of different production feedstocks, diverse process methods, and the absence of globally established common standards, leading to global biofuel nomenclature challenges. He also reported the existence of common misconceptions about the use of certain feedstocks and general processes in the production of specific biofuels, while in reality, the use of different processes and feedstocks was the norm. The EIA (2023) warned that this might become more complicated and result in confusion regarding naming systems and standardization issues. If left unaddressed, worldwide confusion will emerge, hindering international biofuel trade (American Chemical Society, 2007).

The UCSUSA (1999) reported that the benefits of establishing globally accepted biofuel and biorefinery nomenclatures include the promotion of product safety and quality assurance, compatibility, referencing and benchmarking. It also includes comparisons and common technical understanding, identification of technical gaps and acceleration of technological innovation. There is still ambiguity surrounding quality standards and the general nomenclature of some biofuels, while 'denaturation' obligations add to the obstacles mounting against the international trade of bioethanol.

To date, previous studies have not envisaged or addressed the emerging novel biofuel and biorefinery products, and their implications for the existing nomenclature challenges. How the major oil and gas players respond to these issues within their energy transition programs, as well as the policy implications also remains an open question. Therefore, this investigation is important, as it will fill an important gap in the literature while drawing attention to the great need to establish global nomenclature standardization.

This research aims at identifying the different types of biofuels currently produced by several leading international and national petroleum companies (Eni, BP, Chevron, ExxonMobil, Equinor, Total and Shell, and ConocoPhillips, SINOPEC, Aramco, and NNPC). This study will establish their significance in the achievement of net zero targets, and their implications in the search for standardization in international biofuel and biorefinery nomenclatures as well as the impact of applicable energy policies.

MATERIALS AND METHODS

Basis for Research Questions

Biofuels are the only known liquid sustainable energy carriers, as bioethanol and biodiesel (HVO) possess energy densities comparable to those of hydrocarbon fuels. It is therefore relevant to know if and to what extent these companies are producing them. It is also important to determine the innovative fuels produced by these petroleum companies since they can fill the gap created by a decreasing fossil fuel consumption caused by the energy transition and contribute to global energy security and carbon emission reduction.

On the other hand, biorefinery deployment is required to produce not only biofuels, bioplastics, biopower, and heat, but also green chemical alternatives to petrochemicals. As the latter is the largest global oil demand driver, its prompt transformation into biorefineries is critical to net zero attainment. If there are no efficient biofuel policies and standardized global nomenclature, international biofuel and biorefinery production, as well as global trade, will be in danger, compromising their growth and sustainability. This research examines the policy implications and answers the research questions listed in the following sub-section.

Research Questions

1. What are the conventional and innovative biofuels produced by petroleum companies?
2. What global biofuel and biorefinery classification systems and nomenclature exist for their standardization and global recognition?
3. Are current biofuel portfolios and policies sufficient to meet demand gaps due to the anticipated decrease in fossil fuel production?
4. What roles do they play in net zero attainment?
5. How and to what extent has biofuel production addressed global warming threats?

Criteria for MOC Choice

The seven leading multinational oil and gas companies' (MOCs) selection is due to their great influence on global petroleum industry operations and strategic direction. With 12% of world petroleum reserves within their custody, they are equally responsible for 10% of the estimated global industry's greenhouse gas emissions as well as 15% of global production. They are also the largest publicly traded MOCs (Asmelash & Gorini, 2021). ConocoPhillips, SINOPEC, NNPC, and Aramco were included as regional leaders to enable us to obtain a perspective beyond these global industry leaders.

SINOPEC leads Asia; Aramco is a major player in the Middle East, while Nigeria is a top producer in Africa. Since almost all of them are engaged in the energy transition, their choice will shed more light on the status of the global oil and gas industry because, through their practices and investments, they influence and set the pace for the petroleum industry.

Analytical Tools for Assessment

As research questions determine research philosophy choice (May, 2011), a particular philosophy is not necessarily better, rather, it does justice to the methodology, which, in turn, is influenced by the observed phenomena. This investigation employed the deductive method for the development of hypothetical expectations from existing data (Saunders et al., 2007). The existing theory supports the approach used in research design (Silverman, 2013), since it is the acceptable, measurable, and provable knowledge sought, with the aid of pragmatism and positivism (Bryman, 2012).

Research Design

Descriptive investigation clarifies the phenomenon under study, before the acquisition and evaluation of data, as well as the synthesis of ideas, and, with the aid of explanations, enhances descriptive research. It has the advantages of an accurate profile, and detailed description, and answers the 'when', 'where', 'who,' 'how', or 'what' research questions. However, these methods are often lengthy, incomplete, and lack numerical evaluation and idea synthesis.

Explanatory research aids in the resolution of the 'how' and 'why' or research questions, as it establishes the cause-effect relationships between variables. However, they tend to overemphasize relationship resolution between variables and therefore might miss the opportunities for novel theory contributions.

Evaluative research provides answers to 'to what extent', 'how,' 'who', 'which,' 'where,' or 'when,' research questions and how effective policies or strategies are, and evaluates the effectiveness of organizational policies and programs, such as performance and comparisons. This approach might result in new theory contributions if focused on understanding, rather than just effectiveness. The disadvantages of these methods include their focus on strategy or policy effectiveness, which may lead to the neglect of the understanding of 'why', and, perhaps, missed opportunities for theoretical contributions (Creswell & Creswell, 2018; May, 2011).

Consequently, the adoption of evaluative, explanatory, and descriptive, research aided in the evaluation of petroleum companies' biofuel and biorefinery portfolios to answer the research questions. Through descriptive analysis, the biofuel and biorefinery portfolios of these companies was analyzed, explained, and assessed by identifying and documenting the projects each company carried out and eventually assessing them against IEA projections and net zero projections (IEA, 2020, 2021, 2023; IEA Bioenergy, n. d.; IEA Biofuels, n. d.).

Secondary Data Sources

Secondary data was obtained from Shell, Eni, Chevron, BP, Equinor, ExxonMobil, TotalEnergies, SINOPEC, NNPC, Saudi Aramco, ConocoPhillips, and the International Renewable Energy Agency, the IEA and EIA websites and reports, from 2021to 2024.

Ethical Issues

The data copyrights belong to IEA, EIA, and IRENA. The use of the petroleum companies' data evaluated against those of the IEA, EIA, and IRENA's independent reports ensured objectivity (Dale et al., 1988; Hair et al., 2011; Smith, 2008).

RESULTS AND DISCUSSION

Petroleum Companies Biofuel & Biorefinery Portfolios

The results show that Shell, ExxonMobil, TotalEnergies, Eni, Chevron, SINOPEC, ConocoPhillips, Aramco, and BP have research and operational biofuel and biorefinery plants, whereas Equinor has only a biofuel research project. The NNPC had none. Unlike several renewable energy sources, biofuels represent important 'drop-in' or readily usable transportation fuels that are energy-dense, such as hydrocarbons, but are limited in scale, profitability, and sustainability. Unlike countries with petroleum reserves, biofuels can increase energy security, since any country can manufacture them rather than a few. All the petroleum companies except Equinor and NNPC are currently investing in new biorefineries. They are also transforming existing hydrocarbon refineries into

Table 1. Oil companies' biofuels, biodiesel, & biorefineries portfolios

Green fuels	Code	Main features	Companies	Feedstock
1. Sustainable aviation fuel	SAF	Similar to petroleum jet fuel	All but Equinor & NNPC	Bioethanol/bio-based alcohols
2. Bio liquefied natural gas	Bio-LNG	Similar to hydrocarbon LNG	All MOCs except Equinor	Biodegradable wastes
3. Renewable compressed natural gas	R-CNG	Similar to hydrocarbon CNG	Most of the 7 MOCs	Biodegradable wastes
4. Renewable natural gas	RNG	Similar to hydrocarbon NG	All MOCs except Equinor	Biodegradable wastes
5. Hydrogenated vegetable oil	HVO	Similar to petroleum diesel	All but Equinor & NNPC	Animal fats/plant oils
6. Alcohol to jet fuels	ATJ	Alcohol to isobutanol	All MOCs except Equinor	Bioethanol/bio-based alcohols
7. Biobutanol & isobutanol	BbT/ iBbT	Blends with gasoline & dense	Shell, BP, & TotalEnergies	Non-food or grass
8. Bioethanol & biomethanol	BeL/BmL	Used as 100% fuel or blended	All but Equinor & NNPC	Non-food or grass
9. Sustainable liquefied petroleum gas	S-LPG	Similar to petroleum LPG	Eni	Biodegradable materials
10. Biocrude	BcD	Biomass liquefaction	Shell, Eni, & TotalEnergies	Wood & supercritical water
11. Sustainable bio oil	S-BiO	Inert rapid heating & rapid quenching	ConocoPhillips, Shell, & TotalEnergies	Wood & supercritical water
12. Renewable naphtha	RN	By-product of biodiesel product	Eni	Biodegradable plastics
13. Biorefineries with BECC	BrF	Biofuels, green chemicals, power, heat, & bioplastics	All but ConocoPhillips & NNPC	Plant materials

biorefineries along with 'bioenergy carbon capture (BECC) and storage systems'. Since biorefineries also emit carbon, the combination of biorefineries with BECC systems achieves emission reduction and carbon dioxide removal from the atmosphere (Seabra, 2021).

Until recently, the term biofuel was a reference for bioethanol and, in some cases, biomass combustion for heating and cooking purposes. However, this research revealed that biofuels have expanded significantly to include a growing number of products of diverse compositions. The biofuels produced by these petroleum companies include biocrude, bio oil, green naphtha, HVO, and renewable natural gas (RNG). Others include renewable compressed natural gas (R-CNG), SAF, bio-liquefied natural gas, sustainable liquefied petroleum gas, and ATJ (see **Table 1**). Bio-methanol gas, liquefied petroleum gas, and bio-butanol investments, initiated as part of advanced biofuel schemes, have diverse production feedstocks, including biogas, syngas, algae, sugars, oils, organic solutions, lignin, and pyrolysis oil, among others. The same applies to their production systems.

As part of its plan to transform from a hydrocarbon producer to a sustainable energy company, BP has three sugarcane-for-biofuel processing units in Brazil, its production is increasing (from 22,000 to 100,000 bpd). With the joint venture between BP and Bunge Bionergia, BP increased its portfolio by more than 50%, with 11 plants/units, and has a 30% stake in Green bio-fuels, the UK's largest HVO biodiesel producer. The joint venture sold more than 55 million liters between 2020 and 2021. BP intends to use its eco-refining technology for the production of renewable diesel and SAF in Australia and plans to convert its hydro-processing equipment so that it can produce approximately 10 kb of biodiesel and SAF. From its 2021 bioethanol production of 776 million liters of equivalent sugarcane, it is making a 10-fold increase in the $500 million it invested in for the production of 100,000 bpd compared with the previous 22,000 bpd; thus, it doubled the daily customer interface from 10-20 million. BP has a conventional biofuel business that is profitable, yet it plans to make other, more advanced biofuels, including bio jet fuel viable options, renewable liquefied natural gas (R-LNG), and methanol, hydrogen, and ammonia for power and heavy industry decarbonization. It won permission in early 2024, from the Western Australian environmental protection authorities, to transform a hydrocarbon refinery based south of Perth into a biorefinery that will utilize animal fats, vegetable oils, and related waste feedstock. It is one of the five multibillion-dollar biofuel global projects planned by BP. The BP/DuPont joint venture bio-isobutanol (Butamax), increases the renewable content of gasoline more than bioethanol does and decreases the carbon content of fossil-derived isobutanol in petrochemicals. Moreover, the water solubility challenges of bioethanol and bioethanol are lacking, and bio-isobutanol is therefore transportable through existing fuel pipelines.

To maintain its leadership role in biofuel and biorefinery innovation, Shell converts sugarcane waste to biofuel in Brazil, and biomass and waste to biofuel in Bangalore, India, and partners with stakeholders to grow the SAF as demand increases. It intends to offer biogas and R-LNG to Chinese, European, and American customers, and blends approximately 10 billion biofuels liters annually, including R-CNG and liquefied renewable natural gas (bio-LNG), and has six million gallons of SAF supply contract with the Amazon. The company's global alliance with Arbios Biotech is developing a biorefinery that uses wood, biomass waste and supercritical water to produce 'biocrude' and bio oil. The company developed a biofuel plant with 820,000 tons/annual capacity. It converted 14 petroleum refineries to biorefineries. Along with its partners, Shell intends to supply bio-LNG to customers by 2025, and it is building an R-CNG fuel station in California. Its Raízen waste-to-bioethanol plant, which produced 2.5 billion liters of bioethanol in 2019, is the 4th largest RNG facility in the world. Its Rheinland refinery reportedly produces a similar amount of low-carbon fuel (LCF) for over half a million vehicles yearly. Another LCF plant in Quebec will treat more than 200,000 tons of woody waste annually to produce approximately 125 million liters of LCFs annually. Its company's first American RNG facility converts cow manure and farm residues into 2,650 scfm biogas and was subsequently upgraded to approximately 736,000 MMBtu annually.

As the first company to transform a hydrocarbon refinery into a biorefinery in France, TotalEnergies invested $14 million in the Renmatix biofuel project. The facility uses supercritical water to reduce the biomass conversion cost for the transformation of wood and agricultural waste to cellulosic sugars used in biofuel production. The company transformed the La Mède hydrocarbon refinery into France’s first biorefinery in 2017. The biorefinery has a 500,000 ton capacity and uses different oils for the manufacture of biodiesel and biofuel feedstocks. In partnership with SINOPEC, it produces SAF.

After so much global media publicity and completed sea trials of its tertiary (algae) shipping biodiesel, which it developed with its partner Viridos, ExxonMobil stopped the project, saying it ‘requires additional work’. The marine biodiesel project had a 10,000 bpd production capacity. Although ExxonMobil works with many research institutes and universities, the halted project was the most prominent.

In other to become a big player in the biofuel production business, and significantly engage in the energy transition, Chevron acquired the ‘Renewable Energy Group,’ including the latter’s twelve biorefineries, with a combined production capacity of five hundred million gallons of biodiesel and renewable diesel production. Its Imperial Oil affiliate in Edmonton, Canada, is investing $560 million to build a 20,000 barrel biodiesel plant. With a 49.9% stake in the Norwegian Biojet project, it intends to expand RNG to 40 billion BTUs daily, renewable fuel production to 100,000 barrels daily and biodiesel/bio-jet fuels to 100,000 bpd by 2030. Its partnership with Novvi aims to join renewable base oil to lubricant product lines, for SAF production. Its joint venture with CalBioGas produces biomethane, whereas Brightmark produces RNG from dairy waste. Chevron has eight carbon capture and storage facilities, including a BECCS, which captures and stores carbon dioxide emitted from biorefineries. Like ExxonMobil, Chevron closed two of its US-based biodiesel plants in Iowa and Madison, citing market challenges and the US EPA’s renewable fuel standards.

While TotalEnergies was the first company to transform a petroleum refinery into a biorefinery in France, Eni was the first company in the world to do so. In 2014, it transformed two of its hydrocarbon refineries at Venice and Gela into biorefineries. Both of them have capacities of 400,000 and 750,000 tons/year, respectively. Their products include SAF, green naphtha, biodiesel, and renewable liquefied petroleum gas (R-LPG). However, it plans to divest from its biofuel and bioplastic stakes, totaling 1.3 billion euros, citing ‘more focus on greener projects.’

Equinor has no significant portfolio or investment in biofuels, although the company launched a diesel with a 7% biodiesel blend in 2009. In partnership with a Brazilian company, it conducts research into advanced biofuels such as biokerosene and biodiesel.

To create innovative methods of biomass conversion to sustainable transportation fuels, ConocoPhillips signed a $5 million research agreement with some research organizations and universities. As it intends to create renewable fuel from algae, it is focusing on making triglycerides from algae, for the production of SAF, ‘renewable gasoline’, HVO, and renewable diesel production. ConocoPhillips currently converts triglycerides into fuels by using animal tallow and soybean oil to produce biodiesel. The company is also funding research for the use of fast ‘pyrolysis’ to convert biomass to fuel. The process employs heat without oxygen to convert biomass to bio oil. The latter serves as heating oil and is convertible to transportation biofuel in petroleum refineries or biorefineries. Like some MOCs reported above, it stopped one biofuel production project due to energy policy inconsistency when unfavorable legislation reduced some biofuel incentives, specifically, the removal of subsidies. The renewable diesel project was supposed to produce 175 million gallons annually. This is an indication that oil companies, like any enterprise, will not hesitate to reduce or divest from their biofuel portfolios if their profitability is threatened.

As one of its energy transition engagements, Saudi Aramco is researching algae-based biofuel and has already produced the first batch of crude from microalgae. Its majority-owned Satorp started producing SAF in 2023. However, according to Business Green (2024), the company is issuing “misleading environmental claims” that rely on “confusing use of terminology” to promote its biofuels, thus increasing concerns about the implications of the absence of acceptable global nomenclatures, which promote confusion and harm the biofuel market across international boundaries.

China’s largest petroleum refiner, SINOPEC plans to transform from hydrocarbon fuel production to liquid biofuel production, to attain net zero. Consequently, it has started research and development on bio-bioethanol, biodiesel, algae biodiesel technology, cellulose ethanol technology, and biofuel technology. It signed an agreement with TotalEnergies (2024) in March 2024, for the joint development of a SAF production unit at SINOPEC’s refinery for the production of 230,000 tons of SAF annually. The project will utilize SINOPEC’s SRJET technology and TotalEnergies’ technical, operational, and distribution expertise. SINOPEC has a B5 biodiesel project in Shanghai and a B10 biodiesel research program. Both of these factors may significantly increase China’s energy security while ameliorating its kitchen waste disposal problems. According to SINOPEC, its Shanghai plant supplies B5 biodiesel to many vehicles in the city (more than 40% of SINOPEC’s 240 gas stations), and it is capable of producing between 400,000 and 600,000 tons of biodiesel annually.

To enable it to produce approximately two billion liters of biofuel by 2020 and save funds used for ethanol imports, Nigeria issued a national biofuel policy in 2007. In 2012, it signed a 2 billion pound deal with Global Biofuels Ltd. for a biofuel production complex in Nigeria’s Ekiti State and other states. The NNPC says that despite its efforts, none of these projects has progressed much in the last 15 years. They abandoned some projects, while others lacked support. The biofuel policy has suffered from a lack of implementation since 2007, although it has undergone review several times. In addition, no signed agreement exists between the main players and government agencies to enable the implementation of the policy directives.

Generally, almost all these companies have ventured into biofuel production, whereas four of them are divesting from some biofuel portfolios. Equinor refrained from any significant biofuel investment commitment, whereas Eni plans to sell its biofuel and bioplastics stakes. ExxonMobil is exiting its much-publicized algal biofuel project, and although Chevron made significant investments by acquiring twelve additional biorefineries, it is closing two biodiesel plants. ConocoPhillips is not different, as it is divesting from a biodiesel portfolio. This is primarily due to unfavorable energy policies and, indirectly, nomenclature standardization issues that impact profitability, as it hinders global trade across international boundaries. These biofuel divestments raise serious net zero attainment concerns, as even pre-divestment production levels were insufficient.

In the global efforts toward net zero, biofuels accounted for 3.6% of the global transport energy demand in 2021. Its contribution to transportation will quadruple toward 15% as we approach 2030, that is, approximately one-fifth of road vehicle demand. As the ethanol demand increased by 6% between 2020 and 2021, the demand for biodiesel (fatty acid methyl esters [FAME]) was 0.3% above the 2020 demand. Renewable diesel or HVO grew exponentially between 2019 and 2021 to 65% higher consumption levels. The SAF score will need to increase from 0.1% demand in 2021 to more than 5% demand in 2030. Its success will depend on cost gap reduction alignment with that of fossil jet fuel, if effective energy policies are adopted (IEA, 2023). As these policies increasingly mandate biofuel blend requirements in many countries, the demand for biofuels will increase, while that for fossil fuels will reduce.

Biofuel Blends

The fermentation of starch or sugar is the route for bioethanol production, whereas biodiesel production occurs through the transesterification reaction between methanol or ethanol and biomass oil, with valuable glycerol as a coproduct. The most firmly established transportation biofuels are conventional bioethanol and biodiesel (HVO), which include ethyl tertiary butyl esters and FAME. In addition to Brazil, in most countries, it is common to blend biofuels with petroleum diesel and gasoline. This improves their cetane and octane ratings. B100 is 100% biodiesel; B5 is 5% biodiesel blended with 95% petroleum diesel. B7 is a biodiesel blend of 7% biodiesel.

In addition to 6-20% biodiesel, B7 fuel is included in the ASTM D7467 specification. B10 is a biofuel blended with 10% biodiesel whereas B20 is a higher-level biodiesel blend of 20% biodiesel, whereas B99. Contains between 1 and 0.1% petroleum diesel and is the highest-level biodiesel blend. In the US, it is more widely distributed than B100.

On the other hand, E10 is a bioethanol blend of 10% bioethanol and 90% petroleum gasoline. It is the most widely used of all US biofuel blends. E15 is a biofuel blend of 15% bioethanol, whereas E85 is a higher-level biofuel blend of between 51 and 83% bioethanol (Targray, 2024). Many vehicles in Brazil use up to 100% bioethanol. Since bioethanol is often difficult to ignite in compression ignition engines, the addition of 95% hydrous ethanol along with the additive, 'braid' enhances biofuel ignition.

The blending of petroleum fuels with biofuels aids in carbon emission reductions, as smaller volumes of hydrocarbon fuels become available for combustion, and therefore reduce carbon emissions. Consequently, more biofuel blends lead to lower carbon emissions. In addition, since biofuels serve to improve octane and cetane ratings, they enhance the overall fuel combustion efficiency, which translates to better fuel performance qualities along with lower emissions.

Biodiesel blend additives have a relatively high energy density, low calorific value, high flashpoint, and, upon combustion, reduce ignition delays due to the increased oxygen supply. They emit less heat and demonstrate slightly higher efficiency. They also emit less carbon monoxide, hydrocarbons, and particulate matter. With increased oxygen supply due to additives, their combustion rates are high, resulting in increased fuel consumption. The optimization of additives and biodiesel results in minimal diesel engine alterations while enhancing oxidation stability. In general, bio-based additives tend to enhance engine performance and, to some extent, reduce NOx emissions (Palani et al., 2020).

Although the modern consumption of biofuels has increased by approximately 3% annually on average, between 2010 and 2022, greater efforts are required to quicken both their deployment and alignment with the net zero target. This requires an annual 8% increase in deployment and the avoidance of negative social and environmental impacts (IEA, 2023), which has made fossil fuels notorious. They therefore play critical roles in the attainment of net zero. However, consumption rates require acceleration and the traditional use of biomass stopped. If production scale-up and technology learning cannot reduce biofuel costs, then the current biofuel policy support needs to increase to ensure commercial viability (Raval, 2019), since the biofuel forecast predicts an annual 2.5% production growth over five years. This growth and the globalization of the biofuels trade, which translates to profitability, sustainability and net zero attainments, will be impossible without the adoption of common nomenclatures and standardization.

Classification and Nomenclature Issues

Classification systems exist for both biofuels and biorefineries. Biorefineries ensure economies of scale maximization and efficient utilization of all the inputs with process operations integration while advancing towards net zero. Their feedstock, platform process, and product knowledge, systematically enable their classification (Cherubini et al., 2009), facilitating biorefinery system comparison, enhancing the understanding of international biorefinery progress, and identifying technology gaps. Similarly, the classification of biofuel via feedstock generation, physical state, generation of products, and technology maturity also exists (Awogbemi et al., 2008). However, a globally accepted biofuel and biorefinery product nomenclature is lacking.

While biofuels are emerging in significant quantities, especially from MOCs, their diverse feedstock and production processes add to the confusion in defining standard nomenclature for the vast number of emerging biofuels. Government legislation and programs tend to define biofuels differently from industry and other organizations and therefore worsen the nomenclature challenge. Consequently, the accusation against Aramco that it 'misled' its customers was due to their exploitation of nomenclature ambiguity or even its absence. There may be many other similar cases. Emerging feedstock conversion technologies, the use of different production feedstocks and technologies, different

Table 2. Suggested practical steps towards biofuels nomenclature standardization

Key stakeholders	Roles	Possible challenges	Possible timelines
IUPAC, FAO, & chemical researchers/experts	List & classify biofuels	Collation of all globally known biofuels may be time consuming	June 2025
UNEP, EPA, IPCC, IRENA, & national environmental agencies	Definition of emission standards for each biofuel	Differences in EU, China, Brazil, & US emission standards	August 2025
IEA, IRENA, EIA, & national energy agencies	Definition of specific biofuels quality standards	Differences in biofuel quality standards	December 2025
Biofuel producers, researchers/experts, IUPAC, & FAO	Propose globally agreed biofuel names for consideration	Agreements on biofuels nomenclature, different feedstock & processes	February 2026

process methods, and the lack of globally established common standards contribute to biofuel nomenclature problems, which may become more complicated with increasing global production and industry growth (DeTar, 2007; EIA, 2023), thus, creating identity and standardization problems. **Table 2** presents practical steps toward biofuel nomenclature standardization. It includes main stakeholders, roles, possible challenges, and suggested timelines.

Owing to the global dimension of the nomenclature issue, confusion and miscommunication will increase if they are not quickly resolved. Quick resolution is important to enable the adoption of new global standards. This will facilitate the acceleration of biofuel commerce across international boundaries (American Chemical Society, 2007). The absence of significant globalization in the biofuel trade has much to do with the lack of internationally defined standards and nomenclature. This, in turn, affects profitability and sustainability. It is therefore no surprise that Chevron, ExxonMobil, Eni, and ConocoPhillips have or plan to divest from at least some of their biofuel portfolios, whereas one (Equinor) has refrained from any significant biofuel investment. Their concerns hover around inconsistent energy policies and profitability, complicated by a lack of global nomenclature that hinders international trade. Chevron, in particular, cited the US imposed standards, which may not necessarily be the standard beyond the US and therefore may hinder international trade, whereas ConocoPhillips exited due to the withdrawal of previous subsidies.

There is a need for biofuel and biorefinery global nomenclature standardization, just as the need exists for proof of fuel compliance with all applicable industrial testing standards. The biorefinery nomenclature challenge often includes the erroneous assumption that a specific feedstock, technology, or general process is employed in the production of a particular biofuel, whereas this may not be the case (DeTar, 2007). In the absence of an international nomenclature, biofuel quality standards will suffer, and barriers against international trade will be magnified, resulting in long-term harm to profitability, sustainability, and net zero target achievement. Globally accepted biofuel and biorefinery nomenclatures promote product quality assurance and safety, facilitate compatibility, support referencing and benchmarking, promote comparison, enhance common technical understanding, reveal technical gaps, and accelerate technological innovation (UCSUSA, 1999). Ambiguity still exists regarding quality standards and the general nomenclature of some biofuels, whereas denaturation obligations impose barriers against the international trade of bioethanol. Therefore, there is a need to address them.

Energy Policy Implications

Apart from the Brazilian bioethanol, which uses sugarcane cane feedstock and has the lowest production costs globally, biofuels cannot compete successfully with hydrocarbon fuels in the absence of subsidies. With the aid of feedstock substitution (as is the case with secondary and tertiary biofuel production) energy prices as well as technological developments, it is possible to change this (FAO, 2008). If bioethanol and biodiesel compete directly (without subsidies) with hydrocarbon fuels when global oil prices fall below $40 per barrel, biofuel production becomes unprofitable (IEA, 2023). The sharp decline in oil prices (below $40/bbl) creates competitive challenges for biofuels. Policies must address low hydrocarbon fuel prices because more subsidies are needed to support biofuel competitiveness. In the American, Brazilian, and European markets, where there are increased biodiesel blend mandates, biodiesel tends to compete better than bioethanol. Such higher blend requirements, if issued for gasoline since it enhances its octane rating, will increase its demand and competitiveness. With higher crude oil prices, biofuels tend to be competitive. Hence, the sustenance of current biofuel production is possible, partly through national energy policies that account for carbon emissions, carbon taxes on petroleum fuels, and biofuel subsidies, thus enabling its competitiveness. If these policies become inconsistent or are suddenly withdrawn, biofuel investors will exit their portfolios, as reported in the cases of divestments by Chevron, Eni, ExxonMobil, and ConocoPhillips, whereas other investors, such as Equinor, may refrain from any significant biofuel investment commitment.

For Nigeria's NNPC, a lack of policy implementation is primarily responsible for biofuel development failure. Like Chevron, ConocoPhillips cited energy policy inconsistency, specifically subsidy withdrawal, as a reason for divesting from one of its biofuel portfolios. Therefore, energy policies directly influence competitiveness, profitability and sustainability. For primary biofuels, which often utilize agricultural feedstock, energy prices often lead to increases in biofuel prices along with their respective agricultural feedstocks. As primary biofuel feedstock competes with food crops, energy prices often influence agricultural commodities that depend on the same set of resources.

Similarly, according to the FAO (2008), secondary and tertiary biofuel production will not necessarily put an end to the food–fuel competition. The FAO (2008) argues that, depending on technologies, the relative prices of agricultural feedstock and fossil fuels influence biofuel competitiveness. This varies among countries, locations, crops, and the biofuel production technologies employed.

Although the biofuel demand reached a high record of 4.3 E.J. (170,000 million liters), exceeding 2019 pre-COVID-19 levels in 2022, a significant biofuel production increase is still needed to align with the 2050 net zero emission targets along with its associated emission reduction. While approximately 11% annual average growth is required to meet the compliance level, waste and residue, as well as nonfood, energy crop feedstock utilization, must exceed the 9% level of 2021 and the 40% total biofuel projected demand of 2030.

According to the IEA (2021), a successful energy transition and net zero target attainment in 2030 and 2050 will be possible if the yearly renewable energy global investment, including bioenergy, more than triples to an annual four trillion dollars. This should continue until 2030, beginning from 2017. The 83 m tons of oil-equivalent production levels has to be produced so that global warming can be limited to 1.5 °C, and the future supply and demand gap, caused by hydrocarbon fuel reduction, should be closed. The supply of biofuels is lagging behind its demand. The IEA recommended more than threefold supply output by 2030, and this requires an overall average yearly production growth of 10%. Consequently, national energy policies need to provide subsidies or credits that encourage the use of low-cost feedstock and associated input materials such as enzymes, to increase their conversion efficiency and the monetization of coproducts. The use of carbon credit markets created by energy policies for the increased production of HVO at reduced production costs is ongoing in California and Sweden. However, its economy still requires improvement to make it competitive. Policy interventions need to target feedstock costs and capital costs, as these contribute significantly to overall production costs. The production costs when biomass feedstock is used range from 17 to 44 EUR/GJ. Their reduction to 13 from 29 EUR/ GJ is possible if waste materials feedstocks are used (IEA Bioenergy, n. d.). Policy interventions can further enable less expensive access to capital with reduced investment risks just as adequate carbon pricing can close the gap between biofuel production costs and fossil fuel prices.

Biofuel production from nonfood crops, as well as secondary and tertiary biofuels, needs greater policy support. Current policies suggest an important strategic energy transition role for biofuels since more than eighty nations' energy policies support the development of biofuels, including those in the US, Canada, and China. The US made significant investments in biofuel research and deployment in 2021. The US 2022 inflation reduction act extended new policy support for biofuels, green chemicals, and biomaterials, especially advanced biofuels (secondary and tertiary]) and SAFs, whereas India expanded its biofuel program to include liquefied and gaseous bioenergy production support and utilization (2022-2026). A notable global biofuel leader, Brazil, initiated measures to support the production of sustainable biogas. The 2023 regulation of clean fuels supports feedstocks supply expansion policies in Canada, just as Brazil, Indonesia, and Argentina raised their biofuel transportation targets in 2022. While these energy policy support efforts are commendable, biofuel use has expanded at a slower-than-expected rate as far as the net zero targets are concerned; therefore, more expanded policy support is required, to at least, triple global production (IEA, 2023) to attain the net zero scenario. This will increase the safety of innovative fuels and their sustainability. Internationally coordinated policy regulations, large-scale deployment, carbon pricing, and reduced costs, along with nomenclature standardization and certification schemes, are the solutions.

CONCLUSION

This study revealed that in addition to biofuel research, Shell, TotalEnergies, Chevron, BP, Eni ExxonMobil, ConocoPhillips, and SINOPEC are produce the following innovative bio bio-fuels: SAF, R-CNG, R-LNG, RNG, bio-butanol, bio-LNG, R-LPG, green naphtha, biocrude, and bio-oil in addition to conventional bio-ethanol, bio-methane and biodiesel (HVO). They have invested in these biofuels as part of their net zero programs. MOCs produce more innovative than conventional biofuels. They are also transforming their hydrocarbon refineries into biorefineries (alongside the BECC for carbon capture and storage), which integrate biofuels, bioplastics, bioheat, biopower, and green chemical production, into single production facilities that enjoy the benefits of economies of scale. Green chemical production serves as an alternative to petrochemical production, which consumes large volumes of petroleum feedstock.

On the other hand, energy policy inconsistencies and diminishing profitability complicated by the absence of an internationally agreed upon biofuel nomenclature, contributed to the exit of Chevron, ConocoPhillips, ExxonMobil, and Eni from some previous biofuel investments, whereas the NNPC is challenged by a lack of policy implementation. As it stands, current global production levels remain inadequate and need to more than triple net zero for attainment. Therefore, current biofuel policies support feedstock competition with agricultural produce, and low oil prices need to be increased.

Multiple mandatory biodiesel blends are equipped with some biofuels with greater competitive resilience against hydrocarbon diesel when global oil prices drop below $40/bbl. Bioethanol blends require similar policy support to increase their competitiveness.

A biorefinery systematic classification scheme based on platforms, feedstock, products, and processes, exists. The development of biofuels, which is based on feedstock generation, the physical state, the generation of products, and technology maturity, also exists. Both of them are in use. However, detailed globally accepted nomenclatures for both are yet to be established. This deficiency is due partly to their production feedstock, which widely varies, ranging from biogas, syngas, algae, sugars, oils, organic solutions, and lignin to pyrolysis oil, among others. The same applies to their production systems. The absence of an international biofuel global nomenclature hinders the international biofuel trade and profitability; and threatens their sustainability. These biofuels differ greatly in terms of composition, feedstock, and production systems, as no established global nomenclature standardization exists. If global biofuel and biorefinery nomenclatures are not adopted soon, their global trade, growth, and profitability may be compromised and therefore endanger the net zero target.

Confusion might eventually result from multiple naming systems. Consequently, some names and codes proposed in **Table 1** for adoption in an international biofuel and biorefinery nomenclature conference, as outlined in **Table 2** require consideration. An international convention is urgently required for the establishment of globally accepted nomenclatures and standardization, as this will enhance their sustainability, global commerciality, and profitability. Such nomenclature and standards must account for the different feedstocks and diverse production processes employed in their production.

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