Renewable Gasoline in a Declining Market

Market Conditions, Technical Pathways, and the Future of Gasoline Cars

Swedish Environmental Research Institute

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Report number: C11225
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Date: April 2026

Funded by: Swedish Transport Administration

ISBN: 978-91-7883-825-7

[Renewable gasoline, renewable petrol, bio-gasoline, bio-petrol, e-gasoline, e-petrol, gasoline blends, petrol blends, ethanol, E85, bio-naphtha, e-naphtha, methanol-to-gasoline, ethanol-to-gasoline, co-processing, gasoline cars, petrol cars]

Summary

While climate targets require a near-complete phase-out of fossil fuels by 2050, with substantial reductions needed before then, gasoline vehicles are expected to remain in the fleet beyond when these reductions are required. Unlike diesel, there is no widely available renewable substitute for fossil gasoline at scale beyond ethanol and bio-naphtha, with limited blending potential. This creates a structural gap between policy ambitions and the expected development of the passenger car fleet.

The analysis shows that renewable gasoline can be produced through multiple pathways, including methanol- and ethanol-to-gasoline routes, refinery co-processing, and renewable naphtha streams. However, these pathways vary but are generally complex and costly, and scaling them up remains difficult. To date, large-scale investments have not materialized, except for bio-naphtha, a by-product of HVO and SAF production.

The analysis shows that decarbonizing gasoline is inherently challenging. Renewable gasoline faces significant commercial barriers, notably a declining gasoline market, weakening the case for new investments. Additional challenges include high production costs and competition for key intermediates. The analysis further shows that policy instruments are unlikely to fundamentally overcome these structural barriers.

In the short to medium term, the analysis indicates that the most realistic pathway for decarbonizing gasoline cars is to increase the use of existing renewable drop-in components, primarily ethanol and renewable naphtha. Even modest increases can deliver meaningful emission reductions at the system level. However, the mitigation potential with this approach is limited and insufficient to meet the climate targets.

Further reductions will require a broader transition beyond incremental blending, including options such as fully renewable fuels, vehicle adaptation (e.g., flex-fuel retrofits), or a gradual phase-out of gasoline vehicles. The analysis, however, shows that all of these pathways involve significant challenges, and no single solution is clearly dominant.

Ultimately, the scale of the challenge depends on how many gasoline vehicles remain. Faster electrification reduces the number of vehicles needing low-carbon fuels and is therefore critical to limit long-term reliance on gasoline.

Sammanfattning

Medan klimatmålen kräver en nära fullständig utfasning av fossila bränslen till 2050, med betydande utsläppsminskningar redan dessförinnan, förväntas bensinbilar finnas kvar i fordonsflottan även efter den tidpunkt då dessa minskningar behöver vara genomförda. Till skillnad från diesel saknas förnybara alternativ till fossil bensin i stor skala, utöver etanol och bionafta som endast kan användas i begränsade inblandningsnivåer. Detta skapar ett strukturellt glapp mellan politiska ambitioner och den förväntade utvecklingen av personbilsflottan.

Analysen visar att det är tekniskt möjligt att producera förnybar bensin genom flera olika produktionsvägar, inklusive metanol- och etanol-till-bensin-processer, samprocessering i raffinaderier samt bionafta. Dessa vägar skiljer sig åt, men är generellt komplexa, kostsamma och svåra att skala upp. Hittills har investeringar i sådan produktion uteblivit, med undantag för bionafta som uppstår som en biprodukt vid produktion av HVO och SAF.

Analysen visar vidare att omställningen av bensin är förenad med betydande utmaningar. Förnybar bensin möter omfattande kommersiella hinder, inte minst i form av en förväntat minskande bensinmarknad, vilket försvagar incitamenten för nya investeringar. Ytterligare utmaningar är höga produktionskostnader och konkurrens om centrala insatsvaror. Analysen visar också att styrmedel sannolikt inte kommer övervinna dessa strukturella hinder.

På kort till medellång sikt är den mest realistiska vägen att minska utsläppen från bensin att öka användningen av befintliga förnybara drop-in-komponenter, främst etanol och bionafta. Även relativt små ökningar kan ge betydande utsläppsminskningar på systemnivå. Den totala potentialen med detta tillvägagångssätt är dock begränsad och otillräcklig för att nå klimatmålen.

Ytterligare utsläppsminskningar kräver en bredare omställning bortom stegvis ökad inblandning, inklusive alternativ som helt förnybara bränslen, anpassning av fordon (exempelvis konvertering till flex fuel) eller en successiv utfasning av bensinbilar. Analysen visar dock att samtliga dessa vägar är förenade med betydande utmaningar, och att ingen enskild lösning framstår som mest lämplig.

I slutändan avgörs problemets omfattning av hur många bensinbilar som finns kvar i flottan. En snabbare elektrifiering minskar behovet av förnybara bränslen och är därför avgörande för att begränsa det långsiktiga beroendet av bensin.

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1 Introduction

Despite the rapid pace of electrification, gasoline-powered vehicles continue to account for a substantial share of new car sales in most countries and regions. Projections further indicate that gasoline vehicles will remain a significant part of the passenger car fleet for decades to come.

Unlike diesel, there is currently no renewable substitute for fossil gasoline that can, at scale, be used directly in conventional gasoline engines without vehicle modification. This reflects the fact that gasoline is not a single fuel, but a blend of multiple components that must meet strict specifications. Ethanol – and, to a more limited extent, bio-naphtha – are used as drop-in blending components, but their blending potential is constrained by technical limitations. While ethanol can also be used in higher blends, such as E85, this requires vehicles to be adapted to operate on such fuels and therefore does not provide a direct substitute for conventional gasoline.

This report addresses this “gasoline challenge” by assessing the technical and market conditions for renewable alternatives to fossil gasoline. It analyzes the opportunities and limitations of different production pathways for renewable gasoline components, as well as the constraints and possibilities associated with gasoline blending. It also considers alternative strategies that combine fuel substitution with vehicle adaptation, such as high-ethanol fuels. Based on this, the report assesses the realistic role that renewable gasoline could play in the decarbonization of the passenger car fleet.

The report is structured as follows. Chapter 2 examines the role of gasoline vehicles in relation to climate targets and future fuel demand. Chapter 3 analyzes the technical pathways and blending constraints for renewable gasoline. Chapter 4 evaluates policy options and their implications for market development. Chapter 5 discusses the future role of gasoline vehicles in light of the findings.

Methodology

The analysis is based on a combination of literature review and interviews with industry stakeholders and experts. The literature review covers scientific studies, industry reports, and policy-related material on renewable gasoline production, fuel markets, and transport decarbonization. A total of 26 actors across the fuel and automotive value chain were interviewed (see Table *1* for an overview). The study was funded by the Swedish Transport Administration.

Table 1. Overview of stakeholder interviews by category.

Stakeholder category	Description	Number of actors
Fuel producers	Large-scale producers and refiners of transport fuels for conventional markets	5
Emerging fuel producers and technology developers	Developers of new fuel production pathways (e.g. e-SAF, e-methanol, ethanol-to-gasoline)	4
Automotive and engine manufacturers	Developers and manufacturers of vehicles and engines	4
Specialized fuel producers and distributors	Producers of specialized fuels (e.g. alkylate fuels) and distributors of renewable fuels	2
Industry organizations	Industry associations and advocacy organizations in the fuel and automotive sectors, including e-fuels	3
Public sector actors	Public authorities, government bodies, and public inquiries involved in policy development	4
Other industry experts	Industry experts providing technical and market insights	2
Vehicle conversion and retrofit providers	Providers of vehicle modifications, e.g. retrofitting vehicles to operate on E85	2

Scope and analytical approach

This report does not provide a detailed assessment of the life-cycle greenhouse gas (GHG) performance of different renewable gasoline pathways. While such assessments are common in the literature, reported GHG outcomes are highly sensitive to underlying assumptions regarding feedstock origin, energy inputs, and process configuration. In many cases, very low GHG intensities are based on combinations of favorable assumptions that are not necessarily aligned with commercially realistic conditions.

Given these uncertainties, this report instead focuses on the technical characteristics, market conditions, and scalability of different pathways. The analysis is therefore centered on what can be considered commercially and systemically plausible, rather than on best-case GHG performance under idealized assumptions.

2 Gasoline Cars and the Climate Targets

2.1 Climate targets imply a near-complete phase-out of fossil gasoline

Climate targets at both national and European levels imply that the use of fossil gasoline in passenger cars must be almost entirely eliminated over the coming decades. In Sweden, the target of net-zero greenhouse gas emissions by 2045 is accompanied by an assumption in the government's climate action plan that emissions from domestic transport must, "in principle", be reduced to "near zero" (Swedish Government, 2023b). In practice, this leaves little or no room for continued use of fossil gasoline in the passenger car fleet.

At the European level, the EU has adopted a target of achieving climate neutrality by 2050 as part of the Green Deal and Fit for 55 package. According to the European Commission, this requires a reduction of around 90% in transport emissions (European Commission, 2020). The remaining emissions are expected to originate primarily from sectors that are more difficult to decarbonize, not least aviation, implying that emissions from passenger cars must be almost entirely eliminated (European Commission, 2024).

The proposed EU climate target for 2040, corresponding to a net reduction of around 90 percent compared to 1990 levels, further reinforces this trajectory and highlights the very limited remaining emissions space for road transport. While the 2040 target does not define sector-specific outcomes, it highlights the limited remaining emissions space available to sectors such as road transport.

In parallel, the introduction of the EU Emissions Trading System for road transport and buildings (ETS2), expected to take effect from 2028, will progressively reduce the emissions associated with fossil fuel use. As the emissions cap declines over time, the cost of supplying fossil gasoline is likely to increase, further constraining its long-term use.

2.2 Gasoline-dependent vehicles remain a large share of new car sales

Gasoline-powered vehicles continue to account for a substantial share of new passenger car sales across most major markets. In Sweden, gasoline-powered cars, including non-chargeable hybrids and ethanol-compatible vehicles, accounted for 31 percent of new car sales in 2025, while plug-in hybrid vehicles accounted for a further 26 percent (Transport analysis, 2026). Although partially electrified, these vehicles are, at least in a Swedish context, on average driven by the gasoline engine for around half of the total distance (Mandev & Sprei, 2024; Swedish Transport Administration, 2022).

A similar pattern can be observed at the European level, where gasoline-powered vehicles accounted for 61 percent of new passenger car sales in 2025, with plug-in hybrids adding a further 9 percent (ACEA, 2026). In the United States, the dominance of gasoline-based powertrains is even more pronounced, accounting for approximately 75 percent of new car sales in 2024 (EPA, 2026).

At the global level, internal combustion engine vehicles accounted for around 70 percent of new passenger car sales in 2024 (IEA, 2025b). While this includes both gasoline and diesel vehicles, the declining role of diesel in most major markets implies that gasoline vehicles make up the majority of the remaining internal combustion engine fleet.

Given typical vehicle lifetimes of 15–20 years, current sales patterns have long-lasting implications for future gasoline demand, as cars sold today are likely to remain in the fleet well into the 2040s.

2.3 Scenarios indicate persistent gasoline use

Scenarios consistently indicate that gasoline use in passenger cars is likely to decline substantially over time, but not disappear in the near to medium term. Even under relatively ambitious electrification scenarios, a significant number of gasoline vehicles remain in the fleet for decades, resulting in continued demand for gasoline.

Sweden: gradual decline but persistent gasoline use

Scenarios developed by the Swedish Transport Administration show a rapid increase in battery electric vehicles alongside a gradual decline in gasoline-powered cars, as illustrated in Figure *1*. While the number of gasoline vehicles decreases over time, they remain present in the fleet at least until 2050. Plug-in hybrid vehicles increase in the medium term before declining as electrification progresses, while diesel vehicles are phased out relatively quickly.

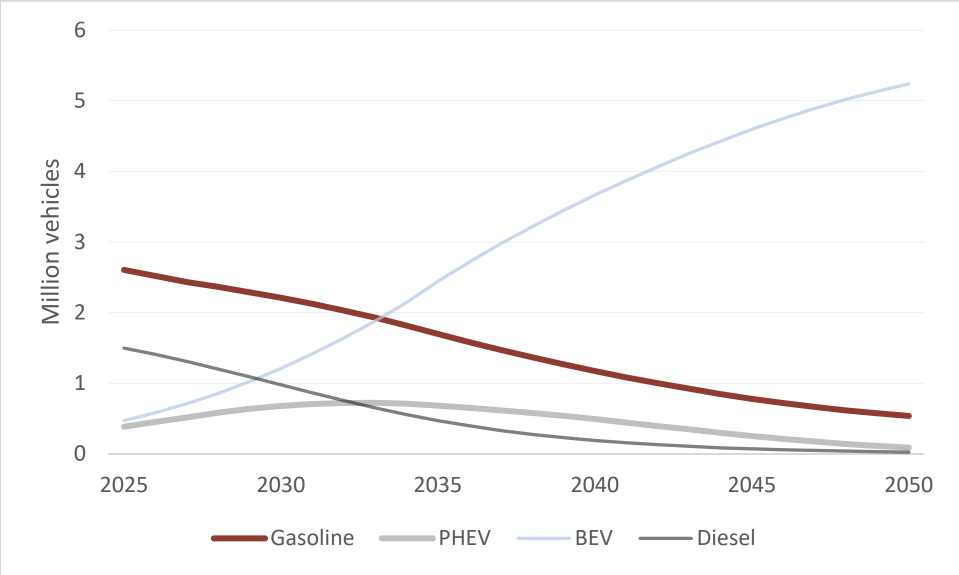

Figure 1. Passenger car fleet by powertrain in Sweden, 2025–2050 (reference scenario)

Source: Swedish Transport Administration, unpublished scenario data.

As a result, gasoline use in passenger cars is also projected to decline substantially over time, as shown in Figure *2*. From a current level of around 20 TWh, consumption decreases by roughly one third by 2035 and more than half by 2040, before falling to around 5 TWh by 2050, with some scenarios indicating an even faster decline, to roughly half this level. Given that climate targets imply near-zero emissions from passenger cars by mid-century, this remaining gasoline use represents a significant gap unless replaced by renewable alternatives.

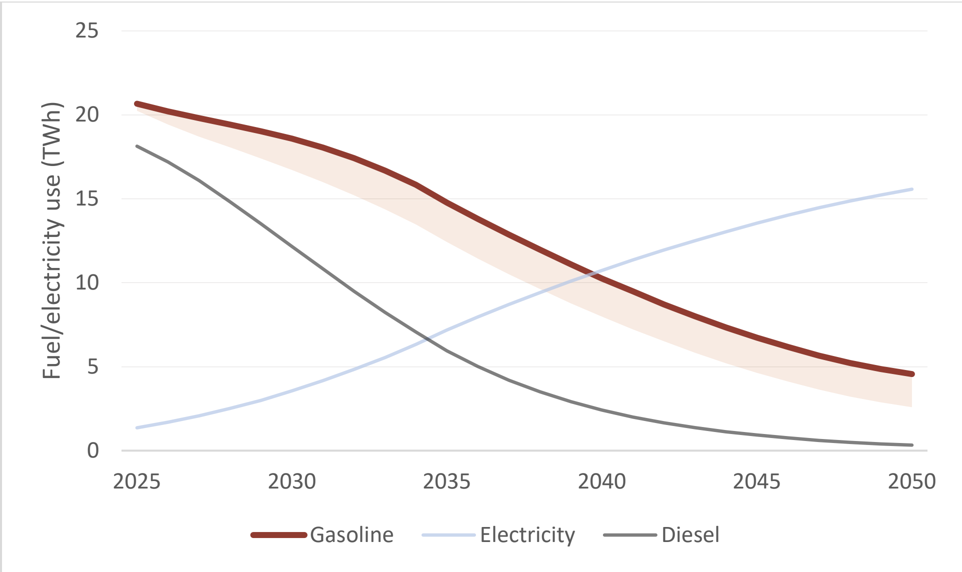

Figure 2. Fuel/electricity use in passenger cars by fuel type in Sweden, 2025–2050 (reference scenario)

Note: The results are based on scenario assumptions developed by the Swedish Transport Administration. These include a phase-out of new internal combustion engine vehicle sales by 2035, lower annual driving distances for older vehicles, and an average electric driving share of around 50% for plug-in hybrid vehicles. The shaded area reflects alternative scenarios with higher gasoline vehicle retirement rates and lower driving distances by gasoline vehicles. *Source: Swedish Transport Administration, unpublished scenario data.*

International scenarios: contrasting perspectives on the phase-out of gasoline

At the European level, scenarios developed by the European Commission illustrate pathways consistent with the EU's long-term climate targets. In these scenarios, the passenger car fleet undergoes a rapid transition, with the share of internal combustion engine vehicles declining from close to 100% in 2015 to around 25% in 2040 and almost zero by 2050, implying a near-complete phase-out of fossil fuels (European Commission, 2024).

However, these scenarios should not be interpreted as projections as they rather represent modelled pathways for achieving climate targets and are based on more aggregated assumptions than the modelling used in the Swedish case. As a result, they may understate the persistence of gasoline vehicles in the fleet, and thus the likelihood for continued gasoline use over time.

At the global level, the transition is both slower and more uncertain. According to the International Energy Agency, electric vehicles are expected to account for around 50% of new light-duty vehicle sales by 2035 under scenarios based on stated policies (IEA, 2025a). Despite this, the global fleet is projected to continue to include a large number of internal combustion engine vehicles for decades, implying continued use of gasoline. Even by 2050, around one billion such vehicles remain in operation, representing almost half of the global fleet. Under scenarios based on currently implemented policies, the share of internal combustion engine vehicles remains even higher.

2.4 The gasoline challenge: a structural gap between targets and reality

The analysis above points to a structural gap between climate targets and the expected development of the passenger car fleet. While climate policy implies a near-complete phase-out of fossil gasoline, gasoline-dependent vehicles are likely to remain in use for decades.

At the same time, there are currently no widely deployed renewable gasoline substitutes that can replace fossil gasoline at scale. While electrification provides a long-term solution, its gradual uptake means that a large share of the existing vehicle fleet will continue to rely on liquid fuels, not least gasoline.

This creates a structural challenge for the decarbonization of passenger cars, as illustrated in Figure 3. Bridging the gap between climate targets and real-world developments would require either a faster phase-out of gasoline vehicles, a rapid scale-up of alternative fuels, or a combination of both. This report examines the latter by analyzing the technical, market, and policy conditions for renewable gasoline and its potential role in addressing this challenge.

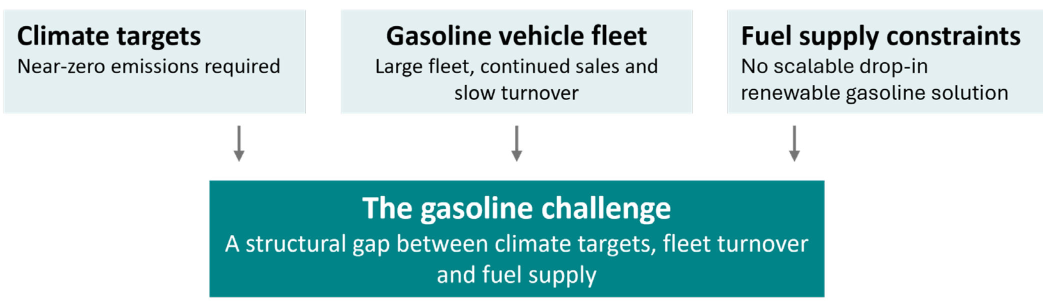

Figure 3. The gasoline challenge: a structural gap between climate targets, fleet turnover and fuel supply.

3 Renewable Gasoline

In this chapter, the available technologies and market conditions for renewable gasoline are examined. It first reviews production pathways for renewable gasoline components, noting that these pathways generally produce blendstocks rather than finished gasoline products. It then analyzes how such components can be incorporated into gasoline blends under existing fuel specifications. Finally, the chapter assesses the feasibility and scalability of these production and blending options in light of broader market conditions. The main characteristics and scale-up constraints associated with these production routes are summarized in Table 2 on page 33 below.

3.1 Production pathways

Renewable gasoline components can be produced via several production pathways. These can broadly be grouped into three categories: dedicated gasoline pathways, generation of by-products within the gasoline range (i.e., renewable naphtha), and co-processing pathways where renewable feedstocks are processed together with crude oil in conventional refineries. This categorization is illustrated in Figure *4*.

It is important to note that gasoline is not a single product, but a blend of multiple components. Typically, up to eleven individual components are combined to meet the requirements of the gasoline standard EN 228 (EU). These requirements include several fuel properties that must be satisfied simultaneously, among which the octane number is particularly relevant in the context of renewable components. The octane number reflects the fuel's resistance to premature auto-ignition ("engine knocking") and must meet minimum specification limits, which can constrain the use of low-octane renewable components.

Consequently, the production pathways described in this chapter do not necessarily yield a finished gasoline blend, but rather individual gasoline components. The blending of these components into market-ready gasoline, that meets the fuel specification, is discussed in Chapter 3.2.

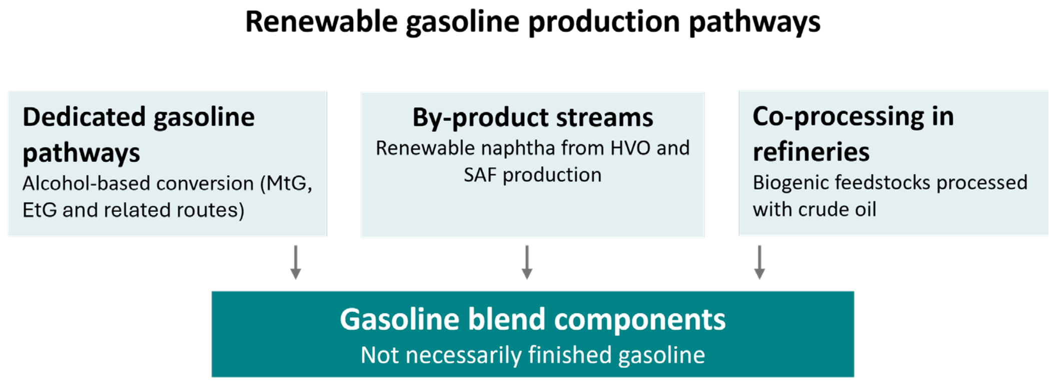

Figure 4. Overview of renewable gasoline production pathways and their primary outputs.

3.1.1 Dedicated gasoline pathways

In a dedicated gasoline pathway, production facilities are designed and operated with the explicit purpose of producing renewable gasoline. Unlike pathways that rely on by-products from other refinery operations, especially renewable naphtha pathways, these routes are purpose-built for gasoline production. In practice, dedicated gasoline pathways primarily refer to processes based on alcohol intermediates.

Methanol-to-Gasoline

The Methanol-to-Gasoline process was developed and commercialized by Exxon in the 1970s in response to the oil crisis. In this process, methanol is catalytically converted into hydrocarbons. The process yields a relatively high gasoline fraction, typically around 85–90% of the hydrocarbon product, characterized by a high octane number due to a significant share of aromatics and isoparaffins (Furusjö & Mossberg, 2020).

While MtG enables the production of renewable gasoline components, it should be noted that methanol synthesis constitutes a separate process. The feedstock from which the gasoline is produced thus depends on the methanol synthesis. Historically, methanol have been – and are still – predominantly produced from fossil natural gas. However, MtG based on renewable methanol has been demonstrated, most notably in New Zealand during the 1980s and early 1990s, where biomass-derived methanol was converted to gasoline at commercial scale (Bube et al., 2024; Furusjö & Mossberg, 2020).

Today, MtG is primarily discussed as a pathway for producing e-gasoline, i.e., gasoline produced from renewable or fossil-free electricity. In this pathway, hydrogen produced through water electrolysis using renewable electricity is combined with CO_2 to produce methanol, which is subsequently converted to gasoline via the MtG process. The CO_2 can be supplied either from biogenic point sources, such as biomass-based industrial processes, or captured directly from the atmosphere using direct air capture (DAC) (Boretti, 2025; Demuynck & Bosteels, 2023).[1]

An often-mentioned example is a small-scale production facility developed by the e-fuel producer HIF, in partnership with Porsche, in southern Chile. Based on information provided on the company's website, the facility has an annual capacity of 130,000 liters (for reference, this corresponds to approximately 0.005% of Sweden's gasoline consumption in 2024). Publicly available information further indicates that the gasoline produced meets the EN 228 specification and can therefore be used directly in existing gasoline vehicles. From a technical perspective, MtG-derived gasoline could also be used as a blending component in a conventional gasoline blend.

Ethanol-to-Gasoline

Another dedicated gasoline pathway relies on ethanol as an intermediate, which is catalytically converted into hydrocarbon fuel blendstocks. The process, often referred to as Ethanol-to-Hydrocarbons (EtH), is flexible and can be configured to favor gasoline-, diesel-, or kerosene-range products, depending on catalyst choice and operating conditions (Anekwe et al., 2024; Furusjö & Mossberg, 2020).

One commonly noted advantage of the EtG pathway is its potential to address the so-called "ethanol blend wall", i.e. the maximum ethanol blending level permitted in gasoline (in the EU, 10 percent; see discussion in Chapter 3.2.2 below). By converting ethanol into hydrocarbon gasoline components, higher blending levels can be achieved. In principle, the process could enable the production of a fully renewable gasoline blend. According to one study, EtG produces gasoline with properties similar to conventional gasoline and can thus meet EN 228 requirements and be used in existing gasoline vehicles (Huang et al., 2024). However, this pathway

[1] Under EU regulations, fuels classified as renewable fuels of non-biological origin (RFNBOs) may use CO_2 originating from biogenic sources or captured from the atmosphere (e.g., through direct air capture, DAC). CO_2 from industrial sources and electricity generation may also be used during a transitional period, provided that the installations are subject to an effective carbon pricing system (Frontier Economics, 2025).

involves additional conversion steps, which increase costs and result in energy losses compared to the direct use of ethanol.

Several companies are currently exploring Ethanol-to-Gasoline pathways; however, none appear to have reached commercial-scale deployment targeting the mainstream passenger car fleet. For example, Lantmännen, a Swedish ethanol producer, announced in late 2025 the acquisition of Ekobenz, a company developing catalysts for EtG applications (Lantmännen, 2025). In addition, Eco Oil, a company affiliated with Umeå University, has developed EtG catalysts, with the company claiming that the resulting products meet the EN 228 gasoline specification.[2]

Other alcohol-based routes

Renewable gasoline components can also be produced through alternative alcohol-based pathways in which an intermediate molecule, typically isobutene, is first generated and then upgraded into a gasoline blend component (Furusjö & Mossberg, 2020; Krämer et al., 2024; Krämer & Send, 2025).

Isobutene can be produced through different routes. One option is to convert methanol into light hydrocarbons in a pathway commonly referred to as Methanol-to-Olefins (MtO). As with Methanol-to-Gasoline, the overall climate performance depends on how the methanol is produced. If methanol is derived from renewable electricity and renewable or captured CO_2 (e-methanol), the resulting gasoline component can be considered an e-fuel component (Krämer et al., 2024; Krämer & Send, 2025). Alternatively, methanol may be produced from biomass (or fossil) sources, with corresponding implications for greenhouse gas performance.

Another route is fermentation of sugar-based feedstocks to produce isobutene. This pathway typically relies on agricultural crops such as maize or wheat and therefore competes with ethanol production for similar feedstocks (Furusjö & Mossberg, 2020). In contrast to Ethanol-to-Gasoline pathways, which yield a broader gasoline mixture, these routes focus on producing specific high-octane components derived from isobutene.

Commercial experience for both of these routes remains limited. Gasoline containing isobutene-derived components has been marketed in small volumes in the Seattle area by the company Gevo, although not through public fuel stations (Gevo, n.d.).

[2] Personal communication

In 2018, Audi and Global Bioenergies announced testing of an isobutene-based fuel marketed as “e-benzine.” In practice, the tested fuel was based on a fermentation route and thus biomass-derived (Automotive World, 2018). Although published studies from company representatives indicates an interest in exploring MtO-based pathways (Krämer et al., 2024; Krämer & Send, 2025), a company representative has confirmed that the collaboration was discontinued in 2020 (personal communication). This assessment is also consistent with views expressed by industry experts interviewed for this study, who noted that similar concepts have been explored repeatedly over time without reaching commercial scale.

3.1.2 Renewable naphtha as a by-product stream

Renewable naphtha generation and characteristics

Renewable naphtha – particularly bio-based naphtha – has attracted growing attention due to its potential role both as a gasoline blending component and as a feedstock for the petrochemical industry. Naphtha is an umbrella term referring to hydrocarbon fractions typically ranging from C5 to C9. Within this range, heavy naphtha (approximately C7–C9) is often considered suitable as a gasoline blendstock (Weigal, 2022), although actual suitability depends on refinery configuration.

Naphtha-range hydrocarbons are formed in most processes that produce liquid hydrocarbon fuels. It is important to note, however, that naphtha is never a primary target product in facilities producing renewable fuels. Instead, renewable naphtha typically emerges as an unavoidable by-product within the broader product slate of hydrocarbon fuel production.

Today, most renewable naphtha available on the market originates from the production of renewable diesel and aviation fuel, primarily through HVO/HEFA processes. As production volumes of these fuels increase, these processes may therefore also generate growing volumes of renewable naphtha that could, in principle, be available for use as a gasoline blending component.

A wide range of production pathways for hydrocarbon fuels may also generate naphtha fractions. In addition to HVO/HEFA processes based on bio-based fats and oils, naphtha-range hydrocarbons may also arise in pathways based on solid biomass, electricity-derived intermediates, or residual waste streams. These include, for example, Fischer–Tropsch synthesis and methanol-based routes. However, since naphtha is generally not the primary target product in these processes, it is treated in this report as a by-product with potential use as a gasoline feedstock rather than as a fuel produced through dedicated production routes.[3]

From a fuel perspective, an important characteristic of renewable naphtha is its relatively low octane value, reflecting its largely paraffinic composition. This limits the share that can be blended into gasoline without additional upgrading or the use of other high-octane blending components, which is discussed further in the following section on gasoline blending constraints.

Current handling and integration into the gasoline pool

Technically, bio-naphtha can enter the gasoline pool through two principal routes. It can either be separated and stored as a distinct blending component, or it can remain within internal refinery streams and be co-processed together with fossil fractions.

In practice, handling strategies vary across producers. Some fuel producers separate bio-naphtha and make it available as a distinct product stream that can be blended into gasoline. In other cases the naphtha fraction may remain within internal refinery streams, where it becomes diluted within the broader gasoline pool. Based on stakeholder interviews, this latter approach appears to be more common where production volumes are small.

Separating bio-naphtha as a dedicated stream is necessary in order to use it as a gasoline blending component. When handled internally within refinery streams, the renewable fraction typically constitutes only a minor share of the total gasoline output.

3.1.3 Co-processing with crude oil

Co-processing of biogenic feedstocks together with crude oil is a relatively mature practice in diesel production. However, similar co-processing pathways can also be applied to gasoline production, an area that has gained increasing research attention in recent years. Not least, co-processing is viewed as a potential to partly decarbonize existing refineries (4refinery, 2021).

[3] Naphtha yields vary substantially across production pathways. For example, HVO/HEFA pathway may generate 5-15% naphtha, Fischer–Tropsch 10–20%, while methanol-based jet fuel pathways can generate below 4% (Bube et al., 2024; Concawe, 2023; Dimitriadis et al., 2024; WGMM, 2026).

In this context, the *fluid catalytic cracker* (FCC) has been identified as a particularly relevant refinery unit, as it can accommodate limited co-feeding of biogenic liquids alongside conventional crude oil. A further advantage often highlighted in the literature is that modifications to the FCC unit itself may be relatively limited, typically involving the installation of a separate injection nozzle. However, implementing co-processing in practice also require additional adjustments to surrounding refinery infrastructure, including feedstock handling and pre-treatment systems, which increase the overall investment requirements (4refinery, 2021; Dyk et al., 2024; Furusjö & Mossberg, 2020; Lutz et al., 2022; Stefanidis et al., 2017).

Co-feeding limitations

Co-processing in FCC units is already tested at industrial scale, for example by the Swedish refiner Preem, which co-feeds pyrolysis oil derived from forest residues. In existing commercial applications, biogenic co-feeding rates are typically limited to approximately 2–5 percent, implying that the resulting gasoline fractions remain predominantly fossil-based (Furusjö & Mossberg, 2020).

Higher co-feeding levels have been explored in experimental and pilot-scale studies. Several studies report that co-feeding levels of around 10 percent can be technically feasible under controlled conditions (Dyk et al., 2024; Furusjö & Mossberg, 2020; Pinho et al., 2022). However, when increasing the biogenic share further, process limitations become apparent. At co-feeding levels of around 20 percent, experimental evidence shows that roughly half of the biogenic carbon is converted to coke and deposited on the FCC catalyst, rather than being recovered as liquid fuel (Dyk et al., 2024).

Because renewable feedstocks are processed together with crude oil, the resulting gasoline fractions remain predominantly fossil-based. This means that co-processing can contribute to partial decarbonization of refinery output but is unlikely to enable gasoline blends with a high renewable share as long as co-feeding levels remain limited. As a result, its role in achieving emission reductions consistent with long-term climate targets is likely to remain limited.

However, as emphasized by an industry representative interviewed for this study, the main advantage of co-processing lies in its ability to scale the production of biogenic gasoline-range molecules that replace fossil carbon within existing refinery infrastructure, rather than in producing fuels with a high biogenic content per unit of fuel.

In addition to technical constraints, regulatory verification requirements pose further challenges, as highlighted in interviews with industry representatives. Under EU rules, producers must be able to demonstrate the biogenic share of co-processed fuels. This is done using radiocarbon (C14) analysis, as specified in a delegated act (European Commission, 2023). However, at low co-processing rates, accurately measuring and verifying the biogenic fraction becomes technically challenging and subject to significant uncertainty. This may reduce the practical attractiveness of very low blending levels, even where technically feasible.

3.2 Gasoline blends with renewable components

Most renewable production pathways generate individual components rather than finished fuels. Whether these components can be incorporated at meaningful shares depends on how they interact with other blend components within the limits set by applicable fuel specifications, which in the European Union are defined by the EN 228 gasoline standard.[4] The following sections outline the most relevant specification constraints and assess their implications for renewable blending opportunities.

3.2.1 Bio-naphtha in gasoline blending

Bio-naphtha in gasoline blends

Bio-naphtha is already used as a blending component in commercial gasoline. However, its blending potential is constrained by fuel quality requirements under the EN 228 specification, most notably the minimum octane number. Because bio-naphtha typically exhibits a relatively low research octane number (RON), increasing its share in the blend may cause the finished gasoline to fall below specification limits.

In Sweden, where bio-naphtha has been included in the gasoline blend pool since 2016, the highest reported annual average blending level has been 5.1 percent (Swedish Energy Agency, 2025). This level was reached in 2023 and was driven by

[4] EN 228 is the European fuel standard for gasoline, applicable at the point of sale to the final customer. It specifies limits for key fuel properties such as octane number, vapor pressure, oxygen content, density, aromatic content, and distillation characteristics. These requirements are designed not only to ensure proper engine performance, but also to address environmental and health considerations, including emissions and air quality. Importantly, the specification applies to the finished gasoline blend, not to individual blending components.

the Greenhouse gas reduction mandate ("reduktionsplikten"), which was subsequently reduced (see further discussion under Chapter 4, *The Policy Context*).

The precise blending limit for bio-naphtha under standard gasoline specifications remains uncertain, as few studies have systematically examined its impact on finished fuel quality. Under conditions without compensating measures, an experimental study by Hájek et al. (2021), evaluating Fischer–Tropsch-derived bio-naphtha, found that a 5 percent blending share resulted in a finished gasoline with a research octane number (RON) below the EN 228 requirement. Based on these results, the authors recommended limiting the share to approximately 3 percent.

However, the experiments were conducted using base gasoline without ethanol or other octane-enhancing adjustments. Given that most gasoline sold within the EU contains up to 10 percent ethanol, and that refiners routinely optimize blend compositions, these results should be interpreted as indicative of the constraint under uncompensated conditions rather than as a general upper limit. The extent to which higher shares can be accommodated through blending optimization is therefore addressed in the following section.

Higher bio-naphtha blends through blend optimization and compensating measures

Despite these limitations, it is – from a technical perspective – possible to increase the bio-naphtha share to some extent if its properties are compensated by other blending components, as it is the final blend, rather than individual components, that must comply with the EN 228 specification (Furusjö & Mossberg, 2020).

A particularly relevant factor is ethanol blending. Ethanol has a high octane number and can therefore compensate for low-octane components such as bio-naphtha (Cracknell et al., 2023). Increasing the ethanol share in gasoline may therefore expand the blending space for low-octane hydrocarbons. However, the quantitative relationship between ethanol content and the maximum achievable bio-naphtha share remains uncertain. Blending interactions between components are complex and not strictly linear, and no studies assessing the blending potential of bio-naphtha under higher ethanol blending levels have been identified in the literature.

Ethanol-to-gasoline (EtG) components may also contribute to octane enhancement. Like ethanol, these components can increase the octane level of the gasoline blend and thereby help compensate for low-octane streams such as bio-naphtha. Unlike ethanol, however, EtG-derived hydrocarbons are not constrained by oxygen content limits under the EN 228 specification, potentially allowing greater blending flexibility (Krämer & Send, 2025).

Beyond ethanol blending, the properties of bio-naphtha may also be compensated for by adjusting the other components in the blend. Refiners routinely use proprietary blending models to optimize gasoline formulations based on specification constraints and cost parameters. Such models can identify how changes in one component – for example, an increased share of low-octane bio-naphtha – can be offset by adjusting other streams in the blend pool.

One example, highlighted by a refining expert interviewed for this study, is that the octane number of reformate – a gasoline blend component produced in the refinery – can be increased in order to compensate for a larger share of low-octane bio-naphtha in the final gasoline blend. However, such compensating measures are not without trade-offs. Increasing the octane number of reformate may reduce process yield, which in turn can increase both refinery costs and crude oil input per unit of gasoline produced. It may therefore also worsen the climate performance of the reformate component.

Because these optimization strategies are company-internal and not publicly accessible, the practical potential for substantially higher bio-naphtha shares under commercially realistic conditions remains difficult to assess from public sources. The extent to which adjustments of other components could enable significantly higher bio-naphtha shares therefore remains uncertain and has not been sufficiently examined in experimental studies.

Upgrading options to increase the octane number of bio-naphtha

A higher bio-naphtha blending potential can also be achieved through additional upgrading processes in which the octane number of the bio-naphtha is increased. At least one experimental study demonstrates that low-quality (heavy) bio-naphtha can be converted into a higher-quality fuel via *hydroisomerization* (Heracleous et al., 2021). Similar upgrading potential has also been suggested in earlier work on renewable gasoline-range fractions derived from bio-based feedstocks (Kasza & Hancsok, 2011).

Despite the technical feasibility indicated in these studies, publicly available knowledge on the upgrading of bio-naphtha remains limited. No studies identified have systematically examined achievable octane improvements and how such upgrading would translate into increased blending potential.

At the same time, interviews with refining companies suggest that these upgrading options appear to be well understood within industry. This apparent knowledge gap may partly reflect the fact that upgrading processes such as isomerization are long established in the treatment of fossil naphtha streams. A substantial technical foundation therefore already exists in conventional refining practice. However, evaluating the extent to which experience from fossil naphtha can be directly transferred to renewable naphtha would require dedicated experimental studies and fall beyond the scope of the present analysis. Given the expected increase in renewable naphtha supply, this represents a relevant area for further research.

3.2.2 Ethanol in gasoline blends

Ethanol is widely used in gasoline as an oxygenated, high-octane blending component. Its primary technical function in gasoline is to increase the octane number, thereby enabling compliance with fuel specifications while allowing the use of lower-octane hydrocarbon streams in the blend. It also contributes directly to the renewable share of finished gasoline.[5]

In contrast to hydrocarbon blending components, whose use is mainly constrained by fuel quality parameters, the maximum ethanol content in conventional gasoline is determined by regulation. Within the European Union, the EN 228 specification – implemented under the Fuel Quality Directive (FQD) – limits ethanol content to 10 percent by volume (E10). Gasoline containing higher ethanol shares (e.g., E85) falls outside this specification and cannot be marketed as conventional gasoline.

Internationally, permitted ethanol blending levels vary across jurisdictions. In the United States, the ASTM D4814 specification allows blends containing up to 15 percent ethanol (E15). However, E10 remains the predominant gasoline grade nationwide, while E15 has been introduced in most states and is increasingly available (Xiarchos et al., 2022). In Brazil, gasoline is subject to a mandatory ethanol blending requirement of 30 percent, with an increase to 35 percent under discussion (BioEnergyTimes, 2025). These examples illustrate that the allowable ethanol content in gasoline is not solely a technical matter, but is defined within specific regulatory

[5] Other oxygenated blending components, most notably ethyl tert-butyl ether (ETBE), are also used in gasoline. However, such components are typically used within the same overall oxygen limits as ethanol and therefore do not expand the total blending space for oxygenates.

frameworks. The possibility of increasing the permitted ethanol share in the EU to 20 percent is discussed further in Chapter 4.1.2.

Because ethanol constitutes the largest renewable component in commercial gasoline products, the permitted blending level plays a central role in determining the overall renewable share of the fuel. However, the resulting reduction in GHG emissions depends on the life-cycle emissions of the ethanol used. At the same time, the presence of ethanol affects the technical blending space available for other components, not least bio-naphtha, as it improves the octane level (as discussed above).

In addition to ethanol, alternative oxygenated blending components include methanol and ethers such as ethyl tert-butyl ether (ETBE), which, like ethanol, are used to increase the octane number of gasoline. Like ethanol, their use is constrained by the overall oxygen limit in the EN 228 specification (3.7% by mass), meaning that they compete directly with ethanol for blending space rather than expanding the total oxygenate share. Within this limit, methanol is permitted at up to 3% by volume, while ETBE can be blended at higher volumetric shares (up to around 22% by volume) due to its lower oxygen content. However, ETBE is only partly renewable, as it is produced from ethanol and fossil-derived isobutene.

ETBE is already used in gasoline blending, although typically at limited levels. Methanol, by contrast, appears to have little or no use in commercial gasoline. Despite some favorable properties (such as a high octane number), methanol is associated with material compatibility issues, including increased wear on fuel system components (Verhelst et al., 2019). Vehicle manufacturers are therefore generally skeptical of methanol as a blending component and have, in some cases, advocated restrictions on its use (ACEA, 2015).

3.2.3 Potential blends with other renewable components

In addition to bio-naphtha and ethanol, gasoline can in principle incorporate any other renewable gasoline components. Pathways such as methanol-to-gasoline (MtG) and ethanol-to-gasoline (EtG) produce hydrocarbons that have similarities to conventional fossil gasoline components. As a result, these streams can be blended into the gasoline pool without the fuel quality constraints associated with oxygenated additives or low-octane bio-naphtha (Huang et al., 2024). Gasoline-range components derived from isobutene may also be incorporated.

Overall, experimental evidence remains limited. Only a small number of studies have assessed gasoline blends with high renewable shares. Krämer et al. (2024; 2025) evaluate blends with renewable contents of up to 80%, combining components such as ethanol, MtO, MtG, EtG, and bio-naphtha. Huang et al. (2024). assess blends containing 40% renewable components, based on ethanol and MtG. These studies demonstrate that compliance with the EN 228 standard can be achieved through multiple blending strategies.

Renewable hydrocarbons may also enter the gasoline pool through co-processing of biogenic feedstocks in conventional refinery units. In such cases, the renewable share becomes integrated into existing fossil streams and contributes proportionally to the final gasoline output.

It should be noted, however, that compliance with fuel specifications such as EN 228 does not necessarily imply that all characteristics mirror those of conventional fossil gasoline. Interviewed refinery experts pointed out that high shares of novel renewable components may result in atypical property combinations within the permitted specification ranges. While individual parameters remain within specified limits, their combined profile may differ from that of conventional gasoline. Even though such blends formally comply with the standard, long-term operational experience with these compositions remains limited.

3.2.4 Market examples of gasoline blends with high renewable content

Although renewable blending levels in commercial gasoline are typically modest, a small number of gasoline products with substantially higher renewable shares have been introduced in recent years, often at limited scale and for restricted time periods. Taken together, these cases indicate that higher renewable blending levels can be achieved while still complying with existing gasoline specifications. However, publicly available information on the composition of these fuels remains limited. As a result, significant uncertainties remain regarding the specific blending strategies, component combinations, and process configurations that enable such high renewable shares.

In late 2025, the Spanish fuel company Repsol announced the launch of a 95-octane gasoline marketed as fully renewable, sold at approximately 30 service stations in Spain. According to company statements, the product complies with the EN 228 gasoline standard and can therefore be used in any gasoline vehicle certified for E10. Public information on the composition of the fuel is limited beyond a reported ethanol content of 10 percent (Repsol, 2025). In an interview conducted as part of this study, a company representative stated that the fuel is produced using existing refining technologies. No further details have been disclosed regarding the specific composition of the renewable fraction or the blending strategies used to achieve the reported renewable share.

In 2021, Finnish fuel producer Neste announced a research initiative with Volvo Cars to develop and test a renewable gasoline with a renewable content of 65 percent (Neste, 2021). The fuel was also distributed for a limited period in Sweden by the fuel distributor OKQ8 (OKQ8, 2021). Neste initially stated an ambition to increase the renewable content to 95 percent. However, interviews with company representatives confirmed that the project was later cancelled due to low demand and high investment costs. As in the case of Repsol, detailed information regarding the composition of the renewable fraction has not been publicly disclosed.

Two additional gasoline products with relatively high renewable shares have also been identified, although neither appears to be currently available on the market. Shell, in collaboration with Volkswagen and Bosch, offered a gasoline product labelled “Blue Gasoline” in Germany containing 22% bio-naphtha in addition to 10% ethanol (Bosch-Mobility, 2021). Chevron has likewise marketed a gasoline product in the United States containing 35% bio-naphtha together with 15% ethanol (Chevron, 2023). In both cases, the technical measures enabling these elevated renewable shares have not been publicly disclosed, limiting the ability to assess the broader scalability or replicability of such formulations. Other regional pilot products may also exist, although no additional examples were identified in the present review.

3.3 Feasibility and scalability of renewable gasoline pathways

While the previous chapters have outlined the technical pathways and blending options for renewable gasoline, the focus in this chapter is on the evaluation of their market feasibility and scalability. Taken together, the analysis shows that the scalability of renewable gasoline is constrained not only by technical complexity and cost, but also by fundamental market conditions – most notably the expectation of declining gasoline demand – along with additional commercial barriers. The sections below examine these constraints in detail.

3.3.1 Technical complexity and commercial barriers

The review of production pathways and blending strategies demonstrates that it is technically possible to produce renewable gasoline, but doing so involves complex and often costly production pathways and blending strategies. Multiple pathways can generate compatible gasoline components, and higher renewable shares are technically achievable under the EN 228 specification, although this requires careful blending optimization and trade-offs between components.

Despite these technical possibilities and advances, including the ability to produce compatible components and high-renewable blends, renewable gasoline has not emerged at meaningful commercial scale. Market introductions of high-renewable gasoline have been limited in volume, geographically restricted, and in several cases discontinued after trial periods. Deployment comparable to that observed for renewable diesel (e.g., HVO) has not materialized. The discrepancy between technical possibility and limited deployment indicates that, beyond technical complexity and production cost, the main constraints are commercial.

This distinction has not received sufficient attention in existing literature. A substantial share of published studies focuses on technical compatibility, fuel properties, and compliance with fuel standards. While essential for establishing feasibility, such analyses often treat market uptake as implicit. The conditions required for large-scale market deployment – including investment incentives, demand certainty, and feedstock/intermediate competition – remain less examined. As a result, the link between technical potential and scalable implementation remains underexplored.

A similar pattern is visible in broader policy and industry discussions, where the technical possibility of producing largely or fully renewable gasoline is frequently emphasized. While commercial conditions and deployment challenges are often acknowledged, they are typically addressed under assumptions of favorable cost developments and rapid scale-up. For example, scenarios presented by the advocacy organization E-fuel Alliance project a sixfold increase in e-gasoline production by

2045, implying higher deployment levels than those reflected in European Commission scenarios for e-fuels in transport (E-fuel Alliance, 2026; European Commission, 2024).

3.3.2 Declining gasoline demand and high upfront costs limit investment

Interviews with fuel producer representatives indicate that expectations of declining gasoline demand are a central factor limiting investment in renewable gasoline. The ongoing electrification of passenger cars is seen as reducing long-term gasoline consumption, thereby weakening the business case for new gasoline-oriented production pathways. In particular, interviewees frequently point to EU climate policy – especially the regulation effectively requiring a near-complete shift to zero-emission vehicles from 2035 – as reinforcing these expectations. However, similar patterns are observed in other markets where electrification is expected to proceed more slowly, suggesting that these expectations are not solely driven by EU policy.

Unlike renewable diesel, which serves heavy-duty transport, non-road machinery, maritime, and can in some cases serve as intermediates for aviation fuels, gasoline remains closely tied to the passenger car fleet. As a result, its long-term demand base is expected to decline. This reliance on a single end-use segment increases exposure to demand risk.

Against this backdrop, interviewees also emphasized that developing and scaling renewable gasoline production pathways entails substantial research, development, and capital expenditure. Combined with expectations of a shrinking market, this results in a weak investment case.

In addition, the European refining system has long produced more gasoline than is consumed within the region, resulting in substantial exports to international markets. The opposite pattern exists for diesel, where European demand has historically exceeded domestic production (Fuels Europe, 2025). This regional surplus of gasoline may further reduce the attractiveness of new gasoline-oriented production pathways.

Across interviews, renewable gasoline was consistently described as a low-priority area for investment, with most actors instead focusing on renewable diesel and aviation fuels. While isolated market introductions have occurred, interviews with these companies indicate that such high-blend products reflect policy positioning or strategic considerations rather than sustained large-scale investment plans in gasoline-oriented production.

3.3.3 Competing uses of intermediates constrain renewable gasoline production

One central dimension of these market constraints concerns the alternative uses of key intermediates. All renewable gasoline pathways rely on intermediate products (bio-naphtha, methanol, and ethanol/ethanol feedstock) that can be used across multiple sectors, including other transport fuels and the petrochemical industry.

Their allocation is therefore not determined solely by technical feasibility or production cost within a given pathway, but by their relative market value across competing applications. Assessing the scalability of renewable gasoline production thus requires consideration not only of whether a pathway is technically viable, but whether its key intermediates would rationally be directed toward gasoline rather than alternative uses.

Competition over bio-naphtha

Bio-naphtha can serve both as a gasoline blending component and as a feedstock in steam crackers for petrochemical production. The allocation of renewable naphtha between these uses is influenced by relative profitability, which has shifted over time and remains sensitive to policy developments and sector-specific demand (see Argus Media, 2023).

It has been noted in both technical studies and industry discussions that renewable naphtha may, in some cases, be better suited for petrochemical applications, such as plastics and chemical production, than for direct fuel blending (see Furusjö & Mossberg, 2020). Unlike gasoline, petrochemical use is not constrained by octane requirements or finished fuel specifications, potentially allowing lower-quality fractions to be utilized without costly upgrading or blending adjustments. Should regulatory pressure to decarbonize the petrochemical sector intensify, willingness to pay for renewable naphtha as a chemical feedstock may increase correspondingly (see Argus Media, 2023).

Although bio-naphtha competes with petrochemical demand and faces blending constraints at higher shares, it may represent a comparatively realistic pathway for incremental decarbonization. As a by-product of expanding HVO/HEFA capacity, increasing its utilization within the gasoline pool does not require dedicated new fuel pathways. However, the technical feasibility and cost implications of substantially higher bio-naphtha blending remain insufficiently examined in the literature.

Competition over methanol

Methanol represents a more constrained case. Although renewable methanol – particularly e-methanol – can in principle serve as an intermediate for gasoline production via MtG or MtO pathways, it can also be used directly as a maritime fuel or as an input for the production of aviation fuels. Announced investments in renewable methanol are primarily oriented toward these sectors, which are supported by targeted regulatory mandates within the EU.

For renewable methanol to be converted into road gasoline at scale, the gasoline segment would need to generate returns comparable to those available in maritime transport and aviation, while offering a similar degree of long-term demand certainty. Given the combination of stronger regulatory demand in these sectors and the price sensitivity of the passenger car market, such a reallocation is unlikely. Even when renewable methanol is produced from biomass, converting it into gasoline adds an additional conversion step that must compete with more direct biomass-to-hydrocarbon pathways.

Large-scale MtG deployment for road gasoline is therefore unlikely. Methanol-based gasoline pathways are more plausibly confined to niche applications characterized by high willingness to pay, such as specific vehicle producer strategies or motorsport segments, including Formula 1’s transition to fully renewable fuels starting in the 2026 season (Formula 1, 2026).

Competition over ethanol

Gasoline routes relying on ethanol as an intermediate differ from methanol-based pathways in that ethanol is already widely used as a blending component in conventional gasoline. The allocation question is therefore not whether ethanol should be directed toward gasoline rather than other sectors, but whether it should be used directly in the blend or upgraded into hydrocarbon components through pathways such as Ethanol-to-Gasoline (EtG).

EtG becomes relevant primarily when ethanol blending limits constrain further increases in ethanol content, or in scenarios where total gasoline demand declines while continued or expanded use of ethanol is desired. In such cases, converting ethanol into hydrocarbon components may enable higher effective ethanol shares within the remaining gasoline pool

From a system perspective, however, converting existing ethanol volumes into EtG does not in itself increase total renewable energy use unless it leads to higher overall fossil substitution. If the objective is to increase renewable content in gasoline, adjusting permitted ethanol blending levels is likely to be more cost-effective than converting ethanol into gasoline-range hydrocarbons, provided that compatibility constraints can be managed.

Ethanol-derived hydrocarbon components may nevertheless be suitable for niche fuel segments where oxygenated fuels are unsuitable, such as certain specialty gasoline grades, including alkylate gasoline used in small-scale machinery. Under such conditions, EtG and related pathways may play a complementary role, but their broader deployment depends on whether they enable an expansion – rather than merely a reallocation – of renewable feedstock use.

Taken together, the analysis across the preceding sections highlights both the technological diversity of renewable gasoline production routes and the constraints affecting their large-scale deployment potential. These characteristics are summarized in Table *2*.

Table 2. Comparison of renewable gasoline production routes and their scale-up prospects

Production route	Intermediate or feedstock	Blend compatibility	Main constraints to scale-up	Indicative market outlook
Methanol-to-Gasoline (MtG)	Methanol (from electricity + CO_2, or biomass)	Fully compatible gasoline component	Competition for renewable methanol	Unlikely at scale for road gasoline
Ethanol-to-Gasoline (EtG)	Ethanol (biogenic)	Fully compatible gasoline component	Competes with direct ethanol blending; higher cost and lower energy efficiency	Possible niche pathway; may address ethanol blend wall
Isobutene from methanol (MtO)	Methanol	High-octane blend components	Competition for renewable methanol	Unlikely at scale for road gasoline
Isobutene from sugar fermentation	Fermentable sugars (biogenic)	High-octane blend components	Competes with ethanol production for feedstock	Long-standing but uncommercialized pathway; unlikely to scale
Renewable naphtha	By-product from HVO/SAF/E-SAF fuel production	Limited by low octane number	Blending constraints; petrochemical competition	Most plausible incremental blending pathway
Co-processing	Biogenic oils, pyrolysis oil	Integrated into refinery gasoline streams	Low biogenic share; verification challenges	Limited incremental decarbonization potential

4 The Policy Context

The analysis in Chapter 0 shows that the scalability of renewable gasoline is constrained by a combination of technical, economic, and market-related factors. This chapter examines whether – and under what conditions – policy could alter these underlying conditions.

4.1 Strategic approaches to gasoline decarbonization

Several strategic pathways exist for reducing the climate impact of gasoline. The following sections examine these options.

4.1.1 Fully renewable niche fuels are unlikely to be a scalable strategy

Two principal strategies can be pursued to increase the renewable share of gasoline: the introduction of fully renewable niche fuels, or the gradual increase of renewable content within the conventional gasoline pool. Although both contribute to fossil substitution, their implications for cost, scalability, and overall system impact differ substantially.

Fully renewable gasoline products require separate distribution and handling, which increases logistical complexity and costs. Unlike incremental blending within the existing gasoline pool, dedicated renewable fuels must be distributed and marketed as distinct products. Achieving a fully renewable gasoline blend also entails greater technical and economic challenges than increasing low-level blending. Incremental approaches may involve adjusting the shares of ethanol, bio-naphtha, or other renewable components. By contrast, fully renewable fuels require the formulation of entirely fossil-free blends, which may necessitate processes with higher production costs.

As a result, fully renewable gasoline products would carry higher market prices and therefore depend on voluntary willingness to pay. Advocates of fully renewable strategies often refer to the experience with HVO100 (i.e. renewable diesel), particularly in Sweden. HVO100 has been available on the Swedish market for over a decade and has reached relatively significant volumes, corresponding to 7 percent of total diesel consumption in 2024 (Swedish Energy Agency, 2025). However, the gasoline market is structurally different from the diesel market, as it is dominated by private consumers with greater price sensitivity. The expansion of HVO100 has largely been driven by public procurement – particularly in bus fleets – and by freight transport, whereas its use in passenger cars remains limited (see Gustavsson Binder, 2022; Swedish Energy Agency, 2019).

From a climate perspective, the central objective is to reduce total fossil fuel use rather than to convert a limited segment of the market to 100 percent renewable fuels. A fully renewable gasoline product used in a small segment result in limited overall fossil displacement. In contrast, increasing the renewable share by 10-20 percent (or more) across the entire gasoline pool may yield a substantially larger aggregate reduction.

Technology-neutral CO_2 standards could shift focus toward niche fuels

The role of fully renewable fuels has become indirectly relevant in the ongoing debate over the EU:s CO_2 standards for cars and vans. These standards are designed to reduce emissions from new vehicles and require a near-complete shift toward electric vehicles by 2035.

However, parts of the automotive industry, component suppliers, and the fuel sector have argued that the standards should be made more "technology neutral." According to this view, emission reductions should not only be achieved through electrification, but also through the use of renewable fuels in combustion engine vehicles. This would make it possible to continue selling vehicles with internal combustion engines beyond 2035, provided that they operate on "climate-neutral fuels".

Industry reports have proposed models where vehicles could be certified as running exclusively on carbon-neutral fuels (WGMM, 2024). In such a system, vehicles would only be able to operate on renewable fuels. The proponents argue that technical solutions could ensure that these vehicles cannot be operated on fossil fuels.

Support for this approach has also appeared in the political debate. For example, German political leaders, including Friedrich Merz, have argued that EU vehicle regulation should allow a greater degree of technology neutrality in order to accommodate the use of renewable fuels among others (Marsh & More, 2025).

In practice, however, such proposals imply a strategy that relies on fully renewable fuels rather than increasing the renewable share within the existing gasoline pool.

As discussed above, strategies based on fully renewable fuels are associated with higher costs and greater challenges in scaling production and usage. It may therefore risk complicating the transition and could also affect the pace of electrification.

4.1.2 Higher ethanol blending: potential benefits amid significant uncertainties

Increasing the share of ethanol in gasoline represents a potentially effective way of reducing the fossil content of the fuel. Ethanol is already widely used as a blending component in conventional gasoline, but further increases in its use would require changes to fuel standards and regulatory frameworks. Such work has been underway within the European Committee for Standardization (CEN), where a technical specification for gasoline containing up to 20 percent ethanol was published in late 2025 (CEN, 2025).[6]

Such an increase in the permitted blending level could, in principle, deliver measurable emission reductions. A study conducted within CEN estimates that a transition from E10 to E20 could reduce greenhouse gas emissions from gasoline by around 10 percent, despite an approximately 4 percent increase in fuel consumption due to the lower energy density of ethanol. If implemented across the EU, this could correspond to an annual reduction of about 8.2 percent of current gasoline-related emissions (Gray, 2020). The actual climate benefit, however, depends on the lifecycle emissions of the ethanol used and the extent to which higher blending levels are adopted in practice.

A further potential benefit of higher ethanol blends is that the available blending space for low-octane renewable components such as bio-naphtha can be increased. However, in practice, this benefit may be more limited than expected, as the E20 technical specification requires higher octane levels in the finished E20-fuel to compensate for the lower energy content of ethanol (98 instead of current 95) (CEN, 2025). As a result, the effective expansion of the blending space may be smaller than suggested by the ethanol content alone.

[6] This was not adopted as a formal standard, but rather as a technical specification, reflecting the fact that gasoline containing more than 10 percent ethanol cannot be marketed within the EU under the current regulatory framework

An alternative approach to increase the ethanol blend levels concern the actual usage of the allowed blending potential. Currently, a significant share of the permitted blending potential remains unused, as E10 is not fully adopted in several European markets. For example, in Germany, E10 accounted for only 26 percent of gasoline sales in 2024 (ePURE, 2024). This indicates that emission reductions could also be achieved through increased uptake of existing allowed blends.

Constraints and implementation challenges

Despite the potential advantages of higher ethanol blending, several constraints and uncertainties remain. One key issue concerns vehicle compatibility, including both material compatibility in fuel system components and compliance with emission standards. According to the CEN study, gasoline containing up to 20 percent ethanol is likely to be technically compatible with vehicles sold in the EU since 2011 (Gray, 2020). However, since these vehicles are not certified for E20, obtaining formal approval for its use may prove challenging in practice. For vehicles that are not compatible with higher ethanol blends, continued access to E5 gasoline could provide a fallback option, as is already the case today. However, if uncertainty regarding vehicle compatibility persists, there is a risk that vehicle owners will choose E5 over E20, which could limit the intended increase in ethanol use associated with a transition to E20.

Higher ethanol blends may also have implications for fuel infrastructure and storage systems. Ethanol can affect material compatibility in tanks, seals, and distribution equipment, and intermediate blends such as E20 may require adaptations beyond those already implemented for E10. Interviews with industry experts indicate that material impacts do not necessarily scale linearly with ethanol content. As a result, intermediate blends such as E20 may, in some cases, pose greater compatibility challenges than both lower (E10) and higher (E85) ethanol blends. These factors could increase transition costs and complicate implementation.

Another frequently cited concern relates to the use of crop-based feedstocks for ethanol production. Conventional ethanol is typically classified as a first-generation biofuel produced from food crops such as sugar or starch, which has long raised concerns about potential competition between fuel and food production. Second-generation ethanol produced from lignocellulosic biomass has often been presented as a way to address these concerns, but despite extensive research and policy attention, large-scale commercial deployment have so far not materialized (Kramer, 2022).

A further constraint relates to the regulatory and political feasibility of increasing ethanol blending levels. A transition from E10 to E20 in the EU would require not only a new gasoline standard but also changes to the EU Fuel Quality Directive. However, interviews conducted as part of this study with participants involved in the CEN standardization process suggest that the issue currently receives limited attention from the European Commission.

4.1.3 Fuel strategies requiring vehicle adaptation: the case of high-ethanol fuels (E85)

Ethanol can also be used in high-blend fuels in the form of E85, which consists of up to 85 percent ethanol mixed with gasoline components. E85 is defined under a separate fuel standard (EN 15293) and is therefore not classified as gasoline. Within the EU, E85 is primarily available in Sweden and France, with more limited availability in other member states (ePURE, 2020).

E85 as a decarbonization strategy; flex-fuel and retrofitting

Conventional gasoline vehicles cannot operate on E85 without vehicle adaptation. In practice, this has primarily been achieved through the production and sale of flex-fuel vehicles (FFVs), which are designed to operate on both gasoline and high-ethanol blends.

Such vehicles have been deployed at scale in specific markets. Sweden provides a notable example, where E85 was actively promoted during the early 2000s. At its peak in 2008, flex-fuel vehicles accounted for approximately 34 percent of new sales of gasoline and ethanol passenger cars combined. However, maintaining demand for these vehicles has proven challenging. By 2013, the share had declined to around 3 percent, reflecting a combination of reduced policy incentives, changed fuel prices, and declining consumer confidence in ethanol as a fuel option (Björnemalm & Sandström, 2026; Kastensson & Börjesson, 2017; Transport analysis, 2026). Today, FFVs have largely disappeared from new car sales in Sweden.

An alternative to new sales of flex-fuel vehicles is the retrofitting of existing gasoline vehicles to enable flex-fuel operation. Conversion kits are commercially available at relatively low cost, and there is substantial practical experience indicating that they can function well (Bondesson & Lindberg, 2022).

However, the broader feasibility of retrofitting remains uncertain, particularly for newer vehicle generations. Available experience is largely based on older vehicles and may therefore not be fully representative of the current or future vehicle fleet. Based on an interview with a company offering retrofit solutions, the feasibility of retrofitting appears to depend primarily on engine design, specifically the fuel injection system and overall fuel system configuration.

In particular, modern engines increasingly rely on direct injection (DI) systems, which are generally more complex and operate at higher pressures than earlier multi-point injection (MPI) systems. Since ethanol has a lower energy density than gasoline, operation on E85 requires a higher volumetric fuel flow, up to around 30 percent more fuel for the same energy output. In some cases, existing fuel system components, such as fuel pumps and injectors, may not be designed to accommodate this, potentially limiting the feasibility of retrofitting.

While such technical constraints may, in principle, be addressed through more extensive modifications, retrofit solutions in practice are typically designed to avoid altering or replacing core engine components, in order to maintain reliability and manage costs. As a result, retrofitting options that would require significant changes to the fuel system or engine control system may be considered impractical in a commercial context. For example, the retrofit provider interviewed in this study does not offer conversion for such vehicles.

Taken together, these observations suggest that while retrofitting can be a viable option for certain vehicle types, its applicability across the broader and evolving vehicle fleet remains uncertain. In particular, the increasing technical complexity of newer vehicles may limit the scalability of this approach as a general decarbonization strategy.

E85 usage is highly sensitive to fuel price differentials

A challenge with E85 as a decarbonization strategy concerns actual fuel use and consumer behavior. Even where vehicles are capable of operating on E85, this does not ensure that they are used in that way in practice. In Sweden, for example, flex-fuel vehicles accounted for roughly 6% of the gasoline-powered vehicle fleet in 2024, yet E85 represented only around 0.5% of total gasoline and E85 fuel use combined, indicating that most eligible vehicles are not operated on E85 (Swedish Energy Agency, 2025; Transport analysis, 2025).

Experience shows that the choice between E85 and gasoline ultimately depends on relative fuel prices, and the actual use of E85 has therefore proven highly sensitive to fuel price differentials (Kastensson & Börjesson, 2017).

Recent developments in California provide a clear example of this dynamic. E85 sales have increased significantly in recent years, rising from around 0.15 million cubic meters in 2020 to approximately 0.45 million cubic meters in 2024. This growth has been supported by a large flex-fuel vehicle fleet and periods when E85 has been priced significantly below conventional gasoline (CARB, 2025b; Renewable Fuels Association, 2023). However, this experience also reinforces that sustained use of E85 – even where compatible vehicles are widely available – depends heavily on strong price incentives.

The renewable content of E85 and prospects for fully renewable blends

Despite its name, E85 does not always contain 85 percent ethanol. The ethanol content varies seasonally, with an allowed range of 65–85 percent by volume in summer and 50–75 percent in winter, in order to ensure adequate cold-start and drivability performance. In Sweden, the annual average ethanol content was 82 percent in 2024 while it appears to be around 75 percent in France (Bioéthanol France, 2025; Swedish Energy Agency, 2025).

Industry-led initiatives have explored the possibility of increasing the renewable content of E85 by replacing the gasoline fraction with alternative hydrocarbon components (Beauchet et al., 2022; Bioéthanol France, 2025). These include bio-naphtha, e-naphtha (produced as a by-product in e-SAF production via Fischer–Tropsch synthesis), and hydrocarbons derived from ethanol through ethanol-to-gasoline (ETG) processes. Available studies suggest that such blends can, in principle, achieve fuel properties comparable to conventional E85, including sufficient octane performance. In particular, reported results indicate that a research octane number (RON) above 95 can be maintained even at lower ethanol shares, such as those used under winter conditions (Bioéthanol France, 2025).

However, several important limitations and uncertainties remain. A key constraint relates to fuel standards. The current specification for E85 in the EU (EN 15293) requires that the gasoline fraction consists of components compliant with EN 228, which limits the use of several of the alternative blending components explored in these studies. While such specifications could in principle be revised, this would require regulatory changes and alignment across markets. In addition, the availability of relevant components remains uncertain. Both e-naphtha and ethanol-to-gasoline (EtG) depend on production pathways that are not yet established at scale, and whose future market feasibility remains unclear (see Chapter 3.1).

A relevant real-world case of high-renewable E85 is found in California, where Pearson Fuels – the leading distributor of E85 in the state – has introduced E85 with near 100% renewable content. The fuel consists of approximately 82 percent ethanol, with the remaining share primarily made up of bio-naphtha derived from HVO and SAF production. According to the company, this fuel accounted for around one-third of its E85 sales in 2022, indicating that high-renewable blends can be deployed at scale under favorable market conditions (Schroeder, 2023).

However, important differences in fuel composition and operating conditions mean that the California experience cannot be directly applied to European conditions. In California, ethanol shares in E85 remain consistently high and do not fall below around 70% (CARB, n.d.), while Pearson Fuels reports ethanol shares above 80% across its E85 offering (Pearson Fuels, n.d.). As a result, it remains uncertain whether similar high-renewable blends would perform adequately in colder climates, where ethanol shares may need to be significantly reduced.

Taken together, these findings suggest that while fully renewable E85 is technically possible and already deployed in specific contexts, its broader applicability remains uncertain and depends on both regulatory conditions and fuel system constraints. In this context, the role of high-renewable E85 may be an important aspect to consider when assessing how the remaining gasoline vehicle fleet can be aligned with long-term climate targets.

Other fuel options requiring vehicle adaptation

In addition to ethanol, other fuels compatible with spark-ignition engines can contribute to reducing emissions from gasoline vehicles. Biogas (biomethane) can be used in vehicles specifically designed or adapted for gas operation (called CNG-vehicles), either as factory-produced models or through retrofitting of conventional gasoline vehicles. Such conversions are commercially available and typically involve installing high-pressure gas storage and associated fuel system components, while retaining the gasoline system for start-up and backup operation.

However, converting vehicles for gas operation generally requires more extensive modifications than liquid fuel retrofits, as it involves the installation of a separate fuel system alongside the existing gasoline system. This increases both the technical complexity and the cost of conversion, and may also introduce practical drawbacks such as reduced luggage space (ADAC, 2025; Energigas Sverige, 2020). More importantly, the broader relevance of this pathway is limited by current market developments. The availability of new gas vehicles is declining, and interest in gas as a fuel for light-duty vehicles has weakened significantly. As a result, while biogas offers a technically viable route to reduce emissions from individual vehicles, its potential as a large-scale decarbonization strategy for the gasoline vehicle fleet appears limited.

High-blend methanol fuels (e.g. M85 and M100) represent a more novel alternative for spark-ignition engines. Their use in passenger cars remains limited and is largely confined to China, where methanol vehicles have been deployed in pilot programs, with over 30,000 vehicles in operation (Li et al., 2023). Interest in methanol as a transport fuel is driven in part by its favorable fuel properties, including a high octane number, as well as the possibility of producing methanol from a broad range of feedstocks, including electricity-derived pathways (Hong et al., 2024; Verhelst et al., 2019). However, in practice, current deployment in China has largely been based on coal-derived methanol (Li et al., 2023).

The conditions for wider adoption remain highly uncertain. The use of high-blend methanol generally requires dedicated vehicles, and while retrofit solutions have reportedly been implemented in China (Verhelst et al., 2019), the available knowledge and experience are limited and the broader feasibility of converting conventional gasoline vehicles remains unclear. Interviews conducted in this project with an engine manufacturer indicate that methanol is primarily considered a fuel option for new vehicles rather than for retrofitting existing ones, due in part to its material compatibility challenges, including corrosive effects on metals and elastomers. In addition, the use of methanol at scale would require the development of a separate fuel distribution system. This is further complicated by the fact that methanol's chemical properties make it incompatible with much of the existing fuel infrastructure, including storage and handling systems (Verhelst et al., 2019). Taken together, these factors make it highly uncertain whether methanol can play a meaningful role in decarbonizing the existing gasoline vehicle fleet.

Overall, the strategic approaches to gasoline decarbonization discussed in this section vary significantly in terms of their potential contribution, scalability, and associated constraints. Table *3* provides a comparative overview of these approaches.

Table 3. Comparative assessment of strategic approaches to gasoline decarbonization.

Strategic approach	Contribution to emission reductions	Key constraints	Scalability	Overall assessment
Fully renewable fuels (separate niche products outside the conventional fuel pool)	Limited at system level due to niche application	High production costs; separate distribution; dependence on voluntary willingness to pay	Low (limited by cost and niche market conditions)	Unlikely to deliver large-scale emission reductions
Increased use of drop-in gasoline components (blending within the existing gasoline pool)	Potentially significant, but dependent on availability and blending constraints	Limited supply of suitable components; blending constraints (e.g. octane); competition for feedstocks	High (but highly uncertain in practice)	Relevant pathway, but constrained by technical and market limitations
Higher ethanol blending (e.g. E10 to E20)	Moderate and bounded by blend limits and actual uptake	Vehicle compatibility; regulatory approval; consumer acceptance; infrastructure constraints	Moderate (bounded by blend limits and uptake)	Promising option, but subject to significant uncertainties
Fuel strategies requiring vehicle adaptation (e.g. E85, flex-fuel vehicles)	Potentially significant in specific contexts, but strongly dependent on market conditions	Vehicle compatibility; fuel price sensitivity; not fully renewable at present	Low-moderate (potentially higher under strong economic incentives)	Uncertain and context-dependent, with limited evidence of sustained large-scale impact

4.2 Policy instruments

Several policy instruments could in principle influence the decarbonization of gasoline. However, in practice, such policies rarely target gasoline directly. The following sections examine the potential role of carbon pricing, fuel mandates, and key knowledge gaps relevant for policy design before summarizing the results in Table 4 on page 49.

4.2.1 Carbon pricing alone is unlikely to deliver new renewable gasoline components

Carbon pricing is often considered a central policy instrument for reducing greenhouse gas emissions. In the transport sector, higher carbon prices can be implemented through carbon taxes or emissions trading systems that increase the cost of fossil fuels. As discussed in Chapter 2, the EU will extend carbon pricing to road transport through the introduction of the new emissions trading system for buildings and road transport (ETS2).

In principle, higher carbon prices could improve the competitiveness of renewable fuels relative to fossil gasoline by increasing the cost of fossil fuel use. However, interviews conducted as part of this study suggest that carbon pricing alone is unlikely to trigger significant investment in production of new renewable gasoline. As discussed in Chapter 3.3, several structural factors limit the commercial attractiveness of renewable gasoline, including high upfront investment costs and expectations of declining gasoline demand as passenger car fleets electrify. Interviewed industry actors emphasized that these conditions make gasoline-oriented investments difficult to justify even under scenarios with substantially higher carbon prices.

Very high carbon prices could nevertheless influence consumer behavior. If fossil gasoline prices increase substantially, alternative fuels such as E85 could become more economically attractive for gasoline vehicle owners. As discussed above, the use of high-ethanol fuels has historically been strongly influenced by relative fuel prices, and large price differentials could therefore stimulate increased use of flex-fuel vehicles or encourage retrofitting of existing gasoline vehicles to operate on high-ethanol blends. At the same time, the magnitude of such effects remains uncertain. Higher gasoline prices could increase demand for ethanol as a substitute fuel, potentially raising ethanol prices and thereby reducing the price advantage of E85. As a result, the extent to which carbon pricing alone could drive significant fuel switching within the gasoline vehicle fleet remains difficult to predict.

4.2.2 Fuel mandates face challenges for large decarbonization of gasoline

Fuel mandates have become one of the most widely used policy instruments for promoting renewable energy in the transport sector. In general terms, such systems require suppliers of transport fuels or energy to reduce the greenhouse gas (GHG) intensity of the energy they place on the market, or to increase the share of renewable energy in transport fuels. Compliance obligations are typically placed on fuel suppliers, and non-compliance is usually subject to penalty payments.

Although the detailed design varies across jurisdictions, fuel mandates generally allow suppliers some flexibility in how targets are achieved. At the same time, the scope of the mandate influences which compliance options are available. Some systems apply only to liquid transport fuels, while others include a broader range of energy carriers. For example, the Swedish GHG reduction mandate primarily targets gasoline and diesel supplied to road transport (although electricity supplied at public charging stations can generate credits). Germany's GHG reduction quota applies to all energy supplied to the transport sector (S&P Global, 2025), while the California Low Carbon Fuel Standard (LCFS) covers diesel, gasoline along with aviation fuels (CARB, 2025a).

Mandates favor the lowest-cost emission reductions

In practice, such flexibility tends to incentivize emission reductions where they can be achieved at the lowest cost within the scope of the mandate. Fuel suppliers therefore typically prioritize measures that offer the lowest cost per unit of GHG reduction. This has resulted in a strong focus on the diesel side, where relatively large reductions can be achieved through blending of technically mature fuels such as HVO and – to a lower extent – FAME. On the gasoline side, compliance has primarily relied on ethanol blending and, in some cases, limited use of bio-naphtha (see Swedish Energy Agency, 2025).

Another factor that may reinforce this pattern is that fuel mandate systems are commonly designed on an energy basis. Because gasoline has a lower energy content than diesel, this design tends to favor renewable diesel blending over renewable gasoline blending, all else equal. This does not imply that such policy design is flawed, but it reinforces the point that mandate systems may, in practice, provide weaker incentives for decarbonization measures on the gasoline side.

Experience from existing mandate systems illustrates how these dynamics play out in practice. Sweden previously introduced separate reduction quota for gasoline and diesel within its GHG reduction mandate. The gasoline quota was originally designed to increase progressively and reach 28 percent GHG reduction by 2030. In practice, however, the highest level implemented before the policy was revised was

7.8 percent (Swedish Government, 2023a).[7] Compliance at this level was largely achieved through the transition from E5 to E10 combined with relatively high use of bio-naphtha (peaking at 5.1 percent in 2023) (Swedish Energy Agency, 2025).

Industry representatives interviewed for this study indicated that substantially higher gasoline quotas would likely have required additional measures. However, as said in the interviews, expectations within the sector were in general that the mandate would eventually be adjusted due to the high costs and technical limitations associated with further emission reductions on the gasoline side.

A similar pattern can be observed in California's Low Carbon Fuel Standard. The LCFS sets progressively declining carbon intensity benchmarks for gasoline, diesel, and aviation fuels. Because compliance credits are tradable across fuels, reductions achieved in diesel or aviation fuels can contribute to compliance for the gasoline benchmark (CARB, 2025a). Public discussion of compliance options on the gasoline side appears to focus primarily on increased ethanol use, including the potential transition from E10 to E15 and expanded use of E85, rather than the introduction of entirely new renewable gasoline components (see Renewable Fuels Association, 2021). This suggests that, at least in current policy discussions, ethanol-based strategies are generally viewed as the most relevant pathway for reducing the carbon intensity of gasoline within the LCFS framework.

Limited incentives for renewable gasoline investments by fuel mandates

So far, no fuel producer seems to have met fuel mandate requirements through the introduction of new renewable gasoline components at commercial scale. As a result, interviewees indicated that fuel mandates have so far provided limited incentives for fuel producers to develop and invest in the production of such components, and that it remains uncertain whether stricter mandates would change this dynamic.

Even if mandates were designed to specifically target gasoline, they would likely mainly increase the use of currently available renewable gasoline components, such as ethanol and bio-naphtha. However, as discussed above, the potential of these components is constrained by technical and blending limitations. While mandate systems could in principle also create demand for novel gasoline components with

[7] The Swedish GHG reduction mandate was reduced to 6%, and the previously separate quotas for gasoline and diesel were merged into a single combined target. The new mandate was primarily intended to ensure continued use of E10 gasoline, which has been maintained in practice. However, the blending of other renewable components – particularly HVO in diesel and, to a lesser extent, bio-naphtha in gasoline – declined significantly following the change.

very low life-cycle emissions – for example through ethanol-to-gasoline pathways based on low-GHG ethanol – such cases are unlikely to alter the overall pattern.

However, there is limited empirical experience of policies requiring such reductions specifically within gasoline. The Swedish GHG reduction mandate is one of the few examples of a system with a dedicated gasoline target, but the higher planned quota was never implemented in practice. As a result, it remains uncertain how fuel suppliers would respond if substantially stricter gasoline targets were introduced, and at what point such policies might begin to create demand for new renewable gasoline components.

Another key uncertainty concerns the costs associated with introducing such new components. If compliance requires the development of new renewable gasoline production pathways, these costs could exceed the level of compliance penalties, raising the question of how high such penalties would need to be in order to ensure that fuel suppliers demand these solutions rather than simply pay for non-compliance.

One potential pathway within a mandate framework could involve increased use of high-ethanol fuels such as E85. If such fuels are included within the regulatory system, fuel suppliers may have an incentive to expand their sales as a way to increase renewable energy use on the gasoline side. Experience from California suggests that inclusion of high-ethanol fuels within mandate systems may contribute to expanded use of E85, although the extent to which this strategy could deliver large emission reductions remains uncertain.[8]

RFNBO sub-targets may stimulate e-fuels but do not necessarily create demand for e-gasoline

In addition to conventional fuel mandates, specific sub-quotas for renewable fuels of non-biological origin (RFNBOs), i.e., e-fuels, have been introduced in several EU Member States. Under such quota systems, energy and fuel suppliers are required to supply an increasing share of RFNBO-based fuels to the road transport sector. These policies are implementations of the EU Renewable Energy Directive, which

[8] In Sweden, E85 are excluded from the GHG reduction mandate. Instead, the ethanol component of E85 has benefited from tax exemptions. If E85 were included within the reduction mandate, this would change the incentive structure by shifting responsibility for creating price incentives from the tax system to fuel suppliers.

requires Member States to ensure that 1 percent of the energy used in transport originates from RFNBOs by 2030.

RFNBO targets do not necessarily translate into demand for either e-gasoline or other liquid electrofuels. The obligation can be fulfilled through three main pathways: the use of renewable hydrogen in hydrogen-powered vehicles, the substitution of fossil hydrogen with renewable hydrogen in refinery processes, or the use of liquid electrofuels. As a result, it remains uncertain whether RFNBO quotas will generate significant for liquid electrofuels, including e-gasoline.

At the same time, as discussed above, several e-fuel production pathways, such as Fischer–Tropsch synthesis and Methanol-to-Jet processes, generate naphtha-range hydrocarbons as a by-product. In such cases, RFNBO quotas could increase the likelihood that this fraction is directed toward gasoline blending rather than petrochemical uses, as its value would increase if it contributes to fulfilling RFNBO obligations in the transport sector. Nevertheless, the extent to which RFNBO quotas will stimulate the production or use of e-gasoline remains highly uncertain.

4.2.3 Limited knowledge as a constraint on effective policy design

A key challenge identified in this report is the limited knowledge base surrounding renewable gasoline and its role in the transport system. While a wide range of production pathways and blending options have been demonstrated at a technical level, there is significantly less understanding of their practical feasibility under commercial conditions. This includes, for example, the realistic potential for increasing the use of bio-naphtha.

This lack of knowledge complicates the design of effective policy instruments, as it remains uncertain which measures are technically feasible, economically viable, and scalable in practice. In this context, policy efforts may not only need to focus on deployment, but also on strengthening the underlying knowledge base. Research and innovation efforts could therefore play an important role in improving the conditions for informed policy development.

Taken together, the considerations presented in this chapter highlight the challenges of designing effective policy in this area. Against this background, Table 4 provides a comparative overview of policy instruments for gasoline decarbonization and their likely impact.

Table 4. Assessment of policy instruments for gasoline decarbonization

The table includes both policy instruments discussed explicitly in the preceding sections and additional measures identified as relevant based on the broader analysis.

Policy	Key mechanisms and constraints	Likely impact on gasoline decarbonization	Overall assessment
Fuel-focused instruments			
Fuel mandates (shared across gasoline and diesel)	Cost optimization within the mandate leads to emission reductions primarily on the diesel side, where lower-cost options are available (see Chapter 4.2.2)	Low – reductions occur mainly in the diesel pool rather than in gasoline	A central policy instrument, but with limited relevance for gasoline decarbonization
Fuel mandates (gasoline-specific quotas)	A separate quota creates incentives within the gasoline pool but is constrained by the blend wall and fuel properties (see Chapter 4.2.2)	Moderate – primarily increased blending of renewable naphtha in addition to the maximum ethanol share	May support partial decarbonization, but constrained by regulatory and technical factors
Fuel mandates (RFNBO sub-quota)	Can create demand for RFNBO fuels but allows multiple compliance pathways and does not specifically target liquid electrofuels (see page 47)	Low – does not ensure demand for e-gasoline, though may influence the allocation of e-naphtha streams	Limited relevance for gasoline decarbonization
Carbon pricing (CO_2 tax, emissions trading systems)	Increases the cost of fossil fuels but provides weak incentives for investment in new renewable gasoline production (see 4.2.1)	Low to high – limited impact on renewable gasoline, but may over time drive the phase-out of gasoline vehicles	An important precondition, but insufficient to drive the development of renewable gasoline
Tax exemptions for fully renewable fuels and E85	Lowers the price for fully renewable gasoline and E85, but effectiveness remains dependent on price competitiveness relative to fossil gasoline.	Low to moderate – unlikely to drive deployment of new renewable gasoline, but could support increased use of E85 if compatible vehicles are available.	A relevant complement, but with limited system impact
Vehicle-related instruments			
Recognition of carbon-neutral fuels - vehicles in CO_2 standards	May create a limited niche market but without connection to broad fuel transition (see Chapter 4.2.2)	Low – limited to small market segments without scale potential	Not suitable – risks slowing electrification without driving fuel transition

Policy	Key mechanisms and constraints	Likely impact on gasoline decarbonization	Overall assessment
Carbon correction factors in vehicle CO_2 standards	Affects only emissions accounting in vehicle regulation without changing fuel demand	Low – in practice negligible impact on gasoline decarbonization	Not suitable – no relevance for gasoline transition while risks slowing electrification
Vehicle scrappage incentives	Affects the composition of the vehicle fleet after the phase-out of new gasoline car sales (see Chapter 5)	Low to moderate – may over time reduce the number of gasoline vehicles	Relevant in the long term for reducing remaining gasoline vehicles
Retrofitting support schemes	Enables retrofitting of gasoline vehicles but with significant technical uncertainties (see Chapter 4.1.3 and Chapter 5)	Low to high – may enable conversion to alternative fuels in parts of the fleet	May become relevant in the long term, but constrained by technical barriers
E85 compatibility requirements for new vehicles	Enables the use of high-blend fuels over time but requires regulatory changes at the EU level	Low to high – enables E85 as an option for existing gasoline vehicles	Relevant, but difficult to implement in practice
Innovation and investment related instruments			
Investment or production support schemes	Reduces investment costs but investments remains constrained by market conditions	Low to moderate – limited impact on investment feasibility	A possible complement, but likely insufficient to drive investment
Public R&D funding	Contributes to knowledge development that may become important (see Chapter 4.2.3)	Moderate – may reduce key knowledge gaps	Important for long-term development
Fuel standards and fuel quality regulations			
Enable E20 in the EU	Enables increased ethanol blending but requires changes to fuel standards and is constrained by vehicle compatibility and costs (see Chapter 4.1.2)	Moderate – enables higher ethanol blending within the existing system	A relevant measure for increased low-level blending, but with limited long-term potential
Enable fully renewable E85	Requires revised standards and access to suitable renewable components (see Chapter 4.1.3	Low to high – may enable full decarbonization through E85	A potentially important option, but dependent on E85 market development and technical conditions

5 The Future of Gasoline Cars

Decarbonizing Gasoline Car Fleet: Fuel Decarbonization or Fleet Adjustment

Decarbonizing the remaining gasoline vehicle fleet can, in principle, occur through two broad pathways. Either the fuel used in these vehicles becomes progressively less carbon-intensive, ultimately approaching fully renewable alternatives, or the composition and use of the vehicle fleet itself changes.

As discussed in Chapter 2, climate policy in the EU implies that the use of fossil fuels in road transport must be phased out by around mid-century, with significant emission reductions required well before that. At the same time, gasoline vehicles are expected to remain in the fleet for decades. Current projections suggest that around one million gasoline cars could still be in use in Sweden by 2040, alongside half a million plug-in hybrid vehicles that also rely on gasoline for part of their operation. Even by 2050, half a million gasoline cars may remain in the fleet.

This creates a fundamental challenge for the decarbonization of road transport. As examined in Chapters 3 and 4, multiple technical pathways exist for producing renewable gasoline components and blending them into existing fuels. However, the analysis also shows that these face significant challenges related to technical complexity, high costs and uncertain market conditions.

If the decarbonization of gasoline itself proves difficult, the transition of the remaining gasoline vehicle fleet must occur through other mechanisms if climate targets are to be achieved. The following discussion therefore explores how fuel-side and vehicle-side adjustments may interact.

While this discussion primarily focuses on the European context, similar dynamics may be even more pronounced in other parts of the world where the electrification of passenger cars is progressing more slowly. In such markets, gasoline vehicles are likely to remain an important part of the transport system for longer, potentially increasing the relevance of renewable gasoline components in efforts to reduce transport emissions in line with the goals of the Paris Agreement.

Market-Driven Adjustment of the Gasoline Vehicle Fleet in the Absence of Fuel Decarbonization

If the decarbonization of gasoline itself proves limited or slow, the reduction of emissions from the remaining gasoline vehicle fleet must instead occur through changes in the existing fleet. In practice, how quickly and through which mechanisms this adjustment takes place is not determined by climate policy. While policy sets the overall direction by limiting the long-term role of fossil fuels in transport, it does not specify how the remaining gasoline vehicles will adjust.

Instead, these outcomes will largely be shaped by market responses to the economic and regulatory conditions created by climate policy. One important factor is the economic attractiveness of continuing to operate gasoline vehicles. If climate policy leads to higher fuel costs or reduced availability of gasoline infrastructure, the incentives to continue operating these vehicles may weaken. Under such conditions, market actors may respond by adjusting how the remaining fleet is used.

In practice, several types of market-driven adjustments could shape how the gasoline vehicle fleet evolves. The pace and form of these adjustments ultimately depend on decisions made by individual vehicle owners. These adjustments may take several forms:

- **Early scrappage.** Some vehicles may be scrapped earlier than expected, particularly if rising fuel costs or other policy-driven changes reduce the economic attractiveness of continued operation and the residual value of the cars. Policy measures such as scrappage incentives could influence this balance by increasing the economic attractiveness of early retirement.

- **Export to other markets.** Some vehicles may leave the domestic/European fleet through export to markets where gasoline vehicles remain in demand. While such exports reduce the size of the European gasoline vehicle fleet, they do not necessarily reduce emissions globally, as these vehicles may continue to operate on fossil gasoline in other markets.

- **Vehicle retrofits.** Vehicle owners may also retrofit existing vehicles, for example by converting them to operate on E85, biogas, or electric drivetrains. However, for such investments to occur at scale, they would likely need to offer a clear economic advantage compared to continued operation on gasoline, as well as be practically viable from a technical and regulatory perspective (see Chapter 4.1.3). Policy measures such as conversion support schemes could influence this balance by improving the economic attractiveness of vehicle conversion.

Risks of relying on market-driven transition

While such market adjustments could accelerate the phase-out of gasoline vehicles, relying on these dynamics to deliver the emission reductions required to meet climate targets is not without risks. In particular, households that rely on older gasoline vehicles may face increasing costs of continued operation while simultaneously experiencing declining resale values for their vehicles. For some owners, this could mean that the economic value of the vehicle erodes more quickly than expected, effectively imposing a financial loss. Such dynamics may be especially relevant for lower-income households or for individuals living in areas where access to alternative transport options remains limited.

These distributional effects are not only socially relevant but may also have political implications. Experience from previous fuel price increases shows that policies perceived as imposing high costs on motorists can trigger political resistance and public backlash. If a large number of gasoline vehicles remain in the fleet while operating costs rise and vehicle values decline, the political support for the broader climate policy framework intended to drive the transition could be undermined.

Electrification as a key factor in limiting the gasoline transition challenge

The scale of the challenge discussed in this report ultimately depends on how many gasoline vehicles remain in the fleet in the coming decades. While the previous sections have examined how the existing gasoline vehicle fleet may adjust under increasingly stringent climate policies, the magnitude of the transition problem is strongly influenced by developments in new vehicle sales.

In particular, the pace of electrification plays a critical role. Faster electrification of new passenger car sales reduces the number of gasoline vehicles that will remain in the fleet in the 2030s and 2040s, thereby limiting the long-term reliance on gasoline as a transport fuel. Conversely, slower electrification would result in a larger remaining gasoline vehicle fleet, increasing the scale of the adjustment challenges discussed above. Policies that support the rapid electrification of new vehicle sales may therefore represent one of the most effective ways of reducing the long-term challenges associated with the decarbonization of gasoline vehicles. By limiting the number of gasoline vehicles entering the fleet today, such policies can significantly reduce the scale of the transition that must later occur through fuel substitution, vehicle conversion, export, or accelerated scrappage.

At the same time, even under scenarios with rapid electrification, gasoline vehicles are likely to remain in the fleet for several decades due to the long lifetime of passenger cars. For these vehicles, the questions examined in this report – concerning the availability, scalability, and policy support for renewable gasoline components – remain highly relevant, even if such components are more likely to contribute to partial decarbonization than to full substitution of fossil gasoline. Electrification can reduce the scale of the challenge, but it does not eliminate the need to address the remaining use of gasoline in the transport system.

6 Conclusions

The analysis in this report points to a structural challenge in the decarbonization of gasoline-powered passenger cars. Climate targets require a near-complete phase-out of fossil gasoline, yet a substantial number of gasoline vehicles are expected to remain in use for decades, even as the overall gasoline market declines.

The analysis does not point to any clear solution to this challenge. While multiple technical and policy options exist, each is associated with significant limitations and uncertainties. As a result, there is no straightforward pathway for aligning the continued presence of gasoline vehicles with long-term climate targets.

The following conclusions summarize the key aspects and implications of this challenge:

1. **Renewable gasoline is technically possible to produce but faces significant challenges in a declining gasoline market**

It is technically possible to produce renewable gasoline components that can be blended at low or high levels while meeting fuel specifications. However, beyond the use of already established components (i.e., renewable naphtha and ethanol), scaling up the production of new components faces significant commercial barriers. These barriers are closely linked to expectations of a steadily declining gasoline market, which weakens the business case for new investments in gasoline production. In addition, such production pathways face substantial challenges related to process complexity, high capital costs, and competition for key intermediates.

2. **New policy is unlikely to fundamentally overcome these structural barriers – but may accelerate fleet adjustment**

The identified barriers to large-scale production of new renewable gasoline components are substantial, making it unlikely that new policy measures—such as fuel mandates, emissions trading systems, or carbon pricing—would fundamentally enable their broad deployment, including pathways based on methanol (MtG) and ethanol (EtG).

This does not mean that policy lacks influence. However, if such policies do not result in a sufficient transformation of the fuel itself, adjustment may instead occur at the vehicle level. This could include measures such as retrofitting vehicles to flex-fuel operation (although not all vehicles may be suitable for conversion), early scrappage, or export to other markets where fossil gasoline is likely to remain in use.

3. In the short to medium term: incremental increases in existing drop-in components are the most realistic pathway

A realistic strategy for reducing GHG emissions from gasoline is to increase the use of existing renewable blending components. Bio-naphtha – and, over time, e-naphtha – is expected to become more widely available as production of HVO and SAF expands, enabling a gradual decarbonization of the gasoline pool. Additional reductions could be achieved through higher ethanol blending, for example through a transition to E20, although such a shift faces significant technical and market-related barriers.

Over the longer term, however, incremental increases in drop-in components will not be sufficient, and additional components or alternative strategies will be required.

4. Strategies based on fully renewable gasoline as a separate fuel are unlikely to scale

Although fully renewable gasoline products have been demonstrated in pilot projects and niche markets, their large-scale deployment appears unlikely under a market model where such fuels are introduced as separate, parallel products alongside conventional gasoline. Such fuels face challenges related to higher production costs, the need for a separate distribution system, and reliance on a voluntary willingness to pay for low-carbon alternatives.

As a result, strategies based on introducing fully renewable gasoline as a niche or premium fuel are unlikely to deliver substantial emission reductions. Such fuels may still find applications in niche segments with a higher willingness to pay, but its overall contribution to emission reductions is expected to remain limited.

5. In the long term: full decarbonization requires a shift beyond incremental blending

In the long term, as emissions from passenger cars must approach zero, incremental increases in existing renewable components will not be sufficient. A more fundamental transition will be required, in which the use of fossil gasoline is effectively eliminated.

This could, in principle, be achieved through the production of fully renewable gasoline, through adaptation of the vehicle fleet (e.g., retrofitting to flex-fuel operation, although its scalability may be constrained by increasing technical complexity in newer vehicles), or through a gradual phase-out of gasoline vehicles via scrappage or export to other markets. All of these pathways, however, are associated with significant technical, economic, and institutional challenges.

Taken together, the analysis suggests that the long-term solution is unlikely to rely on a single strategy, but rather on a combination of fuel- and vehicle-related measures, with fleet adjustment likely to play a central role.

6. Electrification remains the most effective way to limit the gasoline transition challenge

Ultimately, the scale of the gasoline transition challenge depends on how many gasoline vehicles remain in the fleet in the coming decades. Faster electrification of new vehicle sales reduces the number of gasoline cars that will require low-carbon fuels later in their lifetimes. Electrification therefore plays a key role in limiting the long-term reliance on both gasoline and renewable gasoline in the transport system. Renewable gasoline may still play an important complementary role for the vehicles that remain in operation, but it cannot substitute for the emissions reductions achieved through rapid electrification.

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This report has been reviewed and approved in accordance with IVL's audit and approval management system.