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Review

Internal Combustion Engines and Carbon-Neutral Fuels: A Perspective on Emission Neutrality in the European Union

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Abstract: Nowadays, there is an intense debate in the European Union (EU) regarding the limits to achieve the European Green Deal, to make Europe the first climate-neutral continent in the world. In this context, there are also different opinions about the role that thermal engines should play. Furhermore, there is no clear proposal regarding the possibilities of the use of green hydrogen in the transport decarbonization process, even though it should be a key element. Thus, there are still no precise guidelines regarding the role of green hydrogen, with it being exclusively used as a raw material to produce E-fuels. This review aims to evaluate the possibilities of applying the different alternative technologies available to successfully complete the process already underway to achieve Climate Neutrality by about 2050, depending on the maturity of the technologies currently available, and those anticipated to be available in the coming decades.

Keywords: combustion engines; carbon-neutral fuels; E-fuels; E-biofuels; biofuels; synthetic fuels; European green deal

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1. Introduction

Very recently, we have witnessed an intense debate in the European Union (EU) regarding the role that carbon-neutral fuels could play in the current transition framework to bring the European Green Deal to a successful conclusion, which seeks to make Europe the first climate-neutral continent in the world [1–5]. Thus, a priority objective for the EU is to achieve a drastic reduction in CO_2 emissions from passenger cars and vans, imposing a reduction of 55% in emissions from passenger cars and 50% from vans by 2030. It is also planned that by 2035, all new vehicles will present net-zero emissions, in order to obtain the goal of neutrality in carbon emissions set for 2050 [6–10]. To this end, among other measures, the aim is to promote the growth of the market for vehicles with zero or very low emissions. Due to the context of these measures, it is perceived that for the European Commission, these vehicles would be associated with the use of electric cars. In this sense, it is anticipated that by 2026, regulations will be in place for road transport to adhere to emission rights and implement pollution pricing. Moreover, there will be a concerted effort to promote the adoption of cleaner fuels, alongside the development of adequate infrastructure for vehicle recharging, thus ensuring that citizens have convenient access to sustainable transportation options throughout the territory of the member countries of the EU [8]. However, in this scenario, once the permanence of carbon-neutral biofuels has been clarified, after EU energy ministers have adopted a legislative portfolio, stemming from the 'Fit for 55' package on 28 March 2023, both E-fuels and some biofuels could be considered carbon-neutral fuels. Therefore, carbon-neutral fuels could be any fuel that produces neither net-greenhouse gas emissions nor a carbon footprint. This includes fuels obtained from carbon dioxide (CO_2) as a feedstock. Thus, proposed carbon-neutral fuels can broadly be grouped into two different types: synthetic fuels, or E-fuels, which are made by catalytic hydrogenation of carbon dioxide, and biofuels, obtained using photosynthesis CO_2-consuming natural processes, producing different vegetable materials that are transformed into liquid biofuels. More specifically, E-fuel can be defined as all fuels produced by using renewable electricity from renewable sources (hydro, wind, or solar) with low carbon emissions, making them renewable fuels of non-biological origin used as feedstock or as an energy carrier with the purpose of mainstreaming renewable energy in transport vehicles [11]. On the other hand, synthetic fuels obtained either by pyrolysis or by catalytic hydrogenation of any triglyceride of biological origin are currently designated by different names, such as green diesel [12–16], renewable diesel [17–22], bio-hydrogenated diesel (BHD) [23–25], hydrogenated vegetable oils (HVOs) [26–29], alternative fuels [29–33], or advanced biofuels [34–36]. Furthermore, according to Figure 1, in the last decade, there has been an impressive increase in scientific publications that address the transformation of vegetable fats and oils into alkanes through different deoxygenation processes [36].

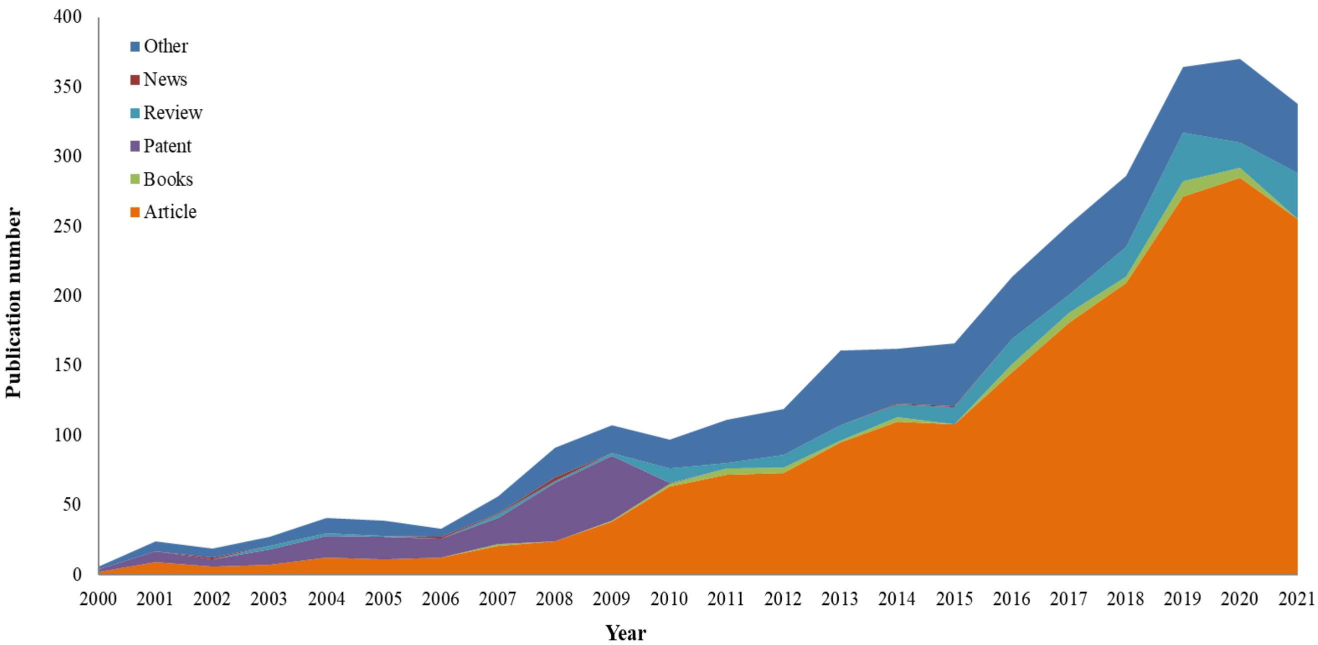

Figure 1. Publications found in the Web of Science database by the keywords "green diesel" from the year 2000 to 2021. (Dark blue area, signaled as "other", refers to publications found with the keywords "biofuel in aviation"). Reproduced with permission of MDPI [36].

In this manner, the thermal conversion of fats and oils presents a viable alternative pathway for producing biofuels resembling diesel, achieved through a deoxygenation process applicable to various feedstocks such as vegetable oils, animal fats, fatty acids, and waste cooking oils [37]. Consequently, subjecting these renewable compounds to diverse thermal treatments like cracking, pyrolysis, or hydrocracking yields hydrocarbons that closely resemble those derived from fossil crude oil. As a result, the hydrocarbons produced after deoxygenating vegetable fats and oils possess boiling points akin to gasoline or diesel [38], so that these green fuels can be used as gasoline, jet fuel, or diesel, as indicated in Figure 2. Furthermore, these green fuels are obtained using the same process used in the hydrotreating of vacuum gas oil, taking advantage of the facilities currently existing in crude fossil refineries [39].

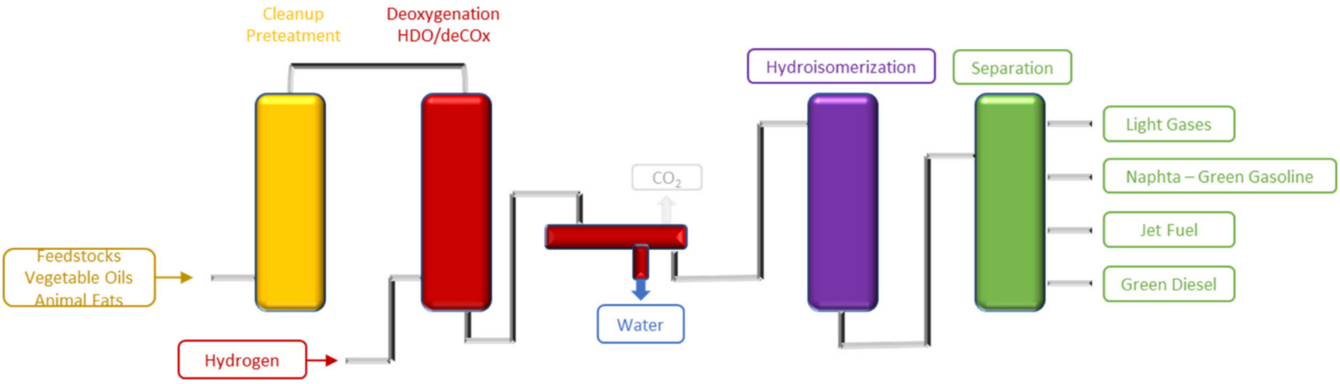

Figure 2. Green diesel production process by hydrotreatment of vegetable oils in a biomass hydroprocessing plant. Adapted from [38].

In summary, several "green fuels" have emerged as products of some pyrolysis or (hydro)cracking processes using different fats and oils as feedstocks [38]. Additionally, different studies have found a significant reduction in anthropogenic CO_2 emissions, despite the use of non-renewable hydrogen gas in their manufacture. Thus, the main proportion of CO_2 generated by these biofuels during combustion will be clearly renewable, since it has been previously captured from the atmosphere through the achlorophyllous function to produce plant material. However, these biofuels cannot automatically be considered 100% neutral fuels, since in cases where green hydrogen is not used in the process, the non-renewable CO_2 produced during the generation of hydrogen used in the hydrotreatment of raw materials must also be considered. Therefore, all biofuels cannot automatically acquire the status of carbon-neutral fuels, prompting plans to set standards that require the production of a minimum percentage of renewable CO_2 during use to consider a given biofuel as carbon neutral. In fact, the amount of non-renewable CO_2 generated during the agricultural production process would also have to be computed. In this respect, there are currently great doubts about the true qualification of conventional biodiesel obtained through the transesterification of triglycerides [36].

In conclusion, true neutral-fuels, characterized as 100% neutral, are only achieved when green fuels are obtained using green hydrogen. This means that E-biofuels are practically all renewable, as nearly all the CO_2 produced would be of a renewable nature. Therefore, at present, it is possible to distinguish three different categories of renewable fuels: E-fuels, E-biofuels, and ordinary biofuels. In E-fuels, green hydrogen is employed to carry out the catalytic hydrogenation of captured CO_2, whereas in E-biofuels, this green hydrogen is used in the hydrotreating of renewable materials. In the case of standard biofuels, the proportion of renewable CO_2 generated must be evaluated beforehand to assign the characteristic of neutral fuel. This proportion will depend on the legislative regulations in force at that time, since it is expected that this may evolve throughout the transition period until 2050. Furthermore, all these neutral fuels can also work perfectly in current internal combustion engines, either with spark ignition, gasoline engines, or with compression ignition diesel engines. Therefore, as part of the strategy to drastically reduce non-renewable CO_2 emissions, the application of neutral fuels could be effective by using sufficiently improved combustion engines to achieve the desired levels of polluting emissions, provided, of course, that the current available technological system can produce the necessary quantities of these neutral fuels at an affordable economic cost for consumers.

On the other hand, despite the doubts that have arisen regarding the immediate future of combustion thermal engines, with a horizon very close in 2035 [40], it cannot be forgotten that both spark ignition (SI) and compression ignition (CI) internal combustion engines (ICEs), mainly powered by fossil fuels [41–43], are actually the primary mobility sources nowadays [26], as indicated in Figure 3. Additionally, ICE diesel engines represent a significant proportion of these thermal engines, both in passenger cars and heavy-duty sectors [44]. In this sense, by using these neutral fuels in current thermal engines, very significant reductions in actual emission levels could be achieved. Furthermore, with respect to ICE engines, it must be also considered that due to their greater thermal efficiency, they can reduce CO_2 emissions between 10% and 40% compared to engines powered by gasoline. Therefore, the use of green hydrogen in obtaining neutral fuels through the hydrogenation of vegetable oils offers certain advantages over the hydrogenation of CO_2 to generate green methanol, a fuel applicable in SI engines. Thus, thermal engines must play a decisive role in the coming years because of the large existing fleet operated by this type of combustion engine, which will need to be fueled in the coming decades with neutral fuels. However, diesel engines generate higher levels of pollution, especially in nitrogen oxides (NOx) and particulate matter [45], which could present greater difficulties in achieving proposed exhaust pollutant emission levels in Euro 7 Regulations [46]. Despite the debated rigor that has advised delaying its implementation, it is evident that the foreseeable trend will continue to be limiting the quantities of permitted anthropogenic emissions. Therefore, when considering the possibility of using any neutral fuel in a thermal engine, in all cases, it will be necessary to evaluate the amounts of the possible generation of contaminants generated during combustion, mainly particulate matter and NOx gas emissions.

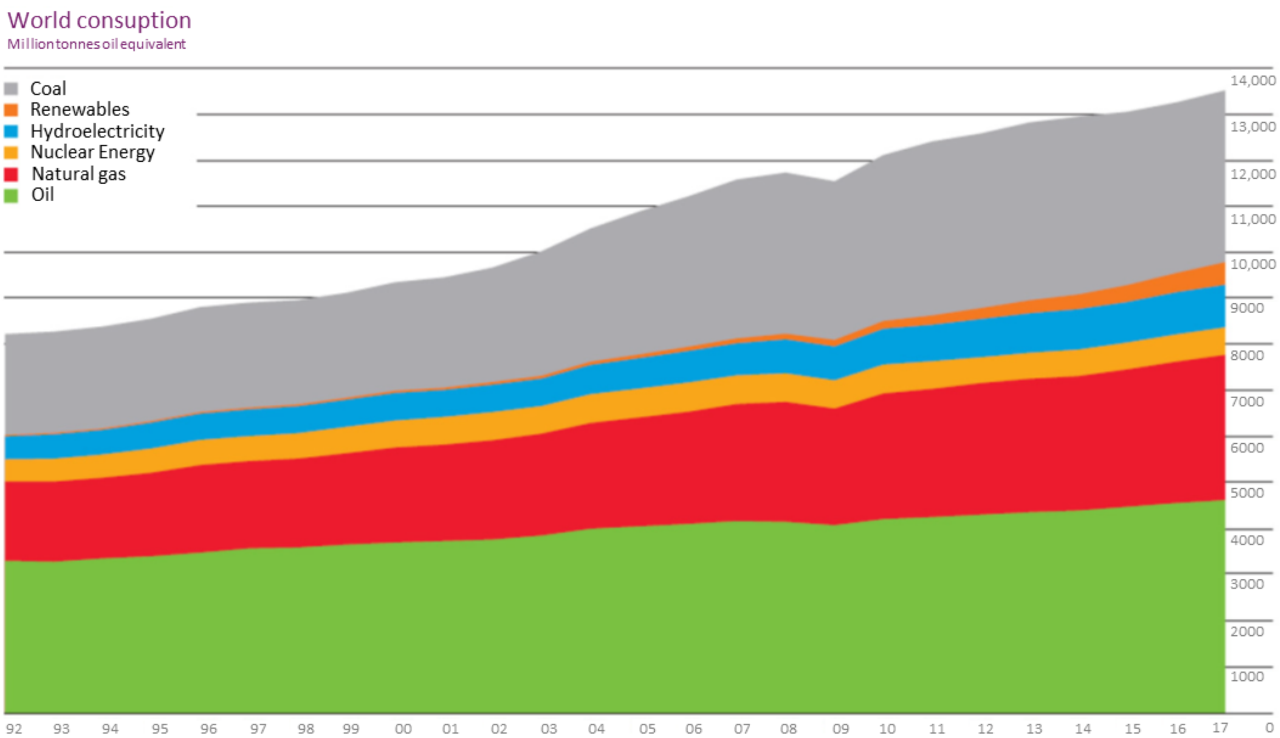

Figure 3. World energy consumption by different sources (millions of petroleum equivalent) in the last 25 years, where about 70% of fossil oil (i.e., about 3000 Mtoe) is consumed in CI engines. Adapted from [41].

Accordingly, combustion engines are able to play an important role in this transition scenario towards minimal CO_2 emissions. In this respect, probably even with the joint action of neutral fuels involving internal combustion engines (ICEs) and electric engines of all kinds operated by batteries or fuel cells, as well as conventional vehicles powered by IC engines, there may be difficulties in achieving the objectives set out in the Fit for 55′ package agenda [11]. Hence, it is advisable to review the capacities of different technologies that could contribute to this process at present, along with their strengths and weaknesses. In this sense, it should be noted that the renewable fuels considered in the new regulations, including E-fuels, E-biofuels, and biofuels, can all be operated in current combustion engines, so limitations on authorized engines may only be established by their emission levels [47]. Therefore, this perspective study intends to provide relevant information regarding the actual possibilities of combustion engines, considering the real situation of available technologies, to achieve emission neutrality in the transport sector within the deadlines established by the EU, mainly by 2035 and 2050. In this way, policymakers can assess the various options to be considered, regarding the real possibilities of combustion engines, to make informed decisions toward achieving a decarbonized energy system.

2. Electric Motor Devices: Battery Electric Vehicles and Fuel Cell Electric Vehicles

Electric vehicles (EVs) are currently considered the most appropriate technology in Europe for achieving zero emissions. Thus, the EV market has experienced unprecedented growth in recent years, with more than 1.36 million new electric passenger cars, including battery electric (BEV) and plug-in hybrid electric vehicles (PHEVs), sold across the region, only since 2020, marking a 143% increase from 2019 [48]. Electric motors can be operated with two very different technologies: electric batteries or fuel cells [49–52]. In this respect, a series of factors, including raw material issues, cost analysis, energy–efficiency analysis, and technology-specific advantages and disadvantages, must be taken into account [49].

There is no doubt that electric engines constitute the best technology for transportation (e.g., the use of battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs), or fuel cell electric vehicles (FCEVs)), to achieve the reduction of GHG emissions in the transportation sector. Thus, the carbon footprint of all propulsion systems is comparable and only approximately half that of an internal combustion engine vehicle (ICEV) [53]. However, these different technologies present important differences regarding their green electricity demand and how they present varying degrees of feasibility depending on factors such as vehicle type, range, and available infrastructure [49]. Conversely, considering the build-up of the necessary hydrogen infrastructure, FCEVs, according to several studies, seem to be more favorable, as they are more flexible and cost-efficient [54]. Nevertheless, it is currently possible to find multiple studies that address comparisons between both types of technologies that use the electric engines to clarify the differences between the two technologies and advise their use in different regions and circumstances to achieve more effective decreases in CO_2 emission levels [55–59].

At the present time, the massive application of BEVs generates some distrust regarding the viability of a secure international trade system for strategic minerals, which would need to integrate a relatively small number of countries (China, Chile, Australia, the United States, and Argentina), which have the capacity to produce lithium, an essential strategic mineral with current technology, yet are geographically very far from the main potential consumer countries (the United States, the European Union, and Japan) [55]. In addition, its extraction entails significant environmental impact. Furthermore, fuel cell hybrid electric vehicles seem to yield better results than fuel cell electric vehicles, according to energy and hydrogen consumption [56]. Thus, fuel cell technologies facilitate highly efficient conversion of hydrogen into electric power, so that fuel cells can extend the portfolios of electric vehicles. These fuel cell vehicles present an important advantage in terms of refueling times over battery-electric options, as hydrogen can be refueled in similar time periods to conventional fossil liquid fuels [57]. However, many other factors must be considered, such as the availability of a sufficient quantity of metals necessary for the manufactue of batteries [58], or the problem of hydrogen gas transportation to supply refueling stations for fuel cell engines [57]. Merely considering these factors does not guarantee the complete replacement of fossil fuels within the projected timelines. The rate of adoption of electric technologies in the road transport sector will hinge on advancements in electric engine technology, the availability of requisite infrastructure, and regulatory frameworks pertaining to emission standards for new vehicles powered by combustion engines [60].

3. Internal Combustion Engines

Taking all the aforementioned into account, it is assumed that the reduction of CO_2 emissions must be achieved fundamentally by replacing the current fleet of vehicles based on internal combustion engines (ICEa) with zero-emission vehicles that employ electricity and/or hydrogen as fuel [40,61]. However, this means not only achieving progress in the technological efficiency of these vehicles but also developing the minimum necessary infrastructure related to electric charging stations for cars that use batteries [62–64], or hydrogen service stations [65–67]. Additionally, there is a need to be able to satisfy the consequent increase in demand for electricity [68] and/or hydrogen [69] obtained from renewable sources. Delays in any of these factors would create a bottleneck that would inevitably delay the deadlines of the entire process. In this regard, the use of E-fuels, E-biofuels, and traditional biofuels in internal combustion engines must be an essential tool to maintain the planned rate of substitution of fossil fuels. In this sense, it should be considered that an important amount of green hydrogen will need to be directed towards the production of CO_2-neutral fuels, which will feed vehicles operated by internal combustion engines. In any case, it is foreseeable that the replacement of current fossil fuels with any other type of neutral fuel may require small modifications to internal combustion engines, so that they present acceptable emission levels as allowed by the regulations in force during the transitory period considered [70–72].

On the other hand, although the EV engine may be more efficient than the internal combustion engine regarding the well-to-wheel (WTW), the overall energy efficiency is not so clear. Currently, research is underway to determine if electric cars are really more energy-efficient compared with ICE-powered vehicles [73]. Therefore, given the magnitude of the problem to be solved, perhaps the most favorable opinion regarding the process to follow to achieve the proposed reduction of greenhouse gases by 2050 would be to apply a mix of all available propulsion technologies, including battery electric vehicles (BEVs) and ICE-powered vehicles fueled by different E-fuels, E-biofuels, biofuels, and hydrogen [74]. However, it is a fact that among all these alternatives, only conventional biofuels and E-biofuels currently present a level of technological development capable of facing the challenge posed by the proposed drastic reduction of greenhouse gases in the coming decades [75]. Without forgetting that in the current context, despite the record growth in the consumption of renewable energy, the world's consumption of fossil fuels is undeterred. In other words, despite the enormous growth in wind and solar capacity, renewables failed to overtake fossil fuels in 2022 [76].

In this respect, at least in the next coming decades, ICE engines will acquire a fundamental role because they probably constitute a solid base on which to advance in the process of decarbonizing transport systems. The most burning question will be how to provide transport systems with renewable fuels capable of making these ICE engines work with acceptable emission levels, in accordance with prevailing regulations. On the other hand, it is a fact that the use of biofuels is being questioned due to the difficulty of obtaining raw materials that do not compete with food production. Therefore, it is essential to identify potential sources of raw materials capable of satisfying the foreseeable increase in the need for these types of compounds without seriously affecting agricultural food development.

4. State-of-the-Art of Different Neutral Fuels That Could Be Used to Feed Internal Combustion Engines in Upcoming Transition Decades

Regarding ICE engines, which currently operate on fossil fuels, two technologies are essentially in use: spark ignition (SI) engines, which operate with gasoline as fuel, and compression ignition (CI) engines, which are fueled by diesel. Thus, to advance in the process of replacing these fossil fuels, rather than identifying a single neutral fuel on which to focus all efforts, it may be more feasible to try to identify, in these initial moments, the largest possible number of alternatives that, in the end, all together, could achieve the objective pursued. For this purpose, it would be advisable to carry out a first selection of potential renewable fuels capable of operating in current spark ignition engines, and another selection of renewable fuels that could successfully replace fossil diesel in current (CI) engines.

4.1. Low Carbon Emission Fuels That Could Potentially Be Used in Current Spark Ignition (SI) Engines

At present, and foreseeably in the next decade, the fleet of light vehicles (LDVs) equipped with spark ignition engines and fueled by fossil gasoline will constitute a very important part of the light vehicles circulating on the roads of the EU [77]. Therefore, to advance in the process of reducing greenhouse gas emissions, it is necessary to use all available different types of low-emission fuels that are capable of operating with these engines. In short, it is a question of locating possible suitable alternative biofuels that do not require interventions in the mechanics of current combustion engines. In addition, by using renewable energies in the production process of these biofuels, it would allow for obtaining neutral electro-biofuels that could also be used in Europe after 2035 [78].

An option with significant potential for direct use as an E-fuel is methanol, since it can be obtained from CO_2 captured from the atmosphere as a raw material, thereby having a great impact on the process of reducing the greenhouse effect of these gases—an example of the effect of "two birds by one stone". Moreover, methanol is currently synthesized on a large scale, so that is possible to use existing fuel infrastructure and production plants [79]. Leveraging the current transport and distribution infrastructure of this E-fuel contributes to what is considered the so-called "Methanol Economy" [80]. Hence, there is considerable interest in acquiring E-fuels via CO_2 hydrogenation processes, as they could seamlessly integrate with actual fuels and power conventional vehicles in operation. In this sense, processes that lead to methanol, hydrocarbons, and dimethyl ether (DME) are being investigated, since all these compounds exhibit physicochemical properties such as molecular weights, density, boiling points, and similar high-octane number, enabling them to operate in Spark Ignition (SI) engines in pure form or as mixtures with fossil fuels. Nevertheless, while the majority of methanol is presently derived from syngas sourced from natural gas, exploring alternative production methods involving CO_2, water, and renewable electricity offers a promising pathway towards achieving carbon neutrality [81]. The question is that now, the amounts of renewable electricity produced in Europe and the rest of the world are relatively small and therefore insufficient to achieve this target. In addition, CO_2 capture technologies are currently very poor, so it is too early to rely on E-methanol as a neutral fuel capable of achieving significant levels of substitution for fossil fuels used in SI engines.

Another alternative fuel that can be used as a transportation fuel in SI engines is bioethanol. This biofuel is currently used in blends with gasoline in many countries as a contribution to limit greenhouse gas emissions. The advantages of bioethanol fuel are that it has a high flame speed, a high octane number, and a high vaporization heat, so that it has better efficiency than fossil gasoline. Thus, at present, there is already very high agricultural production of maize, sugarcane, wheat, and other biomass products worldwide. These sugars are subjected to fermentation, to obtain bioethanol [82] or biobutanols [83], which are used as biofuels in spark ignition engines. Therefore, the necessary technology and knowledge are available to implement these agricultural and industrial processes that would allow, in the next decades, for an important substitution of fossil gasoline in road transport. Therefore, the focus should be on increasing the production of this biofuel under conditions that allow its use as a true neutral fuel; that is, using renewable electricity in the production process of this green fuel. In other words, considering that bioethanol is already being used extensively in mixtures with fossil gasoline as a method to limit anthropogenic emissions, it would be much more profitable, from an environmental point of view, to use available renewable electricity to implement the production of 100% renewable ethanol or neutral ethanol, which could then be used to operate in SI engines with neutral emissions, instead of using it directly in electric vehicles.

4.2. Low Carbon Emission Fuels That Could Potentially Be Used in Current Compression Ignition (CI) Engines as E-Kerosene or Synthetic Aviation Fuels (SAFs)

At this time, there is still neither the technical nor economic possibility to obtain E-fuels suitable for use in Compression Ignition (CI) engines, since currently, only the conventional Fischer–Tropsch (FT) process, which uses a blend of CO with H_2 (syngas), enables the production of hydrocarbon mixtures with suitable Cetane Numbers (CNs) [84], but because these mixtures contain a high proportion of n-alkanes, they require additional hydrocracking and isomerization treatments [85]. Alternatively, on the contrary, FT processes could be carried out with E-fuels obtained from secondary processes, carried out with E-fuels such as DME or methanol. All of this entails an enormous technical complexity as well as non-feasible economic costs of the process.

Therefore, HVOs currently have very high potential to become the main alternative fuels to fossil diesel, constituting so-called synthetic diesel, with rheological properties very similar to conventional fossil diesel [86]. In addition, if green hydrogen were used in the treatment process, since vegetable oils are already renewable compounds, it can be concluded that they would be neutral E-fuels, 100% renewable, with a high energy density [87]. In this sense, HVO fuels, given their high energy density, are the most suitable candidates to replace current aircraft fuels, thus constituting E-kerosene or synthetic aviation fuels (SAFs), obtained from triglycerides present in different raw materials [88–90]. Given the current absolute technological dependence on internal combustion engines to run aircrafts, the production of "sustainable aviation fuels" (SAFs) is presented as an absolute priority because it is the only solution to eliminate aviation CO_2 emissions in the coming decades. Thus, it is estimated that SAF production could require 9% of global renewable electricity and 30% of sustainably available biomass by the 2050 threshold [90].

Therefore, it is necessary to consider all available technologies in the coming process of removing anthropogenic CO_2 emissions because, in some cases, such as aircraft transport, it may not be possible to choose (Figure 4). The renewable energy used for maritime transport and heavy-duty fleets must also be evaluated in detail, although in principle, it should be assumed that some neutral liquid fuel will be necessary for use in some CI engines [91–93]. In this sense, the possibility of directly using green hydrogen or green ammonia as fuel for CI engines must also be considered [94–96]. In other cases, depending on the circumstances of each moment, it may be possible to diversify the available processes. In this sense, under certain circumstances, it will be possible to consider the electric motor, operated with batteries or internal combustion cells, as the most convenient method. However, even in these cases, the use of liquid fuels from biomass could also be considered, especially in the coming decades of transition, during which it will be necessary to continue employing the enormous current fleet of light vehicles.

In this respect, it should be assumed that vegetable oils may currently be an essential part of the decarbonization process of the transport sector. Even though conventional biodiesel is not the most appropriate candidate for this fundamental role, there is currently a great diversity of biofuels derived from vegetable oils as a raw material that could play an important role in the process of replacing the fossil fuels currently used in ICEs operated by conventional diesel [36]. Among the various possibilities for using vegetable oils to replace fossil diesel, the use of Straight Vegetable Oils' (SVOs) blending with Less Viscous and Lower Cetane (LVLC) Biofuels is highlighted due to its simplicity and cost-effectiveness. It has been demonstrated that using this mixture, in the form of triple mixtures, with variable amounts of fossil diesel, allows for the replacement of high percentages of fossil diesel without compromising engine power. This achieves a significant reduction in polluting emissions, with a fuel consumption level very similar to conventional diesel [97].

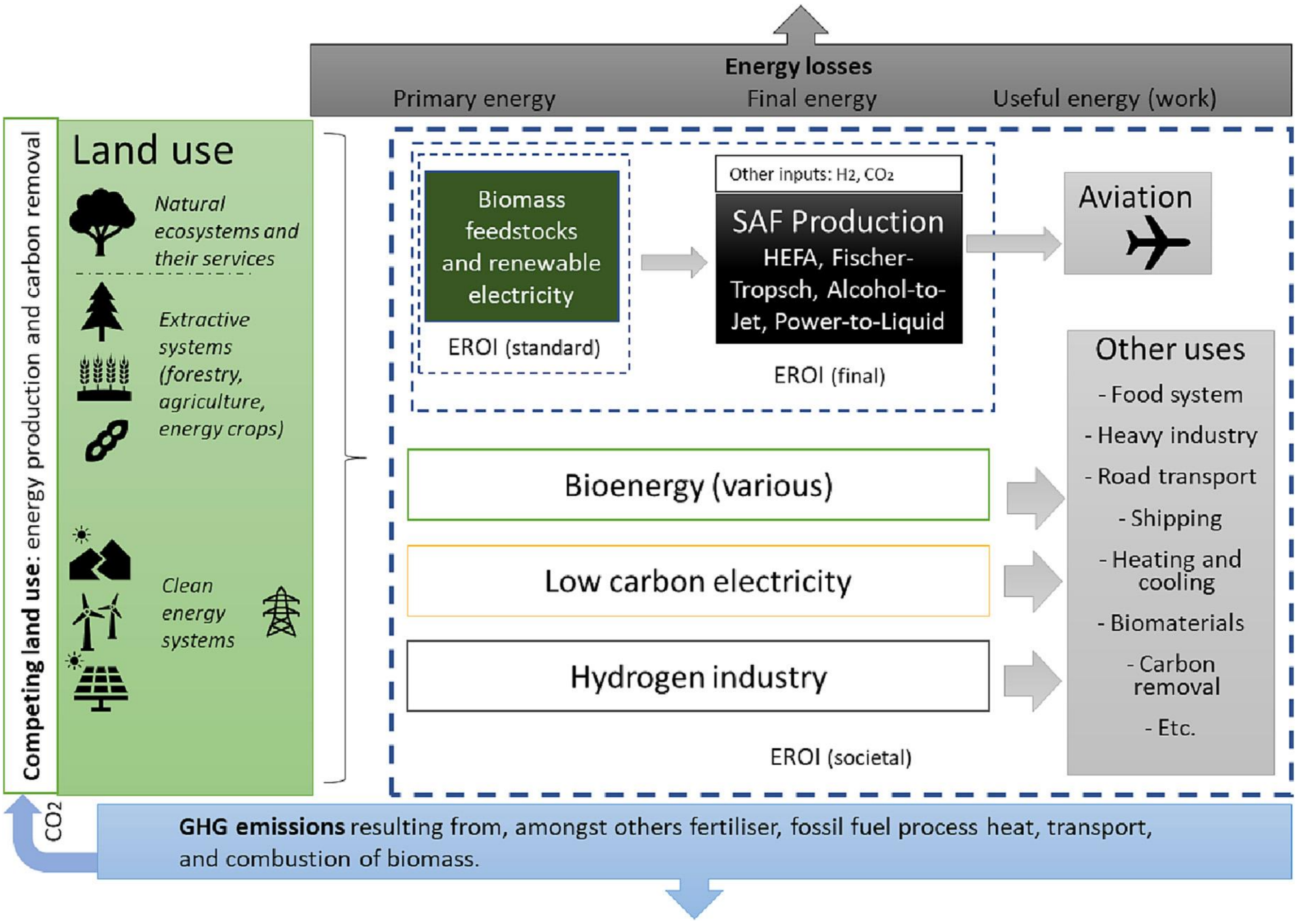

Figure 4. Energy flows and emissions related to sustainable production of E-kerosene or synthetic aviation fuel (SAF) in competition with other possible alternative uses, to optimize the reduction of anthropogenic CO_2 emissions. Reproduced with permission of Science of The Total Environment [90].

5. Conclusions

The necessity of using electric engines to achieve a drastic reduction in CO_2 emissions from passenger cars and vans in the current transition framework of the European Green Deal seems indisputable. However, it is equally true that this goal will not be achieved only through the use of electric motors. Two principal reasons can support this fact. Firstly, logistical challenges arise due to the current practical non-existence of a recharging network, both electrical and hydrogen, to serve vehicles operated by batteries or those that use hydrogen in fuel cells. The second challenge is due to the complexity of obtaining enough amounts of rare minerals, such as lithium, to produce an extensive battery-operated automobile fleet within practically a decade.

On the other hand, to enable transportation based on hydrogen vehicles, a hydrogen refueling infrastructure is necessary, capable of supplying both cars and trucks. This infrastructure should be implemented by 2030 in all urban nodes and every 200 km along the basic network of the Trans-European Network (TEN-T), guaranteeing a sufficiently dense network to allow hydrogen vehicles to circulate throughout the EU.

Therefore, given the difficulty in achieving complete decarbonization of transportation systems within the proposed deadlines, there will be no choice but to apply different types of thermal engines, albeit operating with carbon-neutral fuels. In this scenario, it is a priority to achieve the maximum production of neutral fuels. The joint application of vegetable oils from biomass and green hydrogen may allow for obtaining estimable amounts of neutral fuels, which obviously will require the application of efficient heat engines and adherence to a series of requirements: (i) the fuels must be chemically identical or closely similar and perform the same as fossil fuels. (ii) There must be a large enough production capacity to make these new fuels available at an acceptable cost. (iii) The fuels should be able to be handled without making significant changes to storage tanks, pipelines, and other infrastructures (iv) Commercial production must offer a comparatively acceptable price concerning currently conventional fuels. Finally, (v) the production of these fuels must not compete in any way with any food sources.

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