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PATHWAYS TO MEET TRANSPORT renewable energy targets

Meeting the targets of the Paris Agreement requires fast decarbonisation of the transport sector. Decarbonisation comes at a cost, and hence regulations and mandates are needed to stimulate the transition. The European Renewable Energy Directive (RED) drives decarbonisation through the definition of targets and options; this article discusses the impact of the legislative framework on the fuel industry and the options for Shell to meet and go beyond the mandates through the use of various biofuels, gaseous fuels including hydrogen and e-mobility.

EV charging is an increasingly common sight, but additional solutions are required to meet decarbonisation targets.

For on-road transport to transition to zero emissions, internal combustion engine (ICE) passenger cars will gradually be replaced by electric vehicles (EV), and heavier vehicles for long-distance driving will likely run on hydrogen.

However, there will remain a legacy fleet of ICE vehicles on the roads for many years to come, and decarbonisation solutions are needed for those as well. Biofuels and bioLNG (biomethane liquefied natural gas) are lower-cost options that can play an important role in decarbonising on-road transport in the near and mid term.

For diesel engines, R33 and HVO100 are drop-in fuels, whereas ethanol is a blend component for gasoline engines that reduces fossil carbon and delivers high octane, which could enable the addition of lower-octane bionaphtha or methanol-to-gasoline (MTG) fuel to the blend. A fuel blend containing 20% ethanol by volume (E20) is seen as the logical next step for gasoline engines, as many newer vehicles can already run on this fuel.

As on-road transport transitions towards electric power and hydrogen fuel, and in the long term the need for biofuels in this sector is therefore reduced, the available biofuels can be used in the marine and aviation industries, which will need energy-dense liquid fuels in the longer run. Further into the future, when e-fuels (from green hydrogen produced by electrolysis of water using renewable

electricity and carbon dioxide [CO_2]) can be produced at lower cost and larger scale, these fuels will likely play a role in the aviation and marine sectors.

Introduction to the regulatory framework

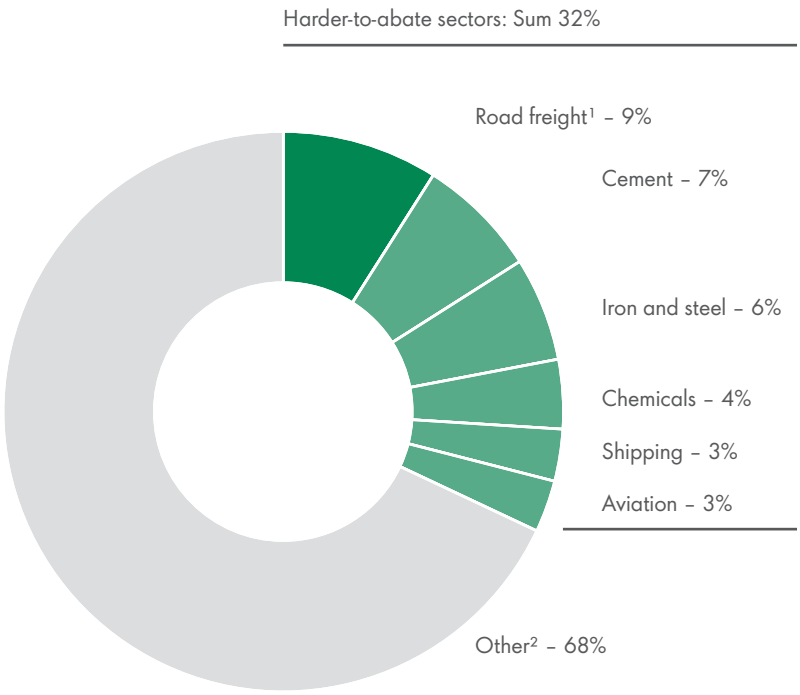
The 2015 Paris Agreement defined a bold ambition to limit global warming to below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C, in part by pursuing net carbon neutrality by 2050. In response, many countries, industries and individual organisations set targets to limit their carbon emissions and developed plans for reaching those targets.

There is action at global, national, regional, local and sector levels, and there are many positive signs, but more can be done to address climate change. The United Nations Environment Programme notes, "On current unconditional pledges, the world is heading for a 3.2°C temperature rise."

The challenge is particularly pronounced in six harder-to-abate sectors that, according to the International Energy Agency (IEA), currently account for about 32% of global CO_2 emissions (Figure 1). These sectors share common characteristics such as long asset lifespans, high energy dependency and complexity of electrification. As a result, decarbonisation of these industries will be slower, more investment intensive and more technically demanding than in other sectors. The transport sector is one such sector, and its CO_2 emissions are significant [Ref 1]. As decarbonisation happens more rapidly elsewhere, pressure and focus on harder-to-abate sectors is expected to increase.

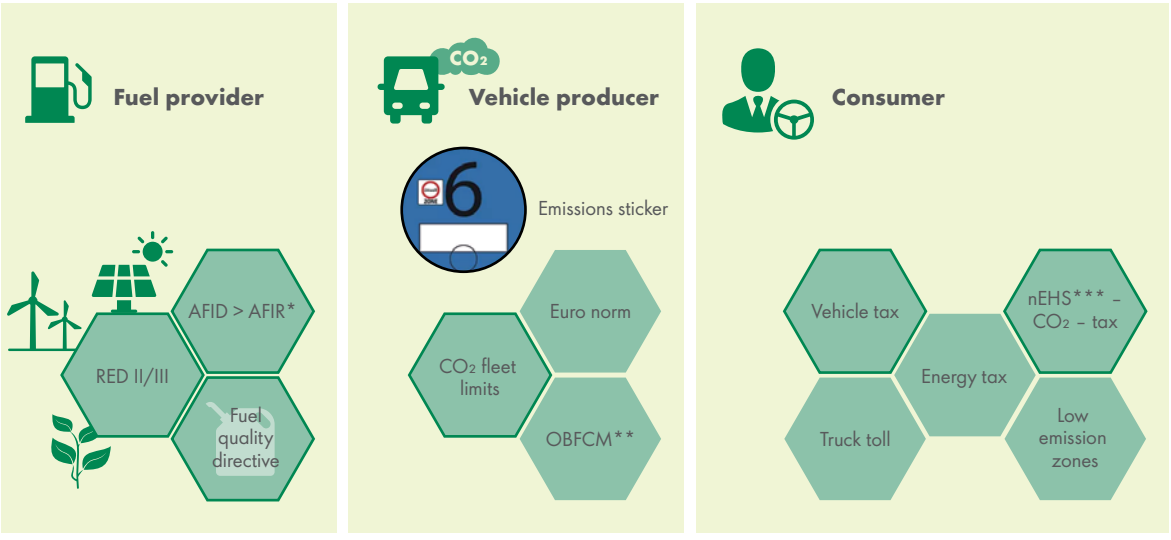
Legislation in Europe is complex (Figure 2) and currently imposes separate regulations on fuel providers (well-to-tank, WtT) and equipment manufacturers (tank-to-wheel, TtW) (Figure 3). Because of all these factors, it is important to determine which options are relevant and viable from the perspective of an energy company such as Shell.

The regulatory framework includes the European Green Deal 2050, CO_2 emission performance standards for road transport, the Renewable Energy Directive, the Fuels Quality Directive and the EU Emissions Trading System.



Sources: IEA, CO_2 emissions by sector, World 1990–2018; CO_2 emissions from idustry, transport and heavy-duty vehicles in the Sustainable Development Scenario 2000–2030; Deloitte analysis
Notes: (1) Including LCVs, MDTs, HDTs and 1.5% from buses; (2) Including power (46.5%), other transport (10.8%), buildings (8.6%), feedstock (1.9%) and other industry (1.6%)

FIGURE 1
Share of CO_2 emissions by sector.



*Alternative Fuels Infrastructure Directive/Regulation, **On-board fuel and energy consumption monitoring,
***National Emissions Trading Scheme (Germany)

FIGURE 2
Regulatory landscape for cars and trucks today.

Separate CO_2 regulation for WtT and TtW

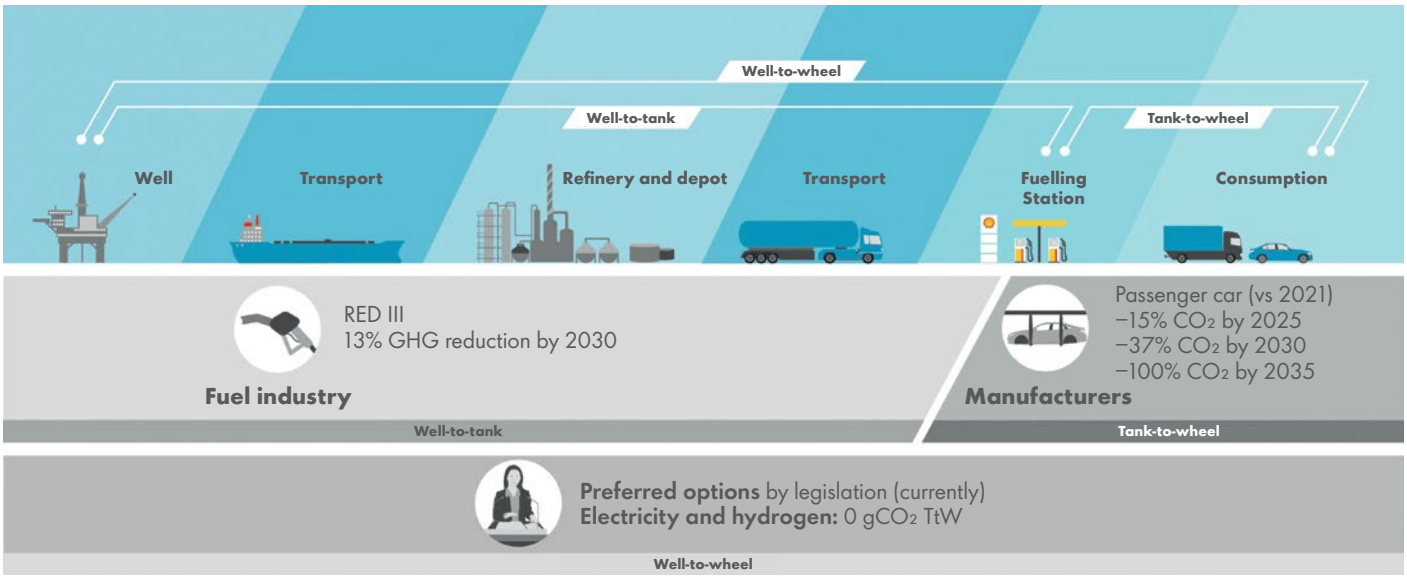


FIGURE 3
Separate legislation for energy companies and vehicle manufacturers. Some targets are preliminary; some are current proposals, not finalised.

Meeting and going beyond mandates

Fuel options for GHG reduction and RED compliance

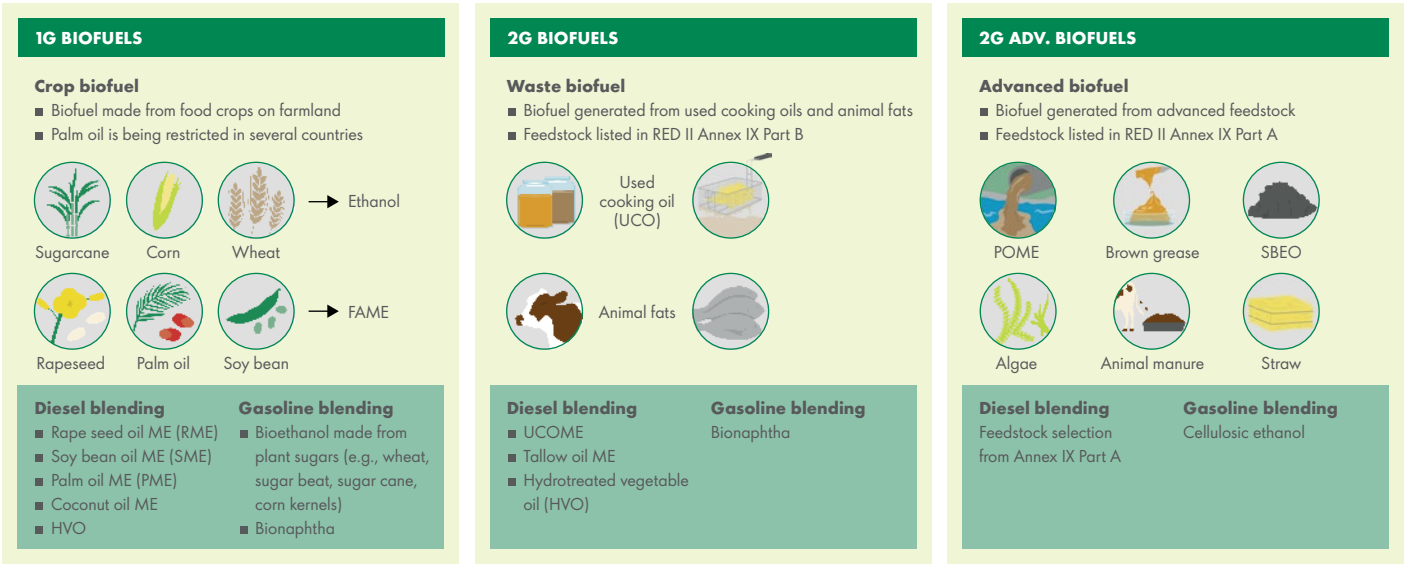
A variety of fuel options exist to reduce greenhouse gas (GHG) emissions as required by RED III. Crop-based biofuels are the established fuel options feeding into the diesel market (in the form of fatty acid methyl ester, FAME) and the gasoline market (as ethanol). Their use is capped by the different regulations, so overall compliance is not feasible based on these two options.

The type of biofeedstock used for renewable biofuel production is becoming more and more relevant as the regulations evolve. So far, three main categories of feedstocks have been identified: crop, waste and advanced (Figure 4). Crop-based, or first generation (1G), biofuel production could be considered to be in competition with food production; waste, or second generation, biofuels (2G bio) are based on by-products; and advanced, also called second generation (2G adv.), biofuels are new products that use by-products of current processes and thus are not considered to be in competition with food production or harmful to animals in any way.

The discussed biofuel pathways enable CO_2 reduction, and thus compliance, not only by their application in new vehicles entering the market but also by leveraging the legacy fleet of vehicles on the road. However, the emission contribution of

FIGURE 4
Types of biofeedstocks and biofuel products.

Biofuel options



ME: methyl ester
Complete list of advanced feedstocks from Annex IX Part A here

POME: palm oil mill effluent
SBEO: spent bleaching earth oil

the electricity used for charging is linked to the share of new battery electric vehicles (BEV) entering the market. As governments want to stimulate the development of EVs, in many EU member states the regulations allow the multiple counting of the EV contribution. This means that, under the current RED II regulations, any unit of electricity sold for BEV charging can be counted multiple times towards the renewable energy mandate (the multiplier varies by member state). Of course, this is only applicable to green electricity, which can be accessed in two ways: a direct line to a green electricity source such as a solar photovoltaic farm, or as the percentage of the common energy grid that the government calculates to be green.

A similar situation applies with hydrogen: only a very small number of vehicles are on the road today. As the passenger car sector is focusing on BEV technology, hydrogen is expected to gain market share in the heavy-duty commercial road transport sector due to its fast refuelling capability, which can deliver similar operational flexibility as that for today's diesel or liquefied natural gas (LNG) trucks. However, sizeable fleets of hydrogen trucks are expected only towards the end of the current decade, so their contribution to CO_2 reduction and RED compliance by 2030 will be limited. In terms of RED compliance, only green hydrogen from electrolysis using renewable electricity is applicable; any other type of hydrogen is not.

Hydrogen derivatives are also gaining momentum. For example, ammonia is used predominantly as a fuel in the marine sector but also as a hydrogen carrier for long-distance transport, for fertiliser production and in the power sector. Again, only green ammonia, from green hydrogen produced by electrolysis with renewable electricity, is applicable for RED compliance, whereas others building on fossil feedstocks, even when carbon capture and storage is applied, are not.

Another option considered in the marine sector is methanol, as it is an easy-to-handle liquid fuel and the supply infrastructure exists in many ports worldwide. While methanol is produced from natural gas or coal today, alternative, biomass-based production pathways exist. Furthermore, synthetic production using green hydrogen plus captured CO_2 to produce e-methanol is possible. A recent Shell publication [Ref 2] provides a detailed description of the different production pathways that are enabling a full range of different gaseous or liquid hydrocarbon products.

While many of these biobased or synthetic fuels are directly fit for purpose in some applications, alcohols such as methanol and ethanol can be processed into blending products for high-demand target sectors. Ethanol, for example, can be converted through an ethanol-to-kerosine process into sustainable aviation fuel (SAF), or through an MTG or ethanol-to-gasoline (ETG) process into an aromatic-rich naphtha stream with excellent properties for blending with gasoline [Ref 3].

Another pathway to decarbonise the gasoline pool is MTG, which has recently gained market visibility because an industry consortium is promoting this concept under the name Haru Oni. This is based on an energy import scenario for Europe that utilises the superior conditions for renewable energy production and conversion in Chile to generate easy-to-transport products.

In terms of CO_2 abatement costs (for the fuel production side only), Figure 5 shows a high-level overview of the costs of decarbonising fuel and energy carriers.

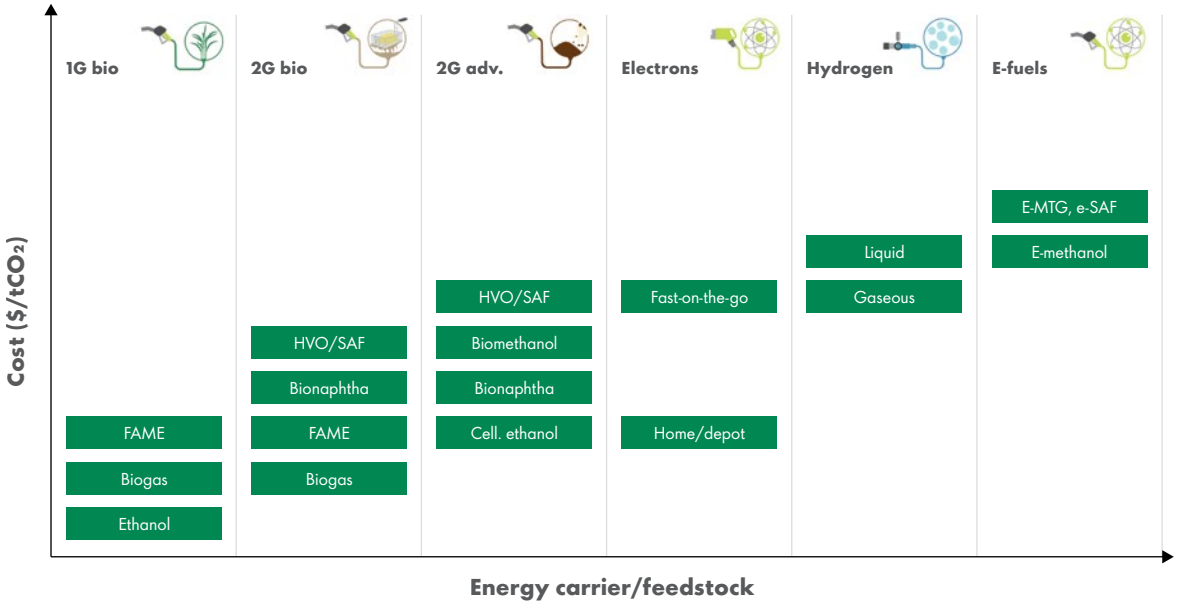


FIGURE 5
Cost ladder of decarbonisation fuels and energy carriers.

R33 Blue Diesel – composition

- Increased share of renewable components to up to 33%
- Clearly defined sustainability criteria – waste and residue only*
- At least 22% CO_2** reduction via biofuels and ≈80% CO_2 compensation via NBS***
- Meets the specification EN590

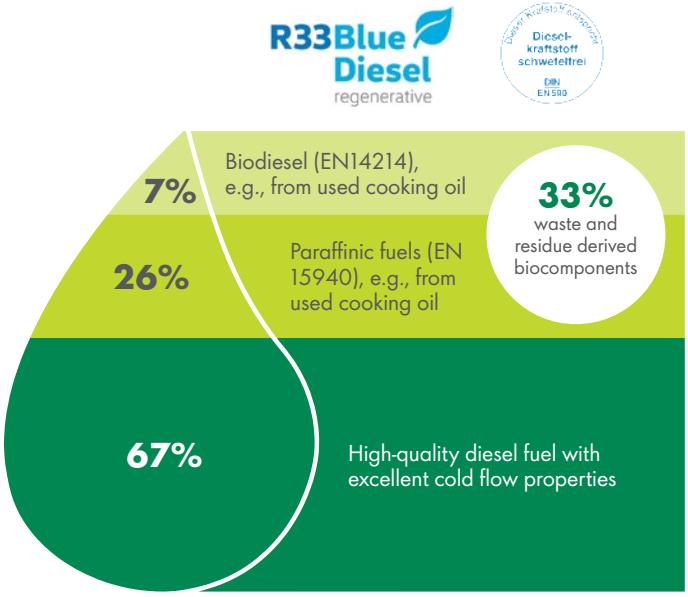


FIGURE 6
Fuel composition and product definition of R33 Blue Diesel.

*According to mass balanced proof of sustainability (PoS)/ certified feedstock
**Well-to-wheel CO_2 reduction based on GHG value of PoS of used components with 95.1g CO_2/MJ as reference for fossil diesel
***Compensation via VCS-certified nature-based solutions (NBS)

Of these options, ethanol and FAME are the most mature. HVO is becoming more mature; however, there are challenges with the feedstock requirement. The fuels based on crops (1G) or based on 2G bio feedstock (Annex IX(b) of RED) are capped and will mostly use ethanol and FAME, so HVO will need to be based more on uncapped sources (RED Annex IX(a)).

The adoption of EVs and bioLNG and hydrogen fuels is dependent on consumer acceptance. Hydrogen will remain a relatively costly product in the immediate future but offers emission-free mobility combined with, compared to BEVs and for certain use cases, a number of customer benefits, for example, long range, fast refuelling and high payload. Although hydrogen requires subsidies in the coming years, there is potential for significant cost reduction when the infrastructure has been set up and large, GW-scale electrolyser projects have come onstream.

Drop-in substitution of fossil fuels

As EU regulations focus on the shift towards zero tailpipe CO_2 emission vehicles, the demand for liquid fuels will gradually diminish. Assuming a phase-out of ICE vehicles in the passenger car sector by 2035, given the announced demand for a 100% CO_2 reduction from new passenger car vehicle sales and an average age of such vehicles on European roads of 11.5 years (according to ACEA data [Ref 4]), demand for liquid fuels will continue into the 2050s. Similar steps are under discussion for commercial road transport, although a technology change from ICE power to battery-electric and/or hydrogen power is much harder to realise for trucks than for lighter vehicles. Demand for diesel-type fuels well beyond 2050 is likely, especially considering the average age of heavy-duty trucks is even greater, at 13 years [Ref 5].

As new biofuel production facilities are coming online this decade, we can expect increased availability of renewable molecules, and production can be expected to continue for decades to support the decarbonisation of transport, particularly the hard-to-abate commercial road transport, aviation and marine sectors. For road transport, however, demand for fuels will decline as ICE vehicles are replaced by BEVs and hydrogen-powered trucks. Depending on the competition for biofuels across the transport sector, the share of renewable molecules in liquid fuel may increase, thereby enabling a fully renewable liquid fuel for the remaining ICE legacy fleet. The fuel options on the trajectory from today's fossil–renewable blends towards fully renewable fuels are discussed next.

Lower-carbon fuel options for existing engines

Low-carbon fuels are already contributing significantly to CO_2 reduction in Europe. For example, the German Federal Office for Agriculture and Food reported that, in 2020, biofuels led to a CO_2 reduction of more than 13 million tonnes [Ref 6]. This reduction will grow further, and the pathway will remain pivotal to overall CO_2 reduction targets. Hence, this topic continues to be of great interest to Shell.

R33 Blue Diesel

It is well known that there will be a significant number of vehicles with diesel engines for the foreseeable future. Germany alone still has about 20 million diesel vehicles, including passenger cars, trucks, buses, vans and off-road vehicles. Similarly, in Europe there are on the road today about 700,000 buses, several million trucks and more than 25 million vans largely powered by diesel engines and with a significant lifetime, often exceeding 10 years. And combustion technology

continues to be present in the overwhelming share of new vehicles – typically about 95% for heavier diesel vehicles [Ref 5].

Hence, there is a clear need to provide fuel solutions for such vehicles that enable customers to choose low-carbon mobility, that is, low-carbon fuels that meet the existing diesel specification, EN590. One example of such a fuel is R33 Blue Diesel, a product developed over several years in cross-industry partnerships. R33 Blue Diesel is a response to the question of how much CO_2 can be avoided within the EN590 specification while also improving fuel quality and setting new standards for sustainability. Figure 6 shows the fuel composition and product definition of R33 Blue Diesel.

R33 has been on the market for several years, both with Shell's business-to-business partners and increasingly at public filling stations operated by a range of partners, thus demonstrating that liquid fuels can be decarbonised to a significant extent. And a compelling combination of CO_2 reduction and compensation can be delivered through Shell Nature Based Solutions. Owing to high-quality components, R33 Blue Diesel has achieved consistent high-quality in important fuel parameters such as cetane number, cloud point, cold filter plug point and stability.

100% HVO and HVO/GTL blends

A 100% HVO option (HVO100) will become available from Shell in the Netherlands in 2022. A paraffinic diesel fuel comprising 45% Shell gas-to-liquids (GTL) fuel and 55% HVO will also be available in the UK. Both of these paraffinic diesels (EN 15940 compliant) provide significant further steps along the diesel decarbonisation journey, as illustrated in Figure 7. Data for the well-to-wheels (WtW) CO_2 impact is taken from the JEC 2020 WtW [Ref 7] and WtT [Ref 8] reports.

Blue Gasoline

In 2021, Shell launched the gasoline equivalent of R33 Blue Diesel, called Blue Gasoline, in partnership with Volkswagen and Bosch. It is based on the same motivation to demonstrate that sustainability can be substantially improved for gasoline fuels while improving overall fuel quality. Moreover, as there is a stock of well over 70 million gasoline cars in Europe, and such vehicles still make up about 50% of new sales, particularly when including plug-in hybrid electric vehicles, long-term, low-carbon fuel solutions will be needed to achieve ambitious CO_2 reduction targets.

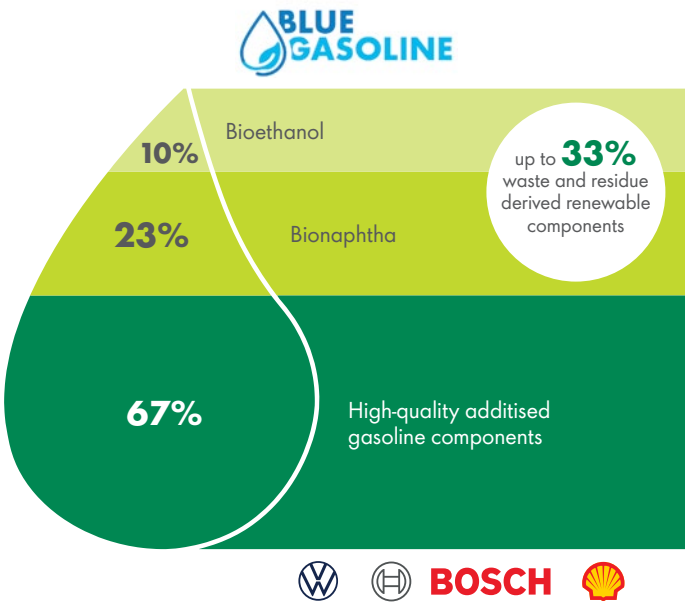
Blue Gasoline has been rigorously tested against numerous technical requirements. To achieve high product quality regarding particulate emissions, the E150 (volume fraction of fuel evaporated at 150°C) of Blue Gasoline was set to minimum 85% and the distillation end point was set to maximum 195°C. Additivation was also set to a premium level to achieve a consistently high level of cleanliness of critical engine components, which contributes to reduced emissions. Figure 8 shows the fuel composition and product definition of Blue Gasoline.

These examples demonstrate that a lot can be done today, but much work remains to be done with Shell's partners. Future priorities for Shell are in the areas of sustainability of feedstocks and final products, new grades such as RON98, future specifications such as E20 and, of course, fully renewable fuels such as HVO100 or B100. ▸▸▸

FIGURE 7
Decarbonisation potential of R33 Blue Diesel, HVO 100 and a 45:55 blend of HVO and GTL.

Blue Gasoline – composition

- Increased share of renewable components to up to 33%
- Clearly defined sustainability criteria – waste and residue only*
- At least 20% CO_2** reduction via biofuels and ≈80% CO_2 compensation via NBS***
- Full compliance with EN228 RON95 E10 specification



*According to mass balanced PoS/certified feedstock
**Well-to-wheel CO_2 reduction based on GHG value of PoS of used components with 93.3g CO_2/MJ as reference for fossil gasoline
*** Compensation via VCS certified NBS

FIGURE 8
Fuel composition and product definition of Blue Gasoline.

An extensive vehicle test programme was run at Shell Technology Centre Hamburg for E20+ fuels (up top E25) to check if any fuel-related problems would occur.

The following parameters were examined during the course of the trial:
- change in fuel consumption during the course of the test;
- excessive lubricant degradation, consumption or ageing compared with those fuelled with reference fuel;
- evidence of severe degradation or breakdown of vehicle fuel systems (tanks, fittings, fuel lines, etc.) compared with those fuelled with reference fuel; and
- other abnormalities or driver observations.

No fuel-related issues were observed, which is an encouraging result. Hence, E20-like fuels could be rolled out to a significant share of the fleet in Europe and offer significant room for low-cost decarbonisation of the fleet.

E20 and Blue Gasoline as steps on the decarbonisation roadmap

When blended into a fossil-derived base stock, the addition of 20% by volume of ethanol to make an E20 grade results in WtW GHG savings of about 10%, compared with a fossil E0 fuel, as illustrated in Figure 9 (assuming GHG emissions of 93.3 gCO_2/MJ as a reference for fossil gasoline and ethanol typically available in the European market). Moving from E10 to E20 would result in an incremental 5% GHG saving, which would be a significant step if integrated across the whole fleet.

Blue Gasoline comprises about 10% ethanol by volume (making it an E10 fuel) and about 23% of a bionaphtha, giving overall WtW GHG savings of 20% (Figure 9). In the C³ Mobility Project, it was shown that, by adding 10 vol% ethanol to a synthetic gasoline produced from an MTG process, it is possible to produce a fuel that meets the prevailing EN 228 gasoline specification [Ref 9]. Indeed, one of the great advantages of ethanol that has been noted in other studies [Ref 10] is that it can be blended with synthetic streams that have a poorer octane quality to make a 95 RON fuel.

Blue Gasoline is an E10 fuel, as was the experimental gasoline produced as part of the C³ Mobility Project. However, it is possible to envisage a subsequent step in which E20 becomes an enabler for a further step in WtW emissions reduction in which E20 is combined with a bionaphtha, MTG or ETG fuel. This step is illustrated in Figure 9, which envisages a 35% WtW GHG saving from having E20 in conjunction with bionaphtha. However, if a synthetic stream with a higher octane content than bionaphtha is used, for example, MTG or ETG, then it might be possible to go further and a 100% renewable content would be potentially possible with very large GHG savings.

Summary

A range of options and processes is available to decarbonise the transport sector in Europe. Some options, such as biofuels, are drop-in solutions and can help decarbonise the ICE vehicles that will still be in the fleet for some time. Other options, for example, bioLNG, electric mobility and hydrogen, require new powertrains and new infrastructure.

Decarbonisation comes at a cost, hence regulations and mandates are needed to stimulate the transition. Biofuels and bioLNG are lower-cost options and will help decarbonise road transport.

FIGURE 9
WtW CO_2 emissions: Illustration of E20 Blue Gasoline as part of the decarbonisation journey.

R33 and HVO100 are fuels that can be used as drop-ins for existing diesel engines. For gasoline engines, ethanol is a blend component that reduces fossil carbon and delivers high octane, which enables blending of lower octane bionaphtha or MTG. E20 is seen as a logical next step for gasoline engines, as many newer vehicles on the roads are technically able to run on E20.

In the medium term, road transport is mandated to move to zero emissions. Hydrogen is expected to grow as a fuel, especially for heavier trucks with long-distance driving use cases. When hydrogen infrastructure has been built up and fuel cell and hydrogen storage systems are mass produced, it is expected that, in some passenger car use cases (e.g., SUVs and frequent long-distance driving), hydrogen can play a role.

With the transition of road transport towards electric and hydrogen fuels, available biofuels can be used for the marine and aviation industries, as they will need energy-dense liquid fuels in the longer run. When e-fuels can be produced at lower cost and at larger scale, it is likely these will play a longer-term role in the aviation and marine sectors.

A possible mobility decarbonisation roadmap is shown in Figure 10. However, the response of the consumer community may affect policy and shape how certain transport subsectors will transition to a decarbonised future. ▸▸▸

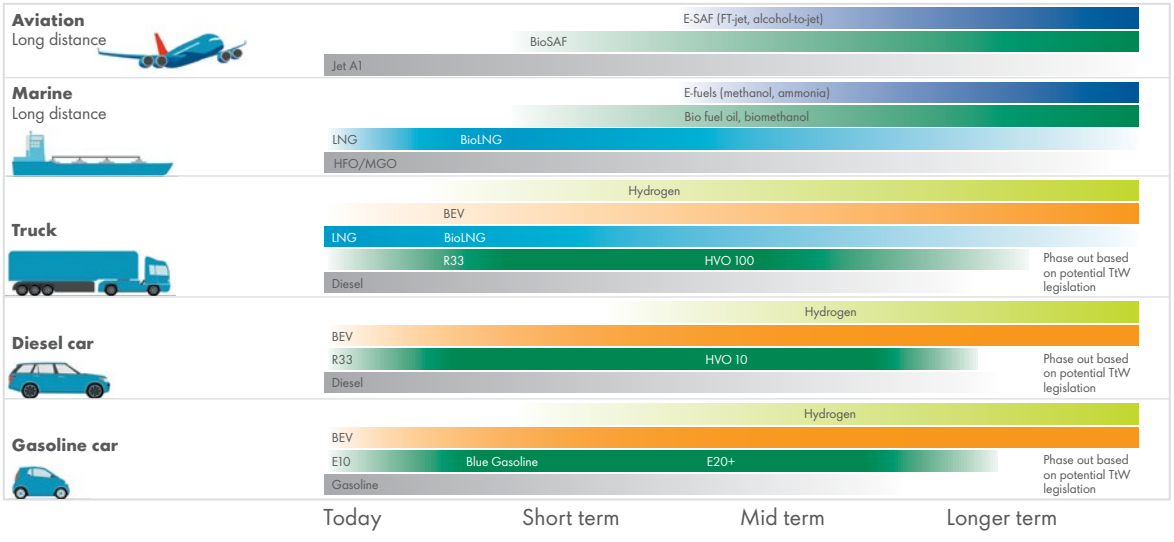


FIGURE 10
Fuel decarbonisation roadmap for the EU vehicle fleet (nonroad excluded).

MGO: Marine gasoil
HFO: Heavy fuel oil

Acknowledgements

The authors would like to thank Filimonas Kaliafetis, Ingo Mikulic, Kim Rijken, Renate Uitz and Wolfgang Warnecke for their contributions to this article. ■

Review:

Kim Rijken, team lead business development low carbon fuels, Europe

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