Moving Forward

ExxonMobil

Exxon Esso Mobil

Planning the journey to lower emission commercial diesel fleets

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How to use this White Paper

There's growing pressure on the transport sector to reduce emissions from on- and off-road commercial vehicles as well as rail operations. This is coming from regulators, shareholders, and customers. Operators therefore are evaluating their options and preparing for a lower emissions future.

That's why ExxonMobil has created this document. It's a detailed resource that aims to help answer questions you may have about how to reduce emissions, efficiently.

The index will guide you to the sections that best meet your needs, with links and references for users wanting to take a deeper dive into the topics covered in this paper. The Definitions section in the Appendix aims to help you with terminology you may not recognise.

> "The journey of reducing emissions to support a net-zero future for the road transport sector will require a portfolio of approaches. At ExxonMobil, we have demonstrated capabilities in large-scale solutions, proven technology expertise, and experience working with key industry stakeholders to create meaningful energy product solutions."
>
> **Steven Plas**, *Lower Emissions Fuels Director, ExxonMobil*

ExxonMobil: A history of innovation

ExxonMobil has powered land transport for over one hundred years, enabling personal mobility and commercial transport on road, off-road and by rail. Our brands, Mobil, Esso, and Exxon, serve customers in countries all over the world, supplying in-yard and across our branded network directly and via our distributors.

We are proud of our technology leadership, employing thousands of scientists, and engineers to develop capabilities, technologies, and product solutions for land transport and other sectors.

The transport ecosystem is complex, with many different players that help serve the need to keep people and goods moving more productively, efficiently, and sustainably. 'Sustainability' as that term is used by society spans multiple sustainable development goals and impact categories. Sustainability priorities vary from company to company, and country to country, but often reduction in greenhouse gas (GHG) emissions is a common goal. ExxonMobil has collaborations and strategic relationships with players across the ecosystem, from engine and truck manufacturers to commercial fleets.

ExxonMobil intends to play a leading role in the energy transition. We understand that the world of transport is changing as the ecosystem strives to reduce emissions while maintaining the levels of productivity and efficiency that society expects so that people and products arrive where they need to be when they need to be there, affordably, and reliably. We are working with governments at various levels to advance policies that will help enable a resilient and reliable transport future while the sector advances towards meeting societal ambitions to reduce emissions.

You'll find useful insights in our position paper, Mobility Reimagined, on the road to lower GHG emissions[1], published in March 2023, which lays out a roadmap to lower GHG emissions from the transportation sector and includes some examples of the role ExxonMobil can play in helping meet societal ambitions.

Manufacturers are developing commercial electric (EV) and hydrogen-fueled powertrains to meet both consumer demand and varying governmental policies.

Yet today, most commercial vehicles on the road are diesel powered. Battery Electric Vehicles (BEV) represented only 0.3% of newly registered trucks globally in 2021 according to the IEA.[2] It is essential to consider ways to reduce emissions from existing commercial fleets instead of relying only on a transition in vehicle technology.

This white paper aims to dive deeper into the need for solutions that can improve efficiency and reduce emissions from the commercial vehicles on the road today, with an emphasis on the role that fuels technology can play in reducing transportation sector emissions.

We hope it will be of use to a variety of transport ecosystem participants, including commercial fleets, the businesses they serve, fuel supply chain participants, and the policy makers that shape the sector.

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Section One

Establishing a platform for productive, efficient, and sustainable commercial transport, with a focus on reducing emissions

01
Enhancing transportation productivity and efficiency

Moving people and goods from A to B is fundamental to society and the economy. And the need to do that more productively and efficiently has shaped the development of the modern transport ecosystem.

Energy Choices: Horsepower set the early standard for transport. With the emergence of electric power, electric carriages, powered by batteries, emerged in urban settings, like New York[3]. Similar to horses before them, batteries get exhausted and need re-energizing, so battery swap out stations emerged. Inventors, including Daimler, introduced internal combustion engine (ICE) technology, both spark ignition (gasoline) and compression ignition (diesel). As these technologies matured, they rapidly displaced battery-power, disadvantaged by early battery packs' weight and low energy density. Gasoline and diesel refueling was quick, energy density higher and the new technology prevailed because it enabled users to go further, get on their way faster, and therefore be more productive.

Engine Technology: Specialist manufacturers and production line efficiencies emerged making mobility more accessible to society. Light-duty automobiles were followed by bigger trucks. Gasoline widely became the dominant power source globally for lighter vehicles, and diesel for heavier vehicles, going longer distances. As vehicle technology improved performance and range, more progressive fleets adopted these technologies, rapidly reducing costs and improving efficiency.

Infrastructure Development: Road infrastructure developments enhanced the driving experience, improved journey times and safety, and lowered vehicle maintenance/repair bills. Just as horses needed feeding, ICE engines required the emergence of convenient refueling infrastructure. ExxonMobil, under brands including Esso and Mobil, has been a leading enabler of land mobility worldwide from the very early days of ICE-powered transport, its participation shaped by the efficiency of its refining, logistics and refueling networks.

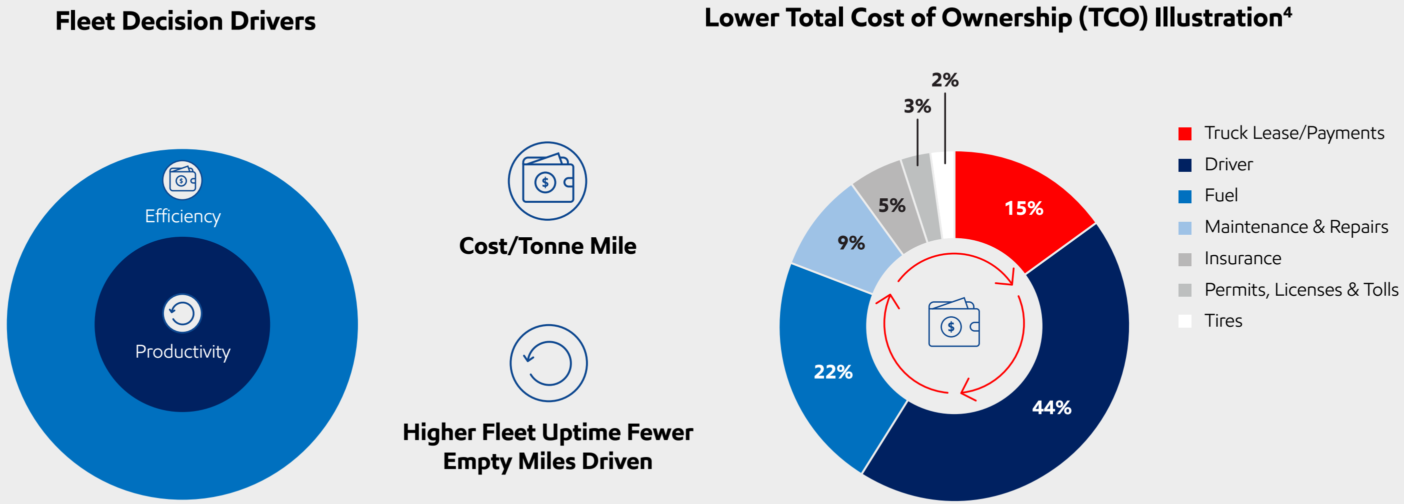
Intermodal: Waterways, rail, and road competed for journey share, ultimately reaching an equilibrium. As international trade grew, marine ports matured into sophisticated containerized operations to make intermodal transfer more efficient and an essential element of fleet strategy.

Fleet Management: A fleet management ecosystem developed around automated, electronic payments that enable fleets to allow drivers to pay using fuel cards across wider national and, later, international networks. This ecosystem helped optimize fleet running costs, provided better visibility of fuel spend, enhancing productivity and efficiency of operations. With the rise of digital and mobile networks, fleet management has evolved into a data-driven science guided by telematics and fleet planning.

The Fundamentals Remain Unchanged: Commercial transport is a competitive business. As with past developments, the readiness and suitability of innovations around truck design, new powertrain options and alternative fueling choices (biofuels, renewable natural gas, electricity and H_2), digital capabilities, and intermodal optimization will be carefully assessed by successful fleet managers through the critical lenses of productivity and efficiency. Total cost of ownership (TCO) models will help steer their choices (see **Figure 1**[4]).

The day-to-day operational challenges faced by commercial fleets was highlighted in research commissioned by ExxonMobil and conducted by Frost & Sullivan in 4Q23 on European heavy-duty truck fleets. See **Figure 2**.[5]

Figure 1
Productivity, efficiency and total cost of ownership



Source: ExxonMobil.

Data Source: ATRI.[4]

Figure 2

Key refueling challenges faced by European heavy-duty truck fleets[5]

What, if any, pain points and challenges does your company face with fueling your trucks today?

Reliable Supply & Quality:
Challenges with fuel availability especially at peak hours leading to queues at peak times. Some face challenges with fuel contamination or poor-quality fuel.

Infrastructure:
Need for dedicated truck-friendly stops. Limited availability of alternatives HVO or LNG.

Time Consumption:
Queuing/fueling time can be a significant pain point, impacting productivity & delivery schedules.

Price Fluctuations:
Frequent fuel price fluctuations. High cost of alternative fuels like biofuels.

Billing & Quantity Issues:
Some companies face challenges with billing accuracy & fuel quantity verification, especially when dealing with external fuel suppliers.

Data Management & Analytics:
Managing fuel-related data accurately can be challenging, especially when incorrect entries affect overall reporting.

"In the past two years, ***the whole of Europe has faced issues with the higher prices of fuel*** ... Norway is facing the high-cost problem ... increases of 20%–25% for biodiesel and other fuels." – **Norway**

"We sometimes face ***issues in terms of the availability of good and clean diesel***, as we had to face issues in terms of the bad fuel quality." – **Norway**

"***LNG gas refilling network is very thin throughout the nation***, so we have to make sure our vehicles operate only in the areas that are accessible from our fueling station." – **Germany**

"Primary ***challenge is to maintain optimal performance of the fuel system*** so, finding a station that provides diesel with high quality grades without causing any impact on performance is crucial." – **Netherlands**

"***Limited availability of refueling stations & congestion*** ... especially during peak hours are some of the challenges that we face with fueling our HD trucks." – **Germany**

"***Delivery schedule is disrupted during peak hours*** due to the problem of having to spend time at fuel stations." – **UK**

"***Time our driver spends at the fueling station is quite high, leading to losing productive time***, impacting our delivery schedules." **– UK**

"Common challenge we have here is the ***availability and accessibility of infrastructure for refueling trucks***. So, the choice of the reliable network is a challenge." – **Italy**

"Currently, it is ***not possible to use electricity over long distances***, and distribution per 100 km is not feasible. The weak points are the lack of facilities for refueling vehicles (for electric)." – **Italy**

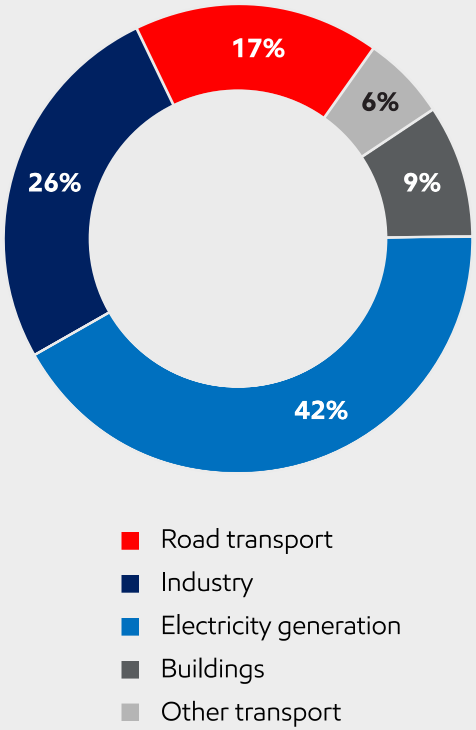
Source: ExxonMobil-commissioned research by Frost & Sullivan.[5]

Establishing a platform for productive, efficient and sustainable commercial transport, with a focus on reducing emissions

02

Commercial transport is growing, with increasing emphasis on sustainability, including reducing emissions

Figure 3
Sources of global CO_2 emissions, 2022[6]



Data Source: IEA CO_2 Emissions in 2022 Report.[6]

Road transport continues to be vital to modern life, transporting people and goods to help meet the needs of society and global economic growth.

Reducing transportation-related greenhouse gas (GHG) emissions plays a part in society's efforts to meet its net zero ambitions. Nearly a quarter of worldwide CO_2 emissions are estimated to come from transportation (see **Figure 3**), and around 74% of those emissions come from the road transport sector[6].

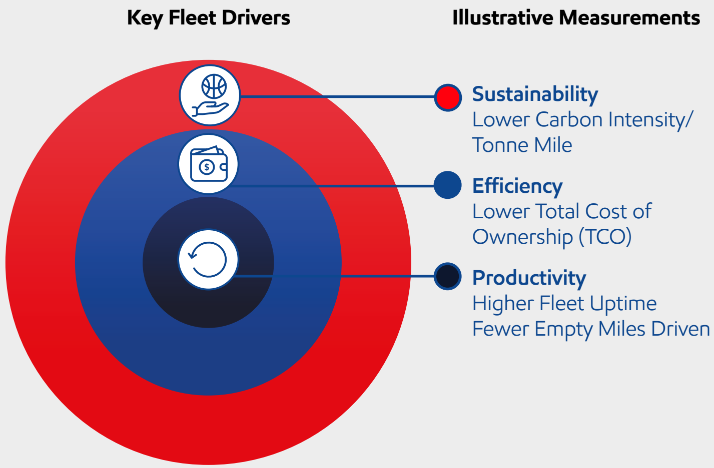
Global transportation energy demand is expected to grow 30% from 2021 to 2050[7] due to global economic growth and the associated increase in vehicles[8] and freight.[9] Road Freight is projected to double over the same period. Energy providers are expected to increase their collective output to meet these needs while providing solutions for lower GHG emissions.

Commercial transport is a complex sector with diverse objectives. Light-Duty (LD), Medium-Duty (MD) and Heavy-Duty (HD) vans and trucks enable freight haulers, consumer goods companies, bulk shipping, and others to get their shipments where they need to be. Route types and duty cycles vary considerably, including short-haul/long-haul, return-to-base/point-to-point, and continuous use/interrupted use. Each case requires efficient fueling solutions, balancing truck downtime and fleet productivity. Each requires affordable and reliable fueling, with an increasing focus on providing potential GHG-emission-reducing benefits while meeting operational performance criteria.

Today, the industry faces many challenges on the path to lower GHG emissions, including a plurality of government policies across regions, technologies, and infrastructure. The sector's complexity requires a higher degree of collaboration than ever before. The energy transition for road transportation will likely require multiple solutions and go through several product evolutions to help achieve societal ambitions to reduce emissions. However, with these challenges come tremendous opportunities for innovation, societal value creation, and transforming government policies.

This has prompted the sector to transition towards lower GHG emission alternatives. In addition to productivity and efficiency, commercial fleets are now assessing their fleet management decisions through a third lens, sustainability (see **Figure 4**), with a particular emphasis on achieving emissions reductions as part of a wider set of sustainability goals without undermining productivity and efficiency objectives. Regarding fleet emissions, in addition to the focus on reducing GHG emissions, focus is also on reducing other tailpipe criteria emissions such as particulate matter (PM), nitrous oxide (NO_x), and sulfur dioxide (SO_x).

Figure 4
Sustainability is emerging as a key decision driver for commercial fleets



Source: ExxonMobil assessment informed by external sources.

Research commissioned by ExxonMobil amongst medium and large commercial heavy-duty fleets in Europe[5] highlighted that decarbonization / reducing emissions is the number one challenge faced by the sector (see **Figure 5**). This is especially true for the largest heavy-duty fleets, particularly government and public fleets. Based on the research, it is a strong organizational focus of nearly 2 in 3 (**65%**) of these commercial heavy-duty fleets, driven by strategic leadership in these organizations in response to organizational sustainability requirements and regulatory developments.

Tackling this challenge means thoughtfully building an integrated plan. Adopting strategies to reduce transportation emissions is a critical element of the activities embraced by forward-looking commercial fleets. This involves reducing the emissions from trucking, but many organizations which operate internationally integrate their logistics efforts across land, sea, and air transport, with some shift from road to rail, into their intermodal strategy.

In addition, many are focused in parallel on reducing emissions from their broader infrastructure (for example, lower emission distribution centers and warehousing operations) and programs to reduce the impact of other elements of logistics activities (including waste management, packaging optimization and recycling programs).

Energy demand for transportation rises 30% as the growing middle class increases travel and buys more goods.[7]

Trucks on the road expected to double from 2015 to 2040.[8]

Road freight growing from 19T tonne-kilometres in 2015 to over 38T by 2050.[9]

Figure 5

Decarbonization/Reducing emissions as a strategic imperative for medium to large European fleets[5]

Biggest Sector Challenges

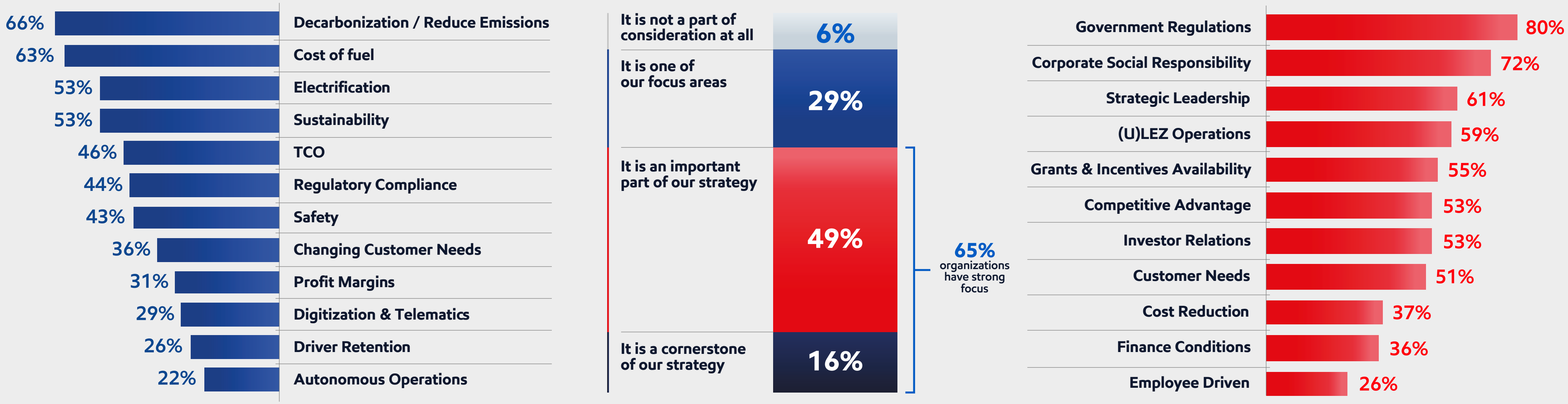
From a fleet operation perspective, which are the major challenges you see in your industry?

Strategic Importance of Decarbonization

How important is decarbonization in your company's strategy?

High Drivers of Decarbonization

What is driving decarbonization in your company?



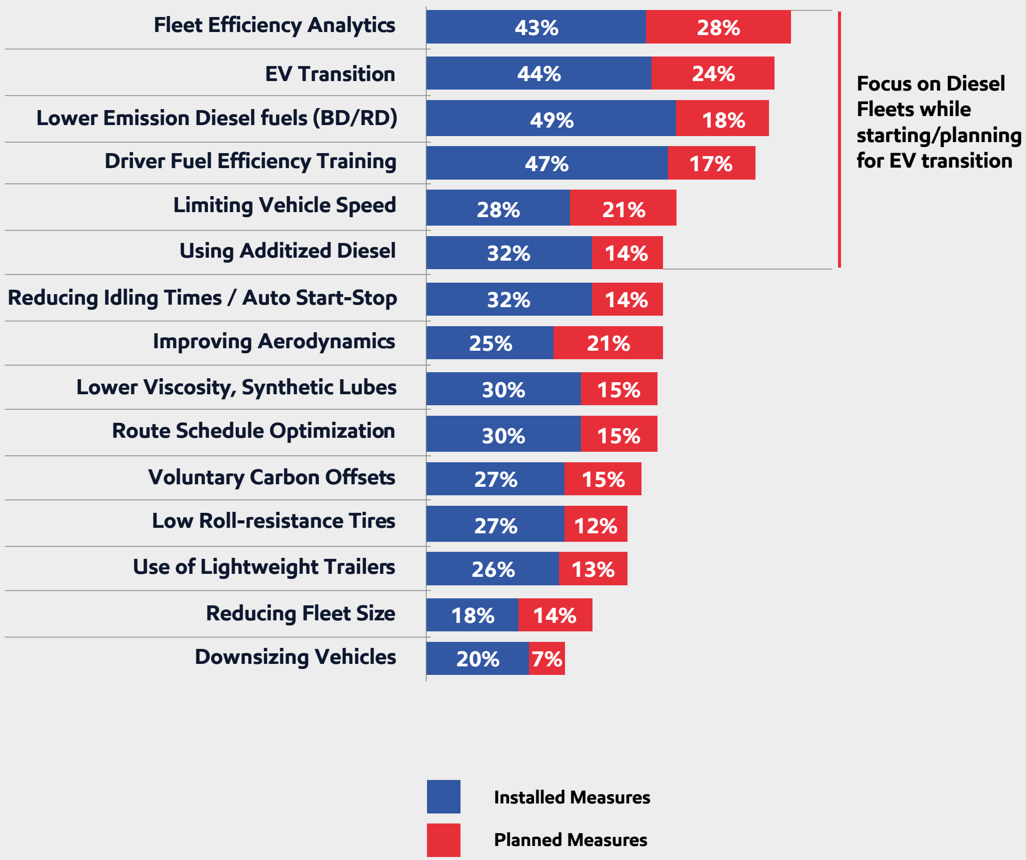
Source: ExxonMobil-commissioned research by Frost & Sullivan.[5]

03
Improving fleet efficiency is the foundation of a lower emission fleet

Regarding trucking operations, ExxonMobil-commissioned research of medium to large European fleets[5] highlighted that improving the fuel efficiency of existing diesel trucks is a foundational priority of their emissions reduction plans. See **Figure 6**. This makes sense because reducing fuel consumption per ton-mile is TCO-favorable AND reduces the effective CO_2 emissions per ton mile at the same time. Furthermore, the fleets interviewed anticipate diesel or diesel hybrid powertrains will continue to play a significant role in their energy mix for heavy-duty trucking for some time to come (see **Figure 7**).

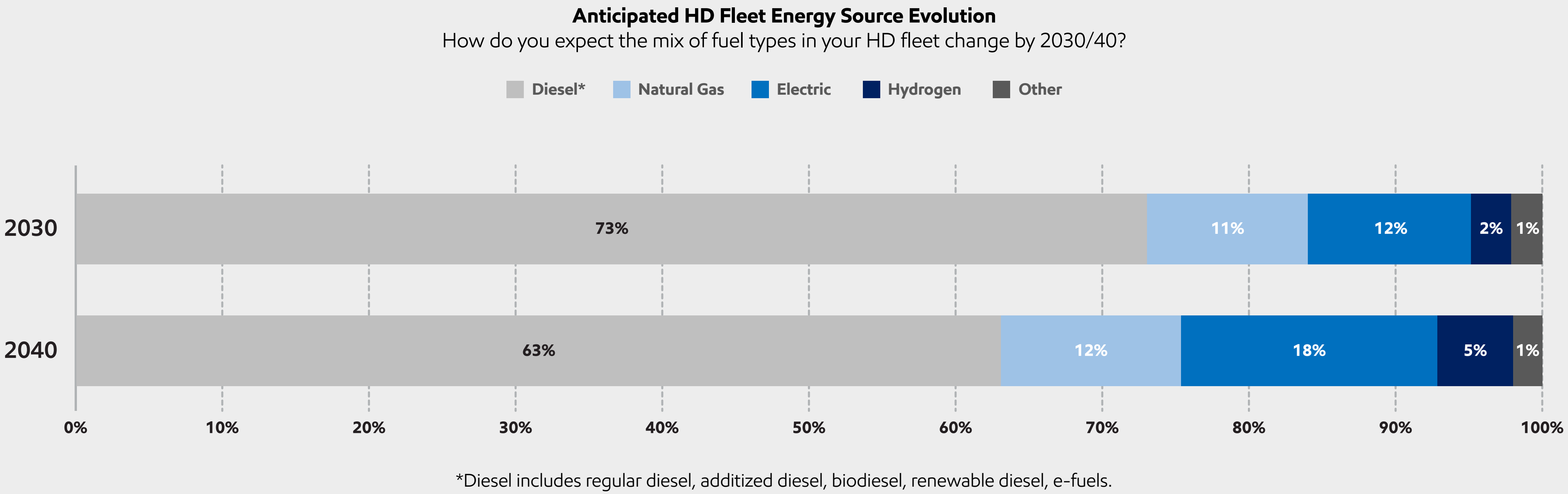
Figure 6
Emissions reduction levers adopted/planned by medium to large European fleets[5]

Emissions Reduction Levers
What measures or tools have you deployed/do you plan to deploy in your organization to manage your fleet towards lower carbon emissions?



Source: ExxonMobil-commissioned research by Frost & Sullivan.[5]

Figure 7
Anticipated powertrain mix 2023-2040 Europe HD truck fleets[5]



Source: ExxonMobil-commissioned research by Frost & Sullivan[5].

The most progressive commercial fleets stayed ahead of the curve, adopted modern trucks and associated efficiency benefits. This makes commercial sense since fuel costs make up ~25% of a North American trucking fleet's cost (greater in Europe where fuel taxes are higher). Efficient fleet operations also form the cornerstone of lower GHG emission fleet operations, and this is growing in importance to commercial fleets and the entities they serve.

Forward-looking fleets have built significant advantages by availing themselves of fuel efficiency enhancements. Organizations like the North American Council for Freight Efficiency (NACFE) have helped drive the development and adoption of vehicle efficiency enhancing and cost-effective technologies, services, and methodologies. Since 2007, fleets in the NACFE Annual Fleet Fuel Study (AFFS)[10] delivered an efficiency improvement of 18% (see Figure 8). This represents a 13% advantage over the average US truck fleet, meaning fifteen fleets in the AFFS operating 75,000 trucks saved $540 million in 2021 alone compared with the average trucks on the road.

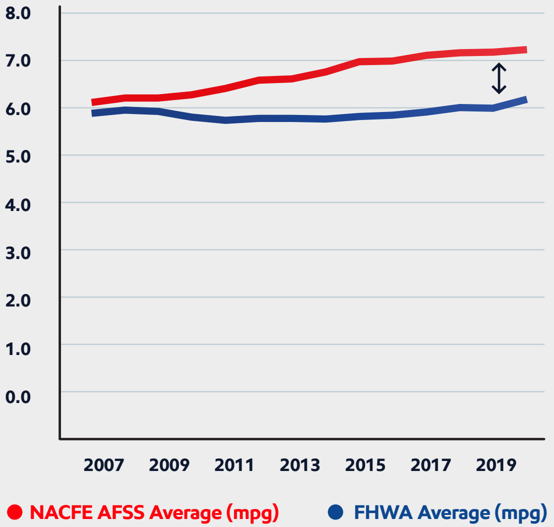
Few, if any fleets, prioritize adopting all the recommended best practices, but the most efficient adopt a higher percentage of the recommended measures. Those fleets adopting more than 50% of the recommended measures reported a fuel economy advantage of 27% in 2021 over those fleets who had adopted <30% of the available measures. For a 100K/mile/year/fleet, at 2021 average diesel prices, this was worth $10K per truck in annual fuel savings, on average.

Opportunity areas include powertrain efficiency, chassis optimization, tractor and trailer aerodynamics, tire/wheel weight and resistance, human factors like maintenance and driving style, smart routing, reducing empty miles driven and using the right fuels and lubricants.

Figure 9 highlights areas where fleets deploy solutions to improve efficiency and reduce tailpipe emissions.[11] In 2017, a study by The ICCT identified the potential for a nearly two-fold efficiency improvement over the prior decade by incorporating these kind of measures.[12]

The Mobil Delvac guide to TCO provides a good overview of TCO and potential optimization opportunities and NACFE[10] offers tools to guide fleets through potential optimizations.

Figure 8
Fleet efficiency improvements in NA: 2007-2020[10]



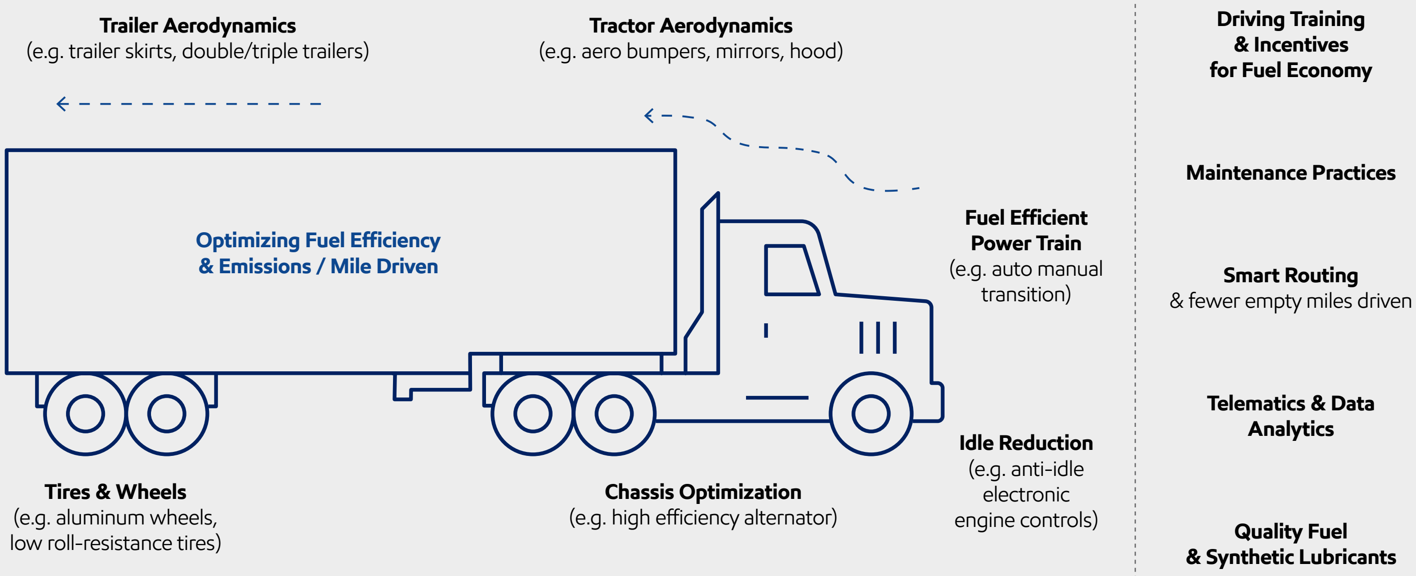
Since 2007, NACFE fleets have achieved a fuel efficiency improvement of 18%. This represents a 13% advantage over the average US truck fleet.

FHWA average is the average class 8 truck mpg according to the US Federal Highway Administration (the FHWA).

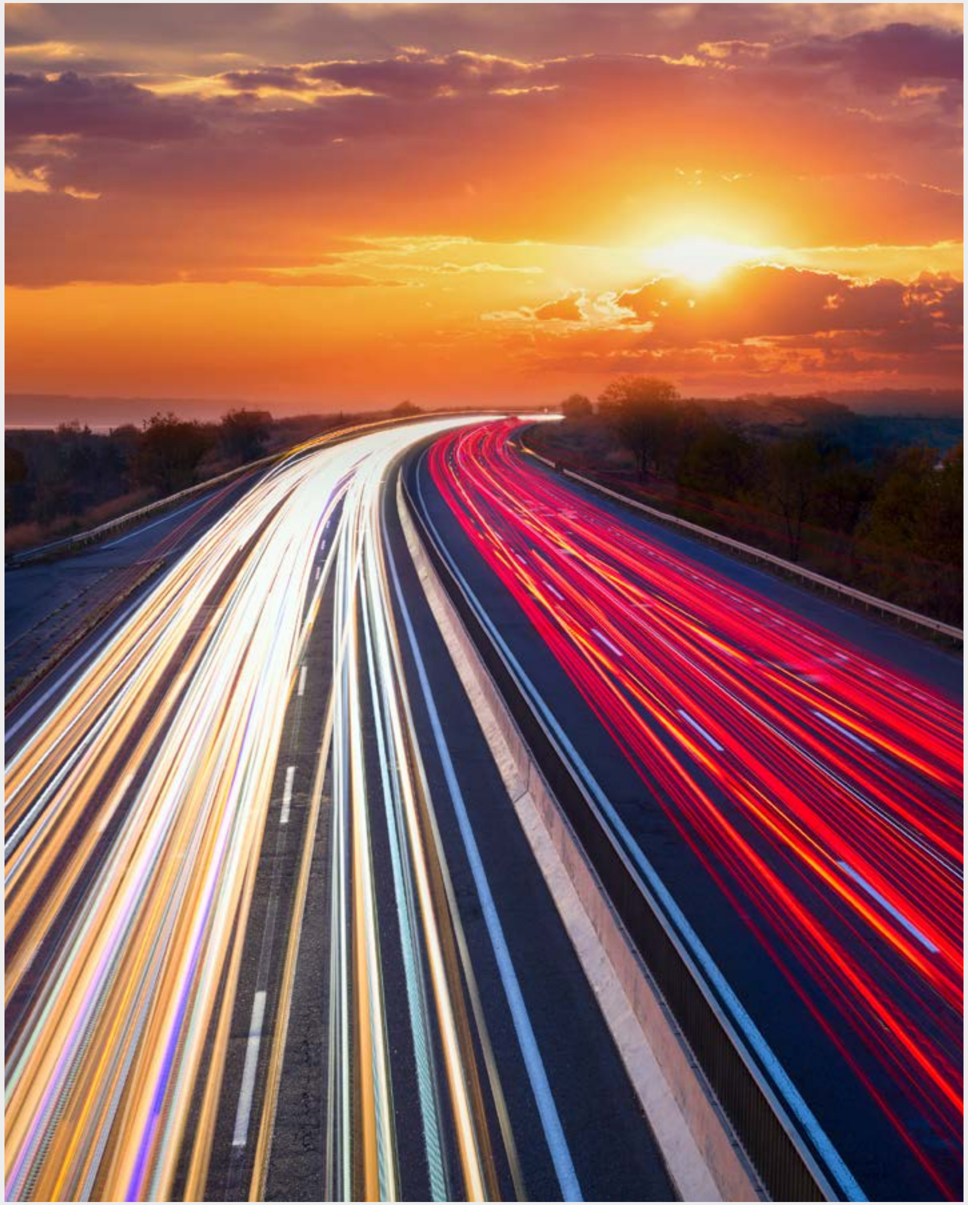
NACFE AFSS average is the North America Council for Freight Efficiency Annual Fleet Fuel Study average Class 8 truck fuel consumption.

Data Source: NACFE.[10]

Figure 9
Opportunity areas for reduced fuel consumption and lower tailpipe emissions/mile driven[11]



Source: ExxonMobil.



04

Lower emission engine technology as a key enabler of lower emission transport

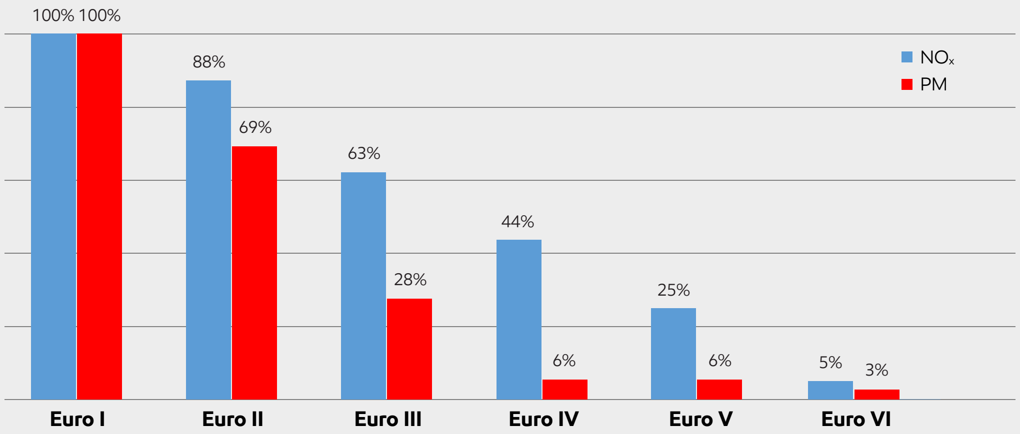
From the 1970s to the early 1980s, diesel engine technology was primarily focused on improving power density and fuel economy. Adopting turbocharging and intercooling was an important technological advancement during this period, as it enabled engines to recycle wasted energy from exhaust gas for more power and better fuel efficiency.

More recently, European, US, and Chinese truck standards have guided stepwise emissions control improvements. The Euro standards progression as an example is shown in **Figure 10**.[13]

> Electronic engine control, exhaust gas recirculation, aftertreatment systems, and high pressure, precision fuel injection technology, have resulted in lower tailpipe emissions.

Figure 10

Evolution of Euro tailpipe emissions standards for NO_x and PM (Euro I–VI)[13]



Source: ExxonMobil illustration.

This has stimulated significant advances in technology, reducing tailpipe emissions. The advent of electronic engine control systems represented a significant transformation. Other innovations, such as exhaust gas recirculation, aftertreatment systems and high pressure, precision fuel injection technology have resulted in lower tailpipe emissions and the diesel engine becoming more integrated with vehicle systems than before.

Figure 11 offers a simplified overview of how these features combine in a current typical lower-emission diesel engine. Future engine technology and emission control systems are expected to be more sophisticated and complex to meet increasingly stringent emission standards globally.

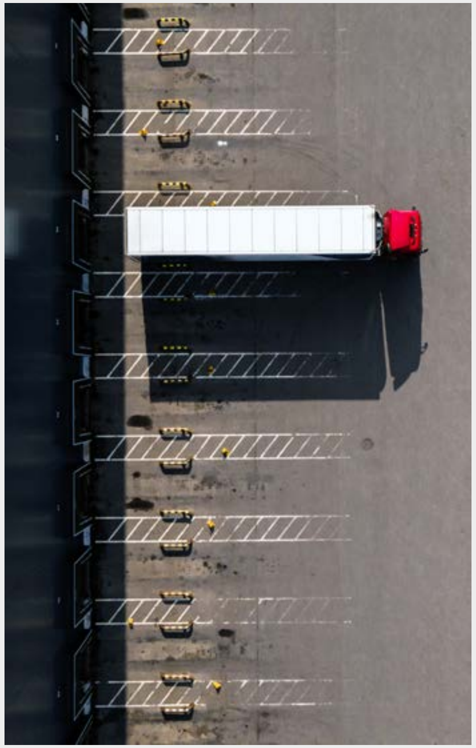
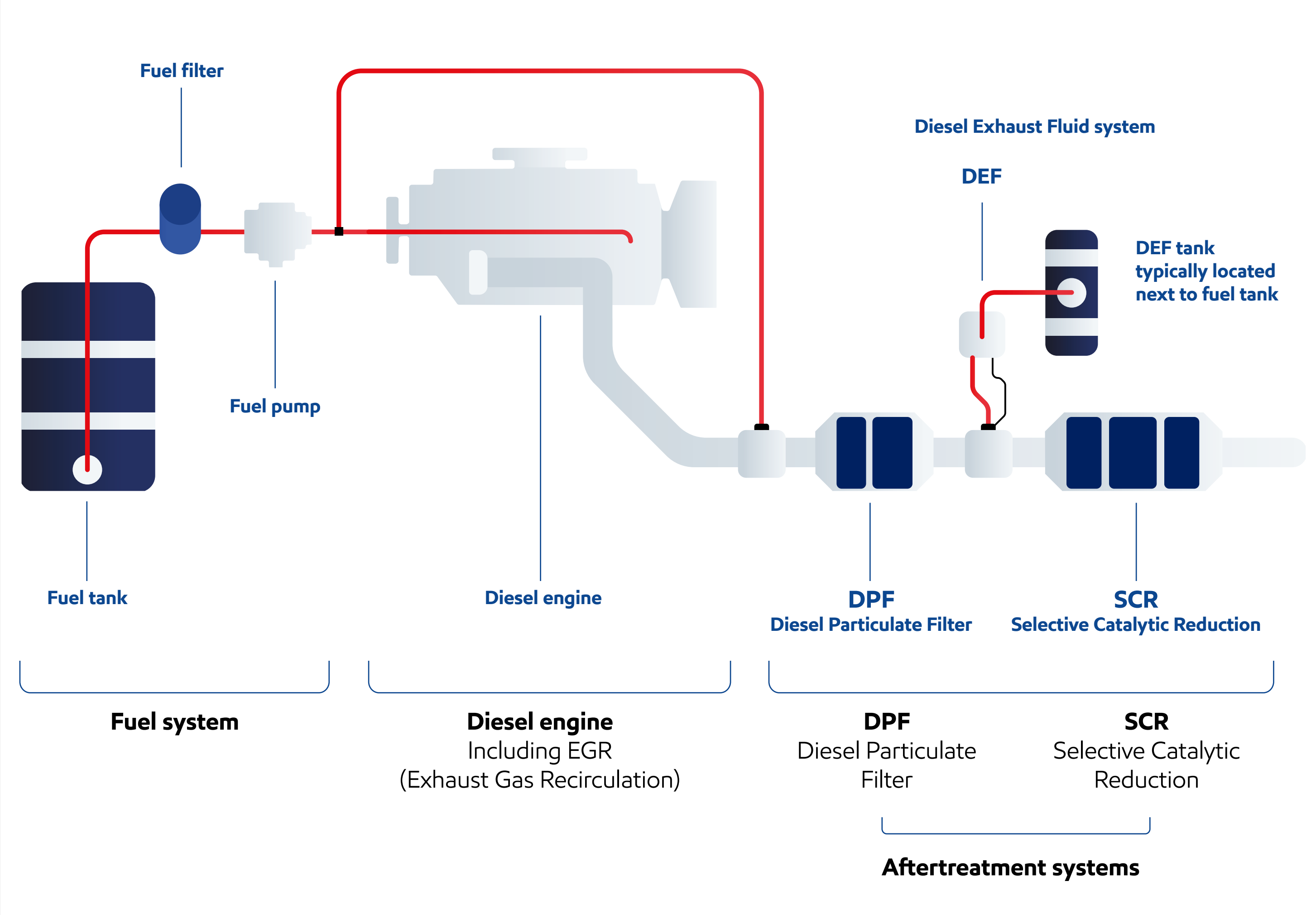


Figure 11
Key elements of a modern lower emission diesel engine



Source: ExxonMobil illustration – not an exact replica but a simplified rendering

05
The importance of fuel quality

The evolution of fuel standards

Changes to diesel engine technology and meeting emissions standards go hand in hand with the evolution of fuel standards. Many regions and countries have their own diesel fuel standards, with specifications like EN590 in Europe and the ASTM D975 standard in the US. Some key diesel fuel quality measures help enable a shift to lower emission diesel technology – see **Figure 12**.

A key focus has been for fuel companies to lower sulfur content, enabling the application of advanced emissions control technologies that substantially reduce emissions from diesel combustion.

Sulfur accumulation in the after treatment system over the lifetime of a truck can poison or deactivate the catalysts used to remove criteria pollutants from an engine's exhaust. Major global economies like US, Canada, the UK, EU, China, India, and Australia have all progressed significant sulfur reductions in road fuel. The European Union implemented its ultra-low sulfur diesel (ULSD) specifications in 1999.[15,16]

The US Environmental Protection Agency (EPA) phased in more stringent regulations to lower the amount of sulfur in diesel fuel to its current ULSD standard of 15 ppm. Several more countries are taking action to upgrade to the Euro IV 50ppm sulfur standard.[17]

Diesel performance additive technology is complementary to an efficient, lower emission fleet

Fuel performance additive technology also plays a complementary role in strategies for lower emission fleets, going hand-in-hand with fleets fully benefiting from the latest diesel engine technology. Given the complexities of today's heavy-duty vehicle systems, the commercial trucking industry demands more from diesel fuel.

Many fleets recognize that high quality diesel fuel is more than just a commodity driven by price and offers significant potential for optimizing modern diesel engine performance. This is an important focus area for fleet managers requiring more product knowledge as the role becomes more strategic. A study in 2022 by a European fleet card service provider highlighted that adoption of additized diesel by heavy-duty commercial fleets in Europe is the number one fuel solution under consideration in their strategy to enhance efficiency and reduce tailpipe emissions.[18]

The use of additized diesel was also highlighted as one of the top 5 levers adopted by the medium to large sized commercial heavy-duty fleets in Europe in ExxonMobil's commissioned 4Q23 research with **32%** adoption and **14%** planning adoption.

As diesel engine technology becomes even more sophisticated and versatile, this significantly impacts what the complete diesel product needs to deliver. Research and innovation at the molecular level, combined with customer feedback, is critical to engineering a fully formulated diesel fuel that helps meet the performance needs of commercial fleet managers.

Figure 12
Diesel fuel quality basics

Sulfur	Occurs naturally in all crude oils. Presence in fuel results in exhaust emissions of sulfur dioxide. Ultra low sulfur diesel fuel is required for exhaust aftertreatment systems because the catalysts can be sensitive to sulfur poisoning.
Lubricity	Fuel's ability to protect the fuel system from mechanical wear, i.e. metal-to-metal contact. As sulfur contents have been reduced to protect aftertreatment systems & reduce emissions, maintaining lubricity levels is important.
Biodiesel	FAME (fatty acid methyl ester) bio-component of diesel fuel. The EN590 specification caps FAME content at 7% by volume (B7). D975 limits FAME content to 5% by volume (B5). FAME does offer additional lubricity to low sulfur fuels.
Cetane Number	Measure of diesel fuel ignition quality. Higher cetane generally benefits cold start in winter time with lower noise and less white smoke.
Cloud Point	Temperature at which paraffinic waxes, naturally present in diesel, begin to crystallize to form a haze in the fuel. Wax crystals can result in fuel filter plugging. The risk of filter plugging is an important consideration in colder climates, especially as new renewable diesel fuels are introduced to reduce lifecycle GHG emissions.

Source: ExxonMobil technology assessment.

Figure 13
Diesel fuels additive technology

Detergent-based additives
Can provide substantial benefits for diesel fuel products by removing injector deposits and preventing them from forming in the first place.

Cetane improvers
Help when the crude selection or processing does not result in an on-specification cetane number on its own. A cetane number indicates the diesel fuel's auto-ignition quality. Higher cetane may benefit cold starts and reduce noise and white smoke upon starting a vehicle, particularly in winter time.

Lubricity improvers
Are required because the natural lubricity-enhancing compounds in diesel fuel are reduced in ultra-low sulfur diesel fuel. Fuel lubricity protects the fuel pump and fuel injectors from wear. Lubricity improvers are not necessary if a minimum of 2% fatty acid methyl esters (FAME) are blended into the fuel.

Cold flow improvers
Cold temperatures encourage wax to drop out of diesel fuel, which can lead to loss of flow from filter plugging or bulk gelling in the fuel tank. Cold flow additives are added at the refinery or the terminal to ensure the diesel fuel flows at the temperatures to which it will be exposed. Blending of cold flow additives depends on geography and season.

Corrosion inhibitors
Over time, corrosion can impact the performance of diesel fuel systems. Corrosion inhibitors are typically added at refineries to help prevent the corrosion of steel and copper or its alloys (brass, bronze).

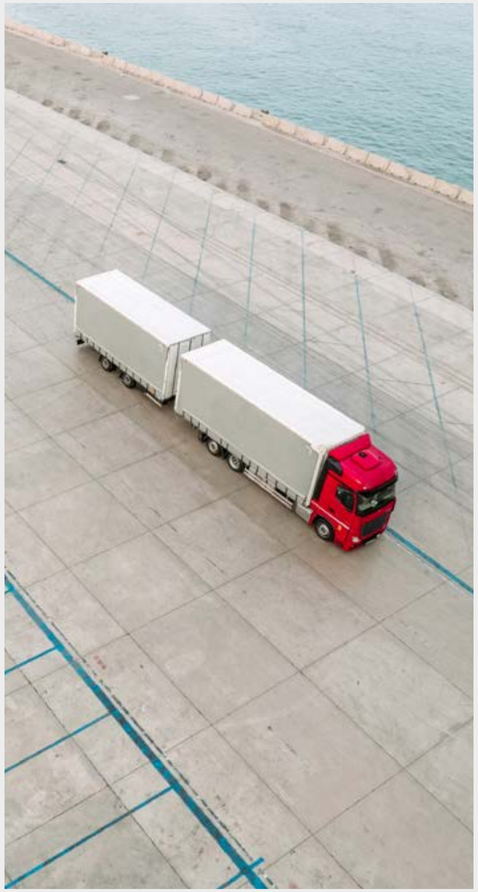
Source: ExxonMobil technology assessment.

Diesel additives are blended in small amounts into the fuel for vehicle performance, product quality, safety, and regulatory purposes. They enhance a fuel's specific properties without substantially altering its bulk physical makeup (such as density, energy content). They come in different shapes and sizes (see **Figure 13**) and achieving the right balance for a particular application requires careful work and significant investment in testing and proof of performance.

Performance technology has never been more important, but it is also complex. Finding the right mix can be tricky. It is important to understand the makeup of the fuel you use to power your fleet and what questions you should ask. High quality diesel from reputable providers, like ExxonMobil, contains an optimized blend of additives to meet local fuel specifications, and exceed those standards to achieve better performance from modern truck fleets.

There are many "aftermarket" additives sold that claim to meet specific customer needs. In contrast to the additives described above that are blended at the refineries and terminals, aftermarket additives are added by hand to fuel. However, in ExxonMobil's view, fuel should meet the required specifications without customers needing to purchase additional additives. Fleet managers should always be cautious of adding additives to diesel fuel as in certain circumstances it can cause more harm than good. For example, aftermarket cold flow enhancers can interact poorly with cold flow additives blended into the fuel at the refinery or the terminal, resulting in filter plugging and potentially worsening the fuel's cold flow properties. Aftermarket additives become less soluble in cold temperatures and may not dissolve correctly in the fuel.

The growing interest in "all-in-one" differentiated diesel fuels has brought additives to the forefront as managers look to harness the best formulation package for their unique fleet needs. Enhancing diesel fuel is a science best left to the experts and we recommend fully formulated diesel products from reputable suppliers with a long-standing commitment to fuels quality.



06
The critical importance of fuel detergency for high pressure, precision injection systems

Just as lower emission engine technology is at the heart of the modern lower emission diesel fleet, the right fuel additive technology is at the heart of the best modern diesel fuels. High pressure, precision diesel injection systems are designed to optimize fuel combustion characteristics (see **Figure 14**).

This elevates the importance of diesel detergency in ensuring the injection system performance stays true over a vehicle's lifetime. Injector cleanliness is critical for the performance of lower emission diesel engine technology, as you can see in **Figure 15**. Fuels designed to help keep precision fuel injection systems clean can also contribute to reduced fuel consumption.

ExxonMobil's Diesel Efficient™ fuel, marketed under Esso, Mobil and Exxon brands, and available in many markets globally, incorporates a terminal-additized detergent and many fleets are benefiting from its fully formulated performance benefits, on-road and on-rail (see **Figure 16**).[19]

Figure 14
Optimizing fuel combustion in modern lower emission diesel engine technology

Optimizing fuel combustion:
Engine manufacturers seek to optimize the diesel combustion process, balancing trade-offs between engine responsiveness, power, fuel economy, and emissions. Diesel fuel, injected into the combustion cylinder, undergoes atomization, vaporization and fuel vapor-air mixing in order to initiate the combustion process.

Fuel injectors are designed to optimize combustion:

Precise timing with tight shutoff:
delivers the right amount of fuel at the right time, without leakage after injection is complete.

Spray pattern:
ensures fuel spray is appropriately placed in the combustion zone, promoting vigorous mixing between fuel and air to initiate combustion.

Fuel droplet size:
ensures proper atomization and vaporization, influencing burn rate. Smaller droplets have a greater surface area to volume ratio, so they evaporate and burn faster.

Spray penetration (or depth):
prevents liquid fuel from hitting and pooling on the piston crown or cylinder wall, where it won't burn completely and can generate particulate matter (soot).

Injector deposits can negatively affect these characteristics, detrimentally impacting engine efficiency, performance, and emissions. Internal deposits can hinder the movement and seating of the injector needle, resulting in non-optimal injection timing or leakage of fuel which can subsequently coke and generate soot. Nozzle deposits (or coking) can alter the spray pattern, fuel droplet size, and spray penetration in undesirable ways which deviate from the original engine design.

Source: ExxonMobil.

Figure 15
Function of an effective diesel detergent technology

How the fuel injector optimizes combustion

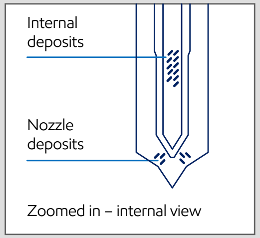
Dirty

Spray pattern:
Inconsistent

Fuel not supplied efficiently & timely

Operation:
Injector motion is hindered

Incomplete combustion



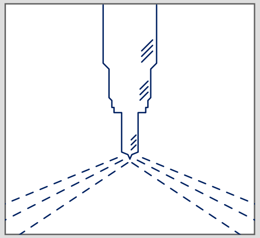
Cleaner

Spray pattern:
Uniform spray pattern

Small fuel droplets

Operation:
Consistent flow

Timely operation



The 1-2-3 of the right fuel detergent

1. Finds deposits
2. Interacts with the deposit
3. Releases deposit from the metal surface & carries away with the fuel

Source: ExxonMobil.

Figure 16
Case Studies – Leveraging Esso Diesel Efficient™ Fuel Technology

On-Road

Esso Diesel Efficient™ fuel helps lower a road transport company's operational cost & improves business efficiency[a]

We worked with one of the largest private transport providers in Singapore, with a fleet of more than 1,000 vehicles. This fleet's on-going search for ways to enhance overall business efficiencies resulted in a trial of Esso Diesel Efficient fuel.

Their fleet's concern centred around:

- **Ensuring vehicles are able to handle the stress from heavy loads.**
- **Protecting engine life and optimising their performance.**
- **Minimising vehicle downtime and lowering maintenance costs.**

The trial[b], which was carried out in collaboration with Esso, exceeded expectations.

Cost savings:

1.8%

average increase in fuel efficiency.

11%

average reduction in DEF consumption.

Efficient and productive fleet operation:

- More powerful and responsive engines.
- Enhanced efficiency with fewer engine breakdowns.
- Greater reduction in black smoke and engine cleanliness retained.
- Fewer refuelling trips required.

Increased product confidence:

- Greater service reliability and customer confidence.

[a] This Proof of Performance is based on the experience of a single customer who used Esso Diesel Efficient™ fuel over a trial period of 6 months. Actual results can vary depending on factors such as type of operation, vehicle, engine, driving conditions, driving behaviour and diesel fuel previously used.
[b] The comparison during this trial period was against our commercial additized diesel (ADO) with different dosage of additive(s). Data collected was based on telematics reporting on fuel consumption and mileage travelled. DEF (AdBlue) consumption was derived from drivers' manual record keeping. Trial was performed in Singapore by our customer on 4 prime movers.

By Rail

Esso Diesel Efficient™ fuel helps a rail freight operator improve fuel economy & reduce emissions[c]

We worked with one of North America's largest rail freight operators. To support its sustainability goals, the customer trialed Esso Diesel Efficient fuel to test its ability to improve fuel economy and reduce exhaust emissions.

The 19-day test used a US EPA Certified Tier 3 GE ES44AC locomotive, during which 16K litres of non-detergent No. 2 diesel fuel were consumed to establish baseline performance. The engine then ran on 66K litres of Esso Diesel Efficient fuel.

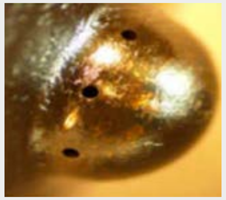
The injectors that ran on Esso Diesel Efficient fuel showed:

- **An average 3.8% higher flow rate than the injectors that ran only on non-detergent diesel.**
- **Smaller diesel fuel droplet size distribution.**
- **Visible reduction in external deposits.**

Post-trial analysis showed that Esso Diesel Efficient delivered an improvement in fuel efficiency.

The finding showed that if the customer's entire fleet switched to Esso Diesel Efficient fuel it could annually achieve a reduction in fuel consumption of 3 ML and lower CO_2 exhaust emissions by 8M KG.[d]

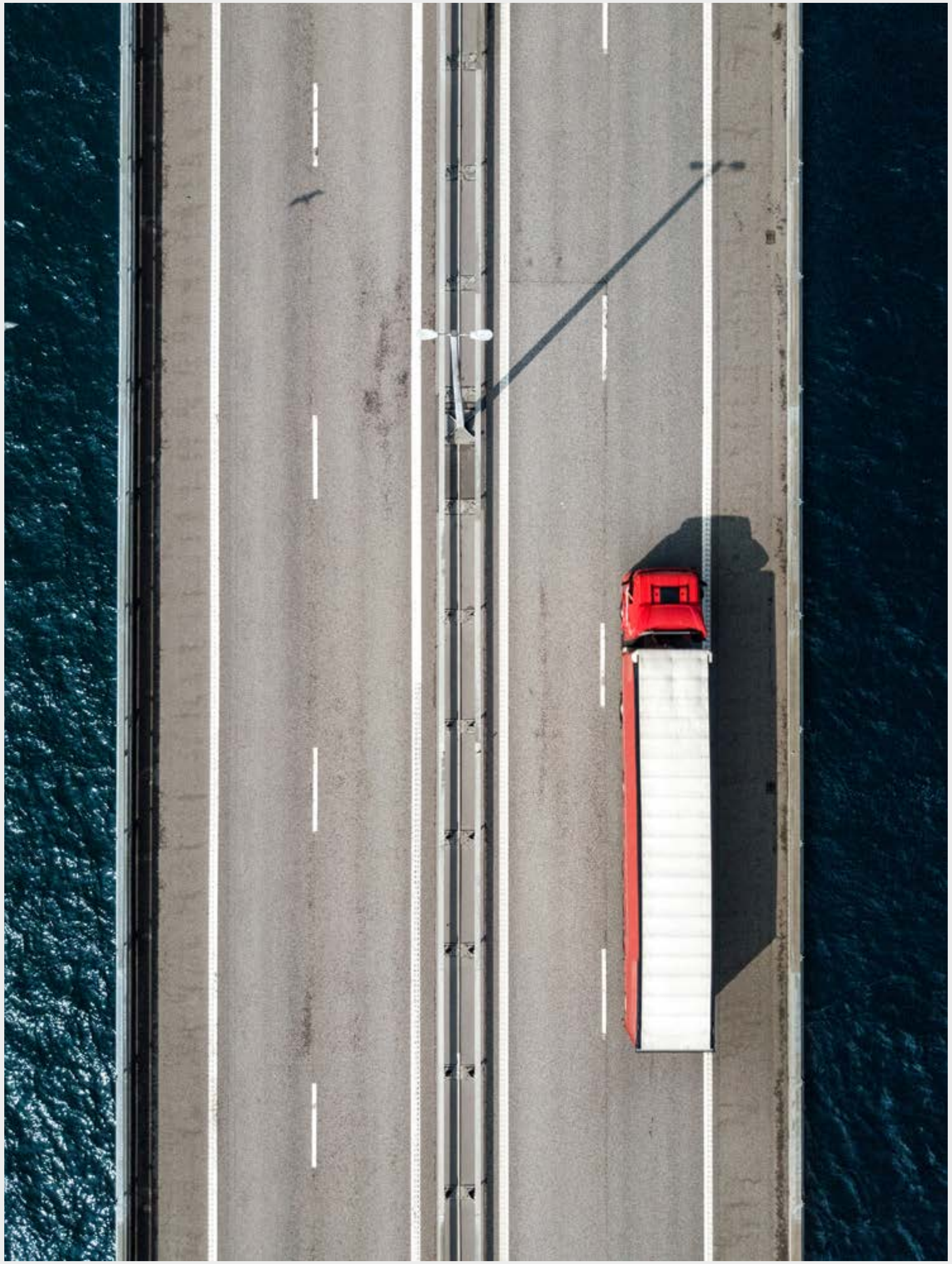
Non-Detergent Diesel
This injector accumulated 8,800 MWhrs on non-detergent diesel only.



Esso Diesel Efficient™
This injector accumulated 12,000 MWhrs on non-detergent diesel prior to **Esso Diesel Efficient™** fuel cleanup.

[c] Results were measured over a 19-day demonstration on a single locomotive. Actual benefits and fuel economy will vary depending on factors such as vehicle engine type, engine conditions and diesel fuel previously used.
[d] Figures calculated as potential benefits that could be realized over an entire year assuming the rail company's entire fleet realized the same benefits as the locomotive in the 19-day field demonstration. Actual benefits and fuel economy will vary depending on factors such as locomotive / engine type, engine conditions, operating conditions and diesel fuel previously used.

Source: Esso Diesel Efficient™ customer testimonials.



Section One in Brief

Establishing a platform for productive, efficient and sustainable commercial transport, with a focus on reducing emissions

- Productivity and efficiency are fundamental needs of commercial fleets, and this has helped shape the solutions adopted for moving people and goods from A to B today. All future choices are assessed through these two critical lenses.
- Demand for commercial transportation is anticipated to rise globally. This growth in demand, and increasing societal efforts to reduce emissions, mean sustainability, and especially reducing fleet GHG emissions, is a rapidly emerging additional consideration of fleet planning.
- Whilst alternative powertrain technology is beginning to gain penetration in commercial fleets, diesel technology will continue to play a major role, for the fleet on the road today and especially longer haul, heavier-duty applications.
- Commercial fleets can now choose from a range of tools (including driver training, telematics, smart routing, and improved aerodynamics) to enhance efficiency and reduce emissions. Leading fleets have demonstrated significant advances, improving productivity and efficiency, thereby lowering both operating costs (TCO) and reducing emissions per ton mile.
- Modernizing the existing fleet to benefit from the latest lower emission diesel engine technology is a key component of the strategy used by many advanced commercial fleets.
- Fuel quality is a key enabler of this transition to lower emission vehicle technology. Fuel detergency is especially important in ensuring high pressure precision injection systems function optimally.
- Utilizing the right fully formulated diesel fuel technology helps advanced commercial fleets maximize the benefits of fleet modernization and helps optimize their efficiency in operation.

Section Two

Lowering lifecycle GHG emissions and shifting towards a portfolio of alternative fuels

Transportation significantly contributes to global emissions, representing around 23% of global greenhouse gas (GHG) emissions, of which road transport makes up around 17%.[6] Commercial transport makes up a significant share of road transport emissions relative to the overall transport fleet. Duty cycles, including the distance traveled and the heavy load hauled, mean that road freight is categorized as a harder to abate sector. [20]

As global transportation energy demand is expected to grow due to global economic growth, a mix of vehicle and fuel technologies will be needed to meet consumers' needs and societal ambitions today and in the future. No one solution will be able to meet all of society's transportation needs while contributing to lower GHG emissions goals.

01

Calculating and tracking emissions is a key challenge for fleets in meeting decarbonization goals

The research we commissioned of medium and large commercial heavy-duty fleets in Europe indicated that over two in three had established emissions targets with approaches varying around a series of common themes – see **Figure 17**. Logistics providers were more likely than general haulers to have established targets.[6]

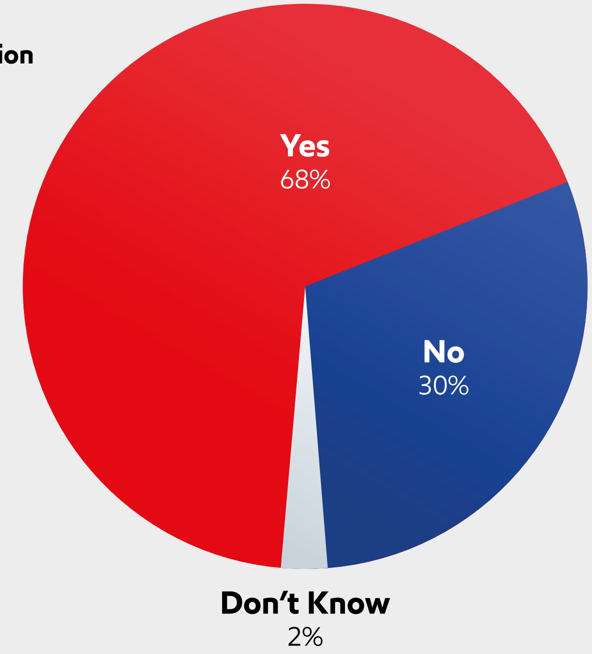
Understanding, calculating, and tracking fleet emissions was identified in interviews conducted with managers of medium to large sized heavy-duty fleets in Europe as one of the top 5 challenges (along with costs and availability of technology, vehicles, and fuels) – see **Figure 18**.

Without measurement it is difficult to establish targets and track progress. Policy varies between regions, countries and indeed states/provinces. This influences how emissions are assessed locally and regionally.

Most vehicle policies today consider tailpipe emissions only. To advance societal goals cost-effectively, policy makers must consider both the full lifecycle emissions of vehicles and the fuels they use.

Figure 17
Fleets are establishing emissions targets[5]

Have you established emission targets for your fleet?



Nature of Emissions Targets (summary)

2030 Targets: Many aim to achieve significant reductions in carbon emissions by 2030 (from 20% to 90%).

Transition to Electric Vehicles: Establishing targets for electrifying fleets.

Use of Alternative fuels: Exploring alternative fuels (e.g. LNG, biofuels, hydrogen & synthetic fuels) to reduce emissions.

Net-Zero Targets: Ultimate goal for most for net-zero carbon emissions by 2050, with interim targets for earlier years.

Regulatory Compliance and Sustainability Initiatives: Many align strategies with regulatory requirements & international initiatives (e.g. United Nations).

Efficiency Improvements: Investing in technology & process improvements for efficiency gains & smart routing.

Alliances & Partnerships: Partnering with organizations & alliances to accelerate emission reduction efforts.

Beyond the Fleet: Strategies for wider operations (e.g. energy usage, waste management & supply chain optimization).

Source: ExxonMobil-commissioned research by Frost & Sullivan.[5]

Section Two

Lowering lifecycle GHG emissions and shifting towards a portfolio of alternative fuels

02

The importance of accounting for lifecycle emissions to help meet societal climate ambitions

The lifecycle assessment of the fuel being used can be broken down into simplified stages as shown in **Figure 19**.[21] This approach offers the most holistic solution towards reducing transportation emissions, as emissions occur at multiple stages along the value chain, both upstream and downstream of the fuel and vehicle. Utilizing a lifecycle approach would enable the quantification of emissions associated with the production, transport, use, and final disposition of both fuels and vehicles. Policies addressing the full lifecycle emissions of vehicles do not rely solely on vehicle replacement to achieve the policy objectives; they also encourage investment and technology development that could result in faster and more robust emissions reductions from existing fleets.

Life Cycle Assessment (LCA) is the process of systematically assessing a product's total GHG emissions over its complete lifecycle. The process calculates the Carbon Intensity of the fuel/energy source.

Carbon Intensity (CI) is a measure of lifecycle GHG emissions, expressed in units of CO_2 equivalent (CO_2e) emissions per unit of energy. CO_2 equivalent (expressed in gCO_2e) is the unit of Carbon Intensity. It is usually expressed per megajoule of energy. It measures the GHG potential of all emissions, not just CO_2, expressed in terms of an equivalent amount of CO_2 based on each emission's GHG potential. The fuel lifecycle assessment is described as **Well to Wheels (WTW)**. The lifecycle assessment can be split into two phases: **Well to Tank (WTT)** and **Tank to Wheels (TTW)**.

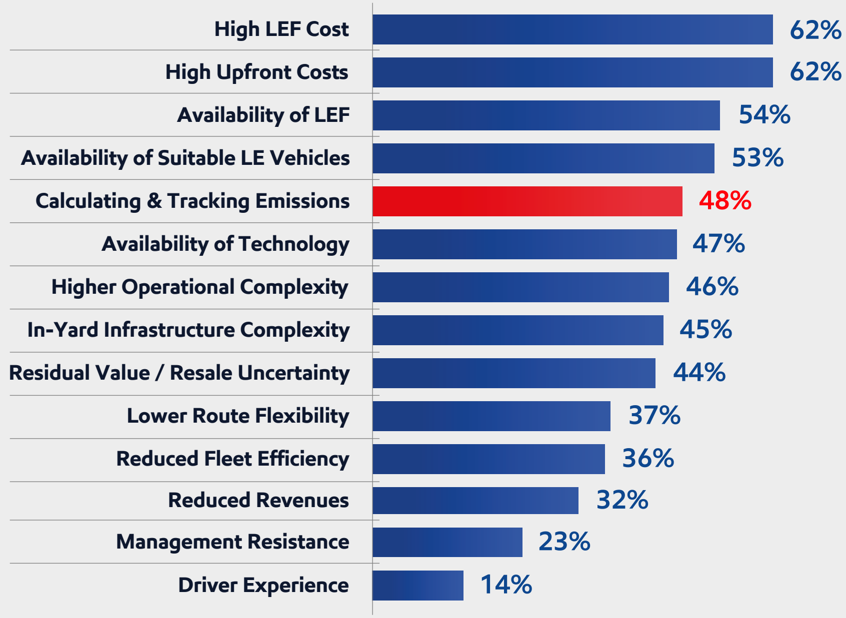
WTT represents the GHG emissions, expressed in CO_2e, associated with fuel production and distribution to the end user vehicle refueling point.

TTW represents the GHG emissions from a fuel's use (combustion) phase, expressed in CO_2e.

WTW analysis does not, however, consider the full lifecycle of the vehicle from production (including its components) through end of life, including disposal. So, while WTW methodology provides a structured mechanism for comparing the lifecycle emissions of different fuels, a more complete analysis of the comparative emissions of various vehicles and their associated fuel/power source is required to make a fully informed choice.

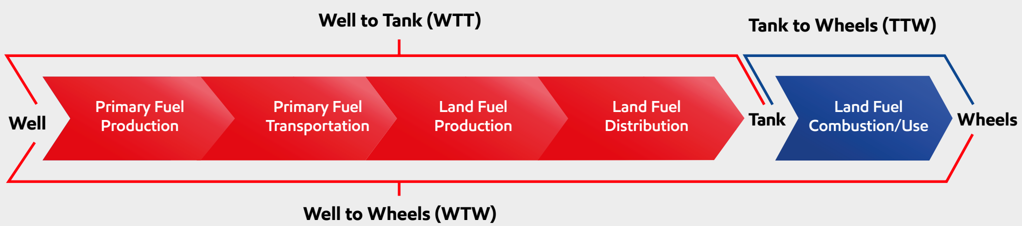
Figure 18
Main decarbonization challenges reported by fleets[5]

High Decarbonization Barriers
What do you see as the barriers to your company's decarbonization efforts?

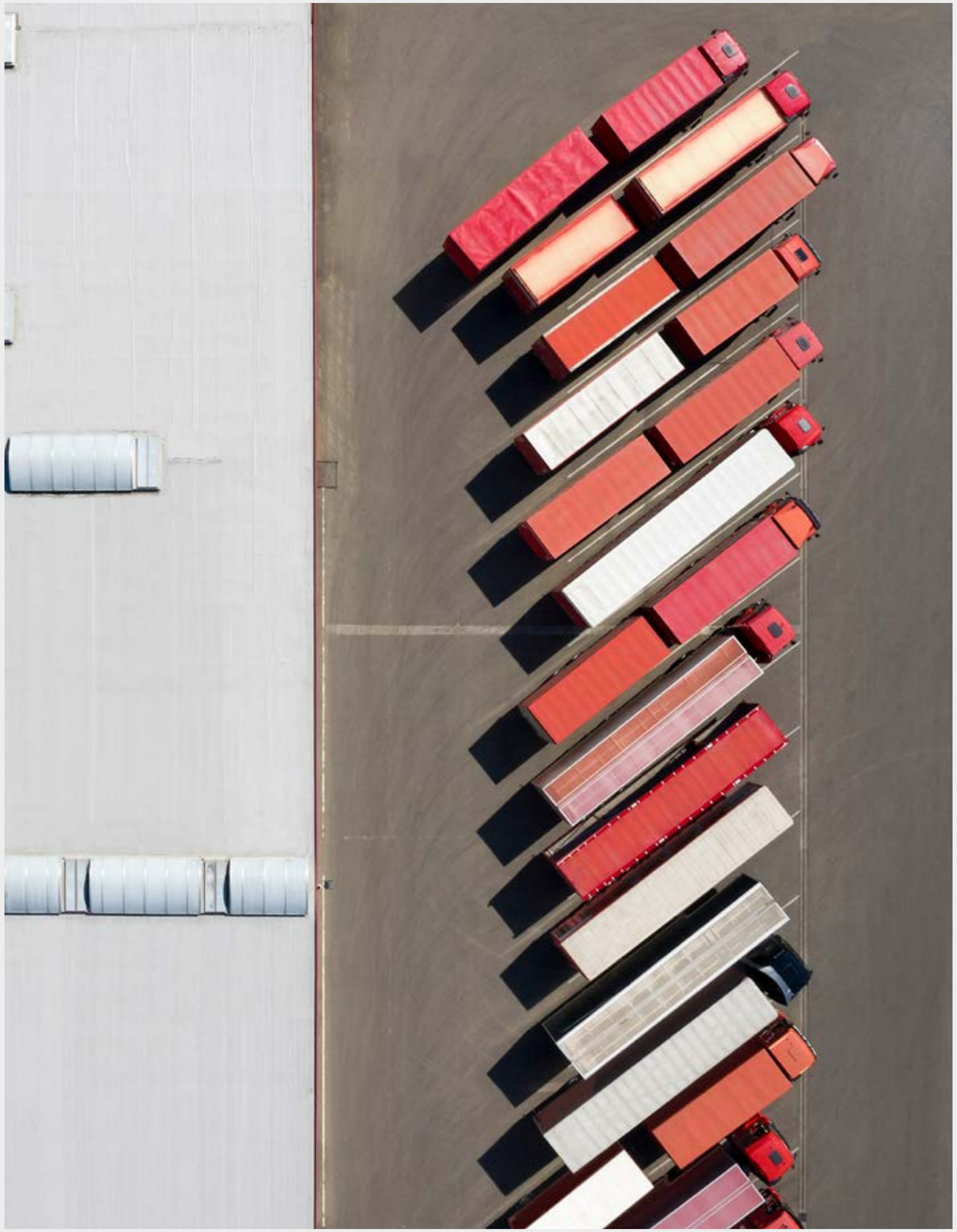


Source: ExxonMobil-commissioned research by Frost & Sullivan.[5]

Figure 19
Lifecycle approach to emissions assessments



Source: ExxonMobil.



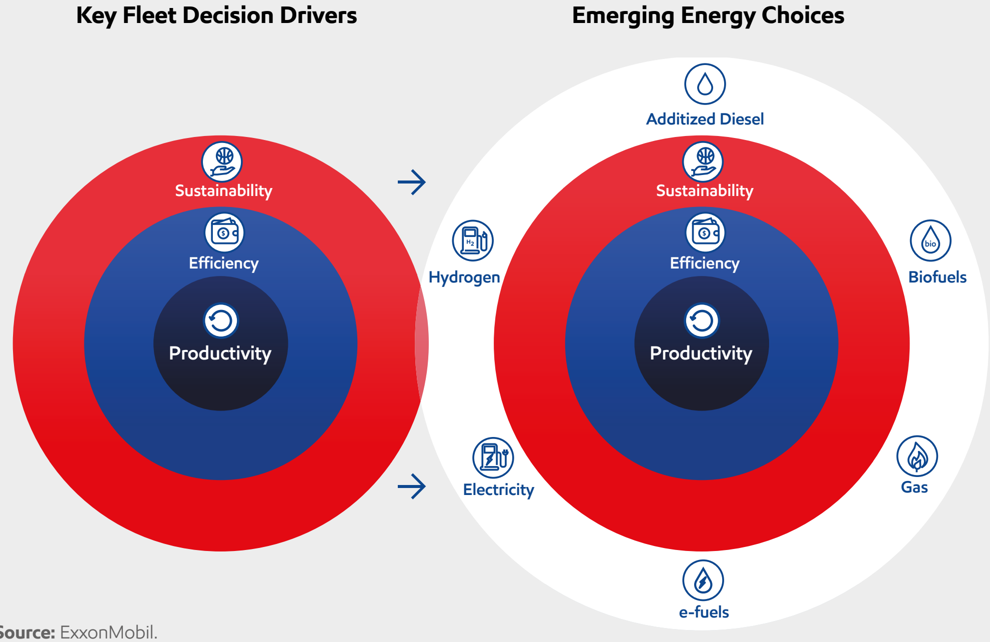
03
The emergence of a portfolio of fueling alternatives

A portfolio of alternative fuel solutions is emerging, offering choices that can contribute to varying degrees of reduction in lifecycle GHG emissions from land transport. Commercial fleets will view the attractiveness of these emerging solutions through the lenses of productivity, efficiency, and sustainability described in Section One.

Figure 20 offers a simplified view of these emerging choices.

Many pathways exist to lower GHG emissions in the road transport sector. A portfolio of solutions approach will be required as each option has advantages and limitations. All solutions will likely have roles to play in reducing emissions from land transport with prospective strengths across the wide range of duty cycles prevalent in land transport.

Figure 20
Emerging alternative fueling choices for land transport



Source: ExxonMobil.

Figure 21 outlines these choices and some specific considerations around the productivity, efficiency, and sustainability lenses, which will guide selection for different applications over time.

For a brief overview of choices facing land transport such as battery electric vehicles, hydrogen (fuel cell electric vehicles or hydrogen ICE engines) and RNG (renewable natural gas) we draw your attention to the companion paper Mobility Reimagined, on the road to lower GHG emissions, but we include a brief summary below.

Biofuels

Solutions like biofuels are an important part of the consideration set for regulators and commercial fleets. In addition to biodiesel and renewable diesel, which will be covered in more detail in Sections 3-5, some commercial operators use compressed and/or liquified renewable natural gas (RNG) to reduce lifecycle emissions[22] from their trucking operations. Switching of fleets from diesel to natural gas (RNG or otherwise) benefits from operational scale given it often requires new truck powertrains, repurposing of in-yard facilities and training of maintenance teams.

Battery Electric Vehicles and Hydrogen

Electrified vehicles (EV) are one component of a multi-technology transportation future to reduce GHG emissions. Early adopters are beginning to incorporate hybrids, full battery electric vehicles (BEVs) and to a lesser extent hydrogen-powered fuel cell electric vehicles (FCEV) in their fleets with consideration of important factors such as range, charging times, and charging infrastructure. Duty cycle, use cases (e.g. refrigerated trucks), terrain, and cab temperature are additional points to consider. Fleet managers are segmenting their vehicles into different duty cycles. Some selectively deploy EV solutions into the elements of their fleet, whose operation and duty cycle best suits available solutions.

The lifecycle GHG emissions reduction potential from electric vehicles is highly dependent on the carbon intensity of the electricity source utilized. The lifecycle GHG emissions of electricity production differ significantly by region. Global emissions from electricity generation have continued to grow; increasing by 1.3% in 2022.[23] Significant investments in a lower carbon intensity grid, well-developed charging infrastructure, and responsible sourcing and manufacturing practices will be key factors enabling these technologies to scale in the future.

In addition to fuel cell electric vehicles, hydrogen can also be used in internal combustion engine applications, although this does not offer zero criteria emissions at the tailpipe. Hydrogen is viewed by many as a good alternative lower emission solution for heavier-duty, longer haul applications[24].

ExxonMobil is helping develop both battery electric and hydrogen ecosystems with projects ranging from collaborations with EV charging networks[25], to lithium extraction[26] and hydrogen production[27].

eFuels

eFuels are synthetic fuels that can be made using renewable electricity to generate hydrogen, and when combined with captured carbon, create drop-in replacements for conventional petroleum fuels with a lower carbon intensity. Delivering lower-cost synthetic fuels, not just from renewable hydrogen, but also from lower carbon hydrogen, produced from natural gas with carbon capture, could accelerate the introduction of such synthetic fuels.

Conventional liquid fuels and internal combustion engines provide convenient and affordable transportation options. Liquid fuels are preferred for commercial transportation (heavy-duty and long-haul trucks, ships and planes) due to energy density requirements where significant on-board energy storage is valued for long-haul driving ranges, heavy loads, or other energy-intensive applications. eFuels should be considered as part of the future lower carbon intensity liquid fuels solution set.

Today, eFuels are expensive with current technology and would require regulatory support to become economically viable. ExxonMobil has significant technical experience and expertise in hydrogen production, carbon capture, and liquid fuel synthesis.

Figure 21
Overview of alternative fueling choices for land transport

Alternative energy solutions that may be leveraged within the portfolio include:

- Biofuels and synthetic fuels that can be blended with or replace existing conventional diesel fuels.
- Renewable Natural Gas as a lower GHG emissions substitute for compressed or liquified natural gas (CNG or LNG).
- Electrification / EV charging that may provide a lower GHG emissions alternative where operating conditions are conducive.
- Lower lifecycle GHG emission hydrogen (e.g. green, blue) for a lower GHG emission alternative to hard-to-decarbonize transportation such as HD trucking.

Key considerations:

- **Scale (supply/infrastructure)**
- **Vehicle/fuel compatibility**
- **Technology readiness**
- **Affordability**
- **Varied transportation needs** (use cases, LD vs. HD)
- **Lifecycle GHG emission reduction potential**

Source: EM Land Fuels Position Paper, 2023 (with minor amendments).

04
The role of duty cycles in shaping pathways

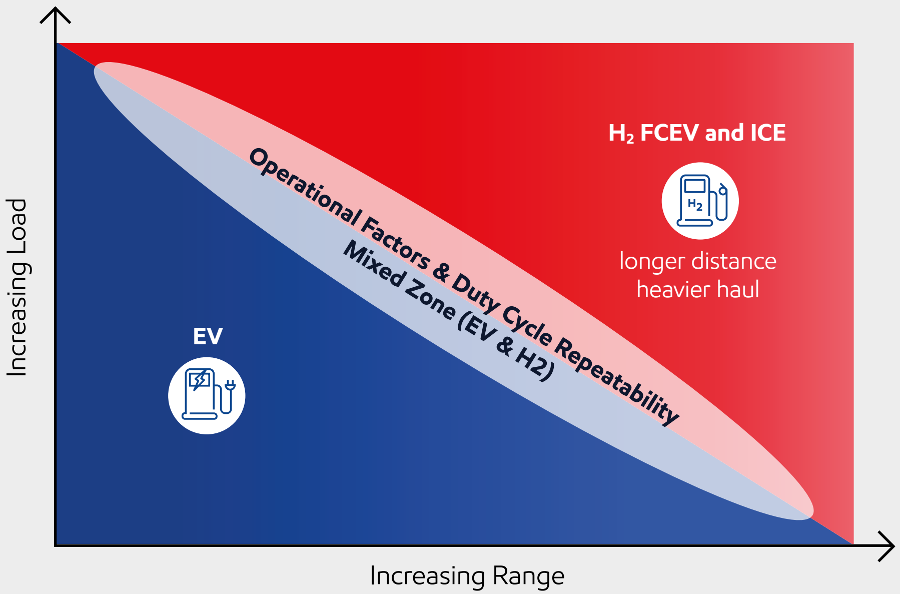
Commercial fleets are typically made up of a range of vehicles from lighter to heavier-duty and operate over a range of operating conditions. So it is to be expected that larger commercial fleets, even though they might prefer to simplify operationally, are likely to operate a mixed regime of fueling choices. They may also choose to move in stages between choices over time as infrastructure is built and policy evolves to support certain pathways.

There are different and constantly evolving views of the relative roles battery and hydrogen fuel cell electric vehicles will play in commercial transport and how it will evolve over time. **Figure 22** is a highly simplified illustration of how two of the key factors of duty cycles, load and distance, are likely to influence fuel selection. The range of EV is based around currently available technology and is expected to increase as battery technology develops further.

Fleet managers with the most ambitious plans to decarbonize their operations are picking the most suitable solution for different subsets of their fleet. This is often with a more accelerated deployment of EV for lighter duty, shorter haul, urban operations, together with the deployment of alternative solutions for heavy-duty, longer haul operations. Charging infrastructure and grid investment is a significant consideration with fleets potentially more likely to decarbonize return-to-base fleets first while reliable heavy-duty charging infrastructure develops for roadside fueling. Hydrogen is expected by many to play a supporting role with an emphasis on longer haul, heavier duty applications, and where faster refueling times are needed to minimize downtime.

We will explore biofuels at greater length in the rest of this paper.

Figure 22
Overview of alternative fueling choices for land transport



- Lighter duty use cases likely to electrify first.
- Drayage & yard tractor heavy-duty use cases most attractive to convert today.
- Return-to-base distribution center operations & point to point applications follow.
- Longer & heaviest haul more challenging to transition.
- Biofuel solutions can play a complementary role across the full range of duty cycles.

Source: ExxonMobil conceptual.

05

The importance of infrastructure in shaping pathways

Battery Electric and Hydrogen-Powered (Fuel Cells and Internal Combustion Engine technology) require significant infrastructure development to support wide-spread, convenient deployment. Enabling the transition to EV requires significant investment in renewable power sources, the power grid and in a suitable high speed charging network (augmented by smart grid / load balancing capabilities and digital route-optimization enablers) to enable battery recharging where it is required to get vehicles back on the road quickly to avoid lost productivity.

Biofuels have the benefit that much of the existing fuel distribution and refueling infrastructure can be leveraged in the supply chain to connect these solutions with end users, conveniently, where and when they need them.

Policy makers play an important role in shaping demand across the portfolio of solutions as well as supply-side incentives, supporting infrastructure development.

06

The role of policy in enabling choices

For more than a decade, ExxonMobil has supported an economy-wide price on CO_2 as the simplest and most efficient way to reduce greenhouse gas emissions. Sector-based policy options, however, if designed appropriately, could also be an effective way to reduce emissions. To this end, we believe a holistic lower-carbon intensity transport policy that combines a market-based, technology-neutral fuel standard with a lifecycle vehicle CO_2 emission standard could drive emissions reductions from across the entire vehicle fleet.

ExxonMobil believes that existing transportation sector-based policies could be improved to achieve meaningful GHG emissions reductions through complementary fuel policy and vehicles standards. This approach would encourage investment in lowering the carbon intensity of fuels (liquid, compressed/liquefied gas, electricity, hydrogen), and vehicle standards that account for lifecycle GHG emissions, including those upstream of a vehicle's tailpipe. Here are some of the desired features of such policy framework:

Fuel policy

To encourage investment in technologies to reduce GHG emissions from existing fuel types, ExxonMobil is encouraging policymakers to consider the development of a holistic lifecycle and carbon-intensity based fuel standard. This would be measured in grams of CO_2 equivalent per Mega Joule (MJ) of fuel energy (gCO_2e/MJ) that would provide a long-term market signal for the production and use of lower carbon intensity solutions.

Such a standard, which could be increased in stringency over time, would establish a market for credit trading that would offer flexibility on compliance mechanisms and underpin investments in technologies to reduce carbon emissions from existing vehicles. Canada's Clean Fuels Regulations (CFR) is just one example that has several of the desired features.

> "To encourage investment in technologies to reduce GHG emissions from existing fuel types, ExxonMobil is encouraging policymakers to consider the development of a holistic lifecycle and carbon-intensity based fuel standard."

Examples of lower carbon intensity fuels that might generate credits under such a standard would include ethanol, biodiesel, renewable diesel, renewable natural gas, hydrogen, electricity produced for EVs, and traditional fuels produced with lower emission technology such as carbon capture and sequestration. Moreover, the standard could be expanded beyond road transportation to the marine and aviation sectors that support multi-modal commercial freight journeys. Some key principles of such a standard are that it:

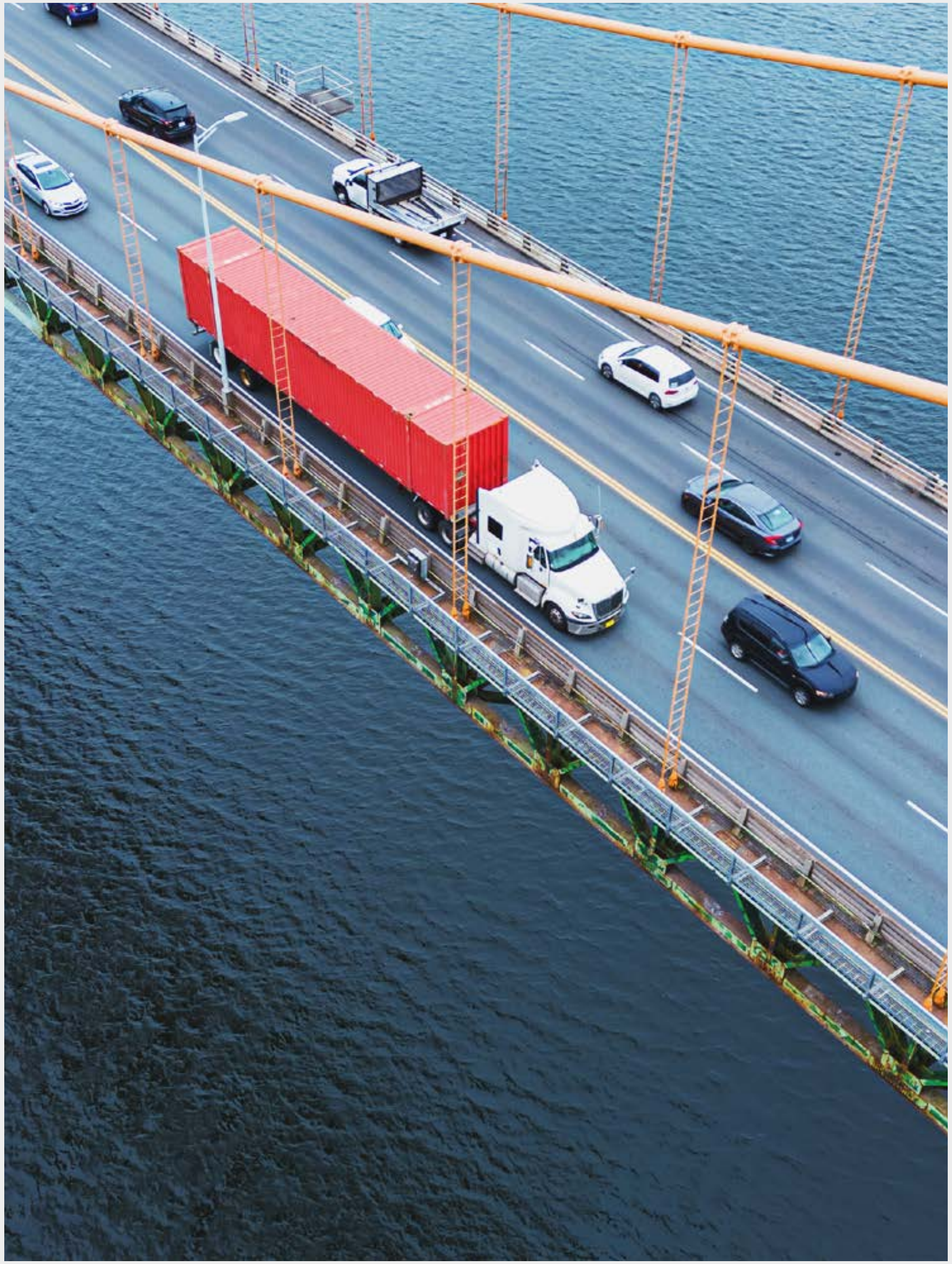
- Supports GHG emissions reductions while preserving consumers' access to affordable and reliable transportation.
- Relies upon credible, and transparent lifecycle assessment to measure GHG emissions reductions throughout the entire lifetime of the fuel and vehicle technology pathway.
- Establishes a clear framework that provides sufficient, long-term certainty to enable investments towards the production of lower emissions fuels and vehicles and avoids conflicts/duplication with other government policies.
- Establishes technology-neutral emissions performance standards and creates an opportunity for market-based solutions and innovations.

> "A lifecycle approach, which accounts for lifetime GHG emissions, allows for a more transparent comparison between the emissions associated with vehicle and fuel types."

Vehicle standards

In addition, complementary emission standards for new vehicles, based on well-to-wheels lifecycle emissions accounting methodology, would encourage lower CO_2e emissions per mile/km driven (gCO_2e/mile or km). Current vehicle GHG emissions standards account only for fuel combustion, or tank to-wheels emissions. A lifecycle approach, which accounts for lifetime GHG emissions, allows for a more transparent comparison between the emissions associated with vehicle and fuel types. Moreover, it enables consistent GHG accounting, and thus provides a more holistic approach toward encouraging advancement in vehicle technologies that can reduce GHG emissions.

Linked fuel and lifecycle vehicle CO_2 standards offer a preferred, technology-neutral policy pathway, relative to mandates which force specific technologies. A policy that aims to reduce GHG emissions from existing fuel types and that recognizes lifecycle emissions from new vehicles can help retain consumer choice for the type of vehicle they prefer to drive, would help lessen risks on energy security and supply disruption, would retain jobs throughout the transportation sector, could grow the role of agriculture in providing energy feedstocks, and ultimately, would be supported through a credit-based system, not taxes, whilst delivering emissions reductions in the most rapid and cost effective way.



Section Two in Brief

Lowering lifecycle GHG emissions and shifting towards a portfolio of alternative fuels

- Given the anticipated continuing growth of commercial land transport, and the contribution land transport makes to global emissions, alternative energy pathways need to be developed to reduce emissions.
- These efforts are complementary to the job of improving the efficiency of the existing diesel fleet and solutions identified in Section One.
- A portfolio of transport energy solutions is emerging from bio and renewable fuels to electrified vehicles, renewable natural gas, and hydrogen.
- Commercial fleets will assess these choices through the lens of productivity, efficiency, and sustainability.
- Larger commercial fleets will likely need to avail themselves of a portfolio of solutions to achieve their goals, given the variety of use cases and duty cycles for land transport with different solutions being advantaged at differing points of the duty cycle map and at different stages in infrastructure and maturity development.
- Policy measures could shape the direction and pace of the energy transition in land transport. A lifecycle approach to emissions should be the preferred approach for evaluating energy choices for land transport.

Biofuels as a portfolio solution for lowering lifecycle GHG emissions from commercial fleets

01
Biofuels demand in land transport is expected to grow

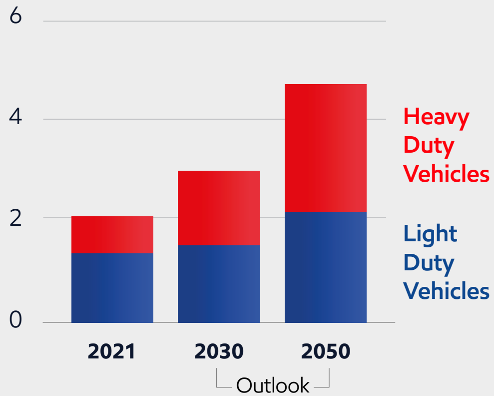
ExxonMobil projects biofuels use will grow in land transport from 2021-2050, as shown in **Figure 23**.[7]

Based on European fleet research, commissioned by ExxonMobil, awareness around biofuel solutions lags behind other alternatives (see **Figure 24**), and fleet managers are still determining their potential and the distinctions between different propositions.

We have found a need for more awareness of these alternatives, and clarification around terminology. We also see an appetite for education about these choices, and associated benefits and tradeoffs, as well as actual experience of other fleet operators. The rest of this document is focused on addressing these questions.

Figure 23
Projected demand for biofuels in land transport 2021-50[7]

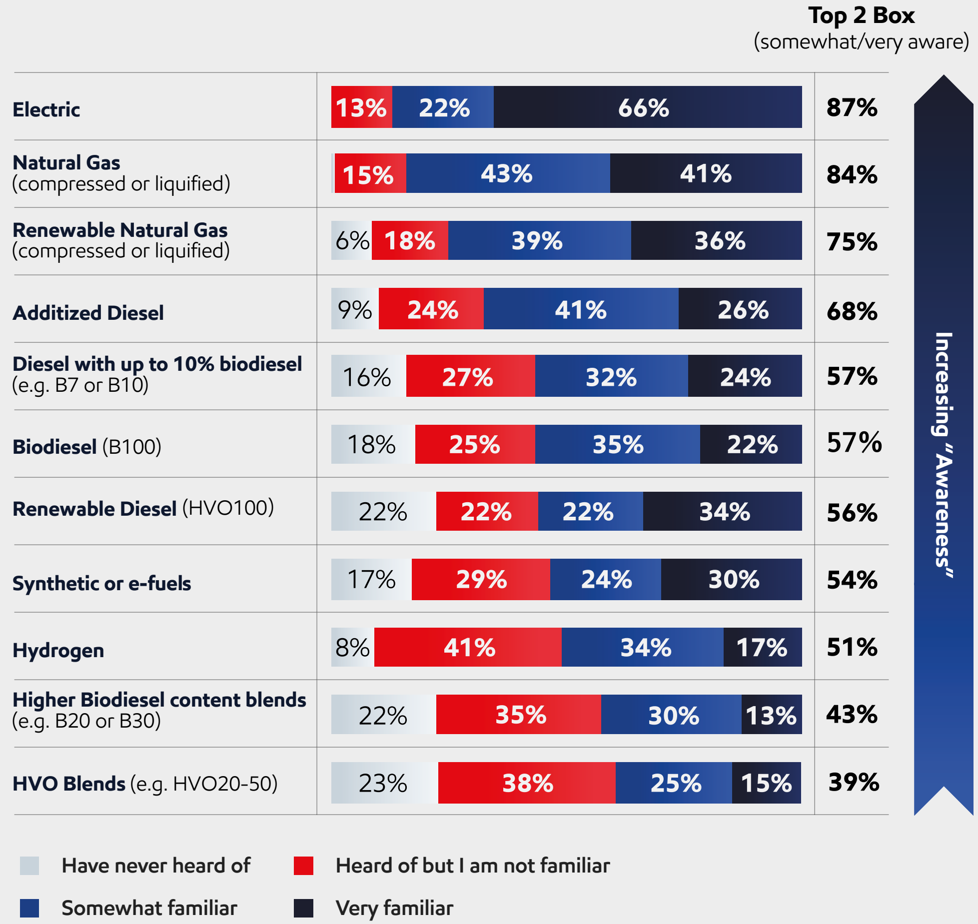
Biofuels use
Million barrels per day of oil equivalent



Source: ExxonMobil analysis.[7]

Figure 24
Alternative fuels awareness – managers, European medium to large sized heavy-duty fleets[5]

How familiar you are with the following?



Source: ExxonMobil-commissioned research by Frost & Sullivan[5].

02
Biofuels are not all the same

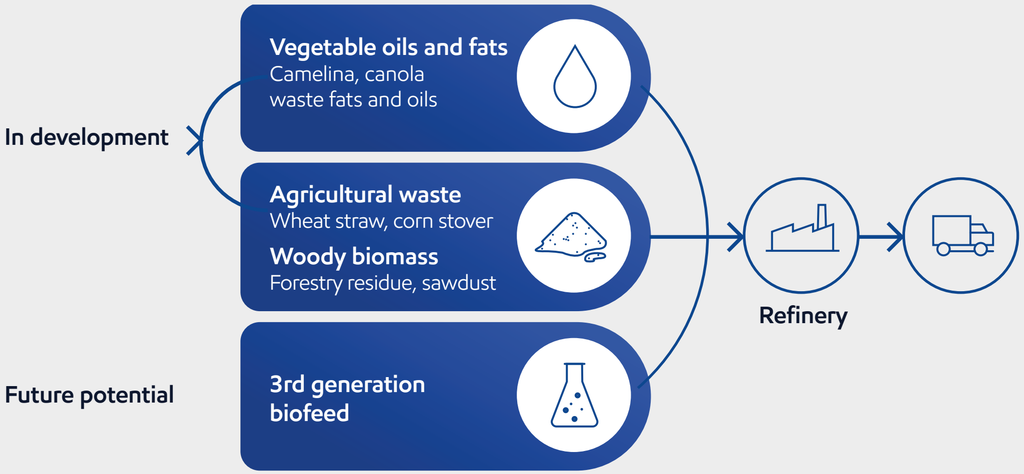
Firstly, and very importantly, not all biofuels are the same, given many variables and associated choices:

- Bio-feedstock.
- Production pathway.
- Carbon intensity (which depends on several factors including the above).

For commercial trucking, there are two main biofuel solutions.

- Biodiesel, also known as Fatty Acid Methyl Ester (FAME). For more details see Section 4.
- Renewable diesel, also known as hydrotreated vegetable oil (HVO) and HDRD (Hydrogenation Derived Renewable Diesel). For more details, see Section 5.

Figure 25
Feedstock choices to replace crude oil with bio-feeds in lower GHG emission transportation fuels



Source: ExxonMobil illustration.

03
There are different kinds of bio-feedstocks

Biofuels producers are navigating a range of choices around biofeed. Depending on the feedstock chosen, biofuels are sometimes designated as 1st, 2nd, and 3rd generation biofuels.

Illustrations of the potential production pathways are summarized in **Figure 25**. Opening up a wider range of pathways would help mitigate potential shortfalls in supply and/or potential competition for feedstock between heavy land transport and marine / aviation transport.

Policy has a bearing on which pathways are supported in different geographies and/or will influence which are more likely to emerge. There are differences in how policy makers in various jurisdictions categorize and assess different feedstocks, with considerations including sustainability criteria, such as potential implications for both direct and indirect land use change (ILUC).[28]

a) Edible oils (First generation biofuels)

Edible, primarily vegetable oils, are currently the most abundant oil feedstock available to produce biofuels. The three most abundant edible oils are soy, canola (also known as rapeseed), and palm. Each is developed in different conditions and regions. The crops are grown, harvested, crushed to separate the oil from the solid matter, and pretreated to remove impurities from the oil to improve its quality.

b) Waste oils & fats (First generation biofuels)

Waste oils are primarily made up of used cooking oil, animal fats, or inedible wastes from the production of other products (e.g. palm oil mill effluent - POME from the production of palm oil, distiller's corn oil from the production of ethanol).

As waste products, they have a wide range of impurities and must be pre-treated like edible oils. Because of their diversity, they also offer unique challenges in reaching the qualities desired for processing into fuels.

However, products made from these waste oils generally have lower life cycle carbon intensities than products made from edible oils. For example, under the European Union Renewable Energy Directive Annex V, the default GHG emission saving vs conventional diesel for rapeseed biodiesel is 47%, whereas waste cooking oil-based biodiesel has an equivalent default saving of 84%.[22]

Two of the largest categories of waste oils are used cooking oil (UCO) and palm waste (palm fatty acid distillate or PFAD, and palm oil mill effluent or POME).

The nature of waste value chains creates a barrier to accessing these feeds. Because waste is inherently a byproduct rather than a primary business, these feeds need to be aggregated by specialty companies. For example, the average US restaurant produces approximately 25 gallons per month[29] of UCO (there are approximately 1M[30] US restaurants).

c) Oilseed cover crops (First generation biofuels)

Cover crops are crops grown between cash crops to help manage soil erosion, soil fertility, soil health, water, weeds, pests, disease, and biodiversity.[31] These include a wide variety of crops, including oilseeds. Unlocking new supplies from oilseed cover crops offers important potential for growing available feedstock for biofuel production.

Using cover crops may have agricultural benefits. It can protect and improve the soil during fallow periods[32]. Common practice has been to use non-oil-bearing plants and to plow under the crop when it is time to plant the primary cash crop (sometimes before the cover crop would even reach maturity). Combining the potential agricultural benefits of cover cropping with the production of a lower lifecycle GHG emission fuel feedstock could create conditions for expanding oily cover crops globally[33], harvesting the oil seeds and plowing in the rest of the crop. These benefits will need to be considered alongside the resources required for additional cropping and policies on oilseed cover crops being accepted or incentivized in respective markets.

d) Cellulosic feedstock (Second generation biofuels)

Cellulosic feedstocks may offer the largest potential supply of lower carbon intensity feedstock, but likely also present a greater challenge in conversion to liquid hydrocarbon fuels. First, they are low energy density solid materials like municipal solid waste (MSW), agricultural waste (straw, stover, bagasse), and forestry waste (branches and thinnings), which are difficult to move and process in existing assets. Second, they often contain more than 40% oxygen by mass, compared with closer to 10% for oils and 0% for hydrocarbon fuels, which reduces product yields. However, their global supply potential is larger than any other categories discussed previously.

This waste needs to be collected and consolidated, so new value chains must be developed to collect and prepare the feedstock to an appropriately homogenized quality that can be converted into fuel. Two exceptions to this are the categories of municipal solid waste and forestry wood pellets.

The first is widely collected in much of the developed world, but the degree to which it is sorted is often not sufficient to allow for processing into fuels. Additional municipal waste sorting would be an enabler of production of lower carbon intensity fuels from the organic waste which has been separated out.

The second is waste from the forestry industry, where there is a growing value chain collecting wastes like sawdust, slash (branches left in the field), and thinnings (small trees removed from commercial forests to facilitate growth of other trees). Frameworks are in place to help prevent this value chain from contributing to deforestation, harming biodiversity and ensuring that forestry waste genuinely is unavoidable waste from existing (necessary) activities. These wastes are processed into homogenous chips or pellets and transported globally for heat and power production, but they could also be suitable for conversion to hydrocarbon fuels.

While cellulosic feedstock is the most abundant potential feed, it is highly distributed and difficult to move, so local supply may be advantaged. With the expected importance of cellulosic conversion pathways, access to affordable local feed will be important for competitiveness.

e) Algae and seaweed (3rd generation biofuels)

Algae and seaweed, if they can be produced at commercial scale, are a potential bio-feed to consider as part of the mix of solutions for the longer term.[34]

"Combining the potential agricultural benefits of cover cropping with the production of a lower lifecycle GHG emission fuel feedstock could create conditions for expanding oily cover crops globally."

04

There are different production pathways

In conjunction with different bio-feedstocks, there are also different production methods. We will cover these in more detail in the following sections on biodiesel and renewable diesel.

These pathways influence end product quality, suitability for different applications and carbon intensity.

05

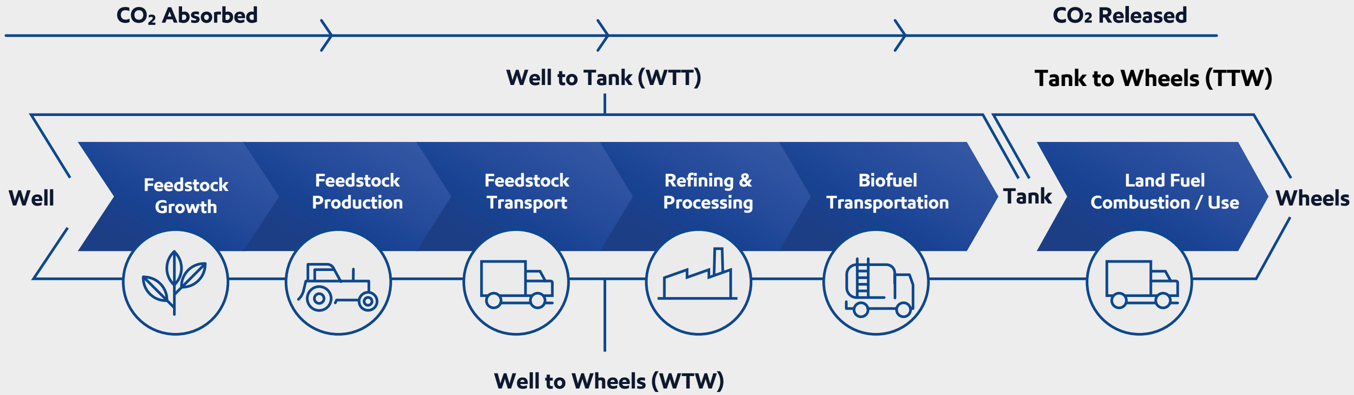
Pathways and feedstocks influence the carbon intensity of biofuels

Increasingly, policymakers are establishing more standardized approaches for the lifecycle analysis of products like biofuels, which account for the GHG emissions along the entire chain, covering sourcing, distribution, and use of the products. Canada's federal Clean Fuel Regulations use an Environment and Climate Change Canada (ECCC) developed LCA model. Canadian provincial systems use the GHGenius Model. In California, California GREET (CA-GREET 3.0) life cycle model is used to calculate estimated GHG emissions for differing transport fuels under California's Low Carbon Fuel Standard (LCFS). The European Union's Renewable Energy Directive includes a WTW formula and some default values for different types of biofuels.

Figure 26 shows in conceptual terms how lifecycle analysis is applied to biofuels.

Figure 26
Lifecycle approach to biofuels emissions

Biofuel Lifecycle Analysis
During the biofuels lifecycle, CO_2 released in the combustion phase of the product is at least partly abated by absorption in the growth phase, meaning biofuels often have a lower carbon intensity than conventional fuels



Source: ExxonMobil illustration.

06

Biofuels are supported by certification agencies and voluntary schemes

Responsible sourcing of bio-feedstocks has an important bearing on the overall societal benefits of biofuels as part of a strategy to reduce lifecycle fleet GHG emissions.

Voluntary Sustainability Certification Schemes like the ISCC (International Sustainability and Carbon Certification) issue Proof of Sustainability (POS) documentation that can indicate sourcing and associated carbon intensity of biofuels. Carbon Intensity estimates can be calculated following ISCC methodology. Policy (e.g. the European Union's Renewable Energy Directive) may also determine the applicable methodology.

Voluntary assurance schemes like RFAS (The Renewable Fuel Assurance Scheme run by Zemo Partnership, a public-private partnership in the UK) seek to fill the gap between ISCC certification at production level and the transfer of these products through the supply chain to multiple end users.

Section Three in Brief

Biofuels as a portfolio solution for lowering lifecycle GHG emissions from commercial fleets

- Biofuels can play an important role in reducing lifecycle GHG emissions from land transport and demand is expected to grow.
- Different choices of bio-feedstocks are available, from 1st generation crops to cover crops and waste oils, to the emerging potential of cellulosic materials and 3rd generation feeds like algae and seaweed.
- Different feedstocks may require different production pathways.
- Various types of biofuel are available for commercial fleets, with different production pathways and differing levels of carbon intensity.
- The assignment of carbon intensity values of biofuels is also impacted by the models adopted by policymakers in various jurisdictions.
- Certification schemes help document carbon intensity and feedstock origins of different biofuels. Voluntary assurance schemes play an important role in auditing the pass through of biofuels and their associated carbon intensity benefits to end users through a complex supply chain.

Section Four

Biodiesel has a role to play in reducing lifecycle GHG emissions from commercial fleets, with some limitations

01
What is biodiesel?

Biodiesel is what most people think of when they talk about biofuels for commercial applications. Biodiesel's technical name is FAME (Fatty Acid Methyl Ester).

Biodiesel has been questioned for quality and performance, in part from examples of people "brewing" their own biodiesel in the back garden, something we would not recommend. Modern biodiesel production is significantly more controlled and sophisticated than that.

Whilst biodiesel has some apparent constraints, we do believe all solutions are needed in reduce lifecycle GHG emissions from land transport. Indeed, biodiesel is already being blended into conventional diesel in many markets around the world as part of bio-mandate compliance programs.

Figure 27
End to end biodiesel (FAME) production pathway

How is Biodiesel Produced?

Source: ExxonMobil illustration.

02
How is biodiesel produced?

Biodiesel is derived from a variety of feedstocks (see the previous section). In first generation biodiesel production, the feedstock is collected, consolidated, and pre-treated before undergoing an esterification step to produce Fatty Acid Methyl Ester or FAME, which is the generic chemical term for biodiesel (see **Figure 27**).

In the critical transesterification step, triglycerides derived from the feedstock, typically vegetable oils and animal fats, react with short chain alcohol in the presence of a catalyst, usually sodium hydroxide, to produce FAME (see **Figure 28**).

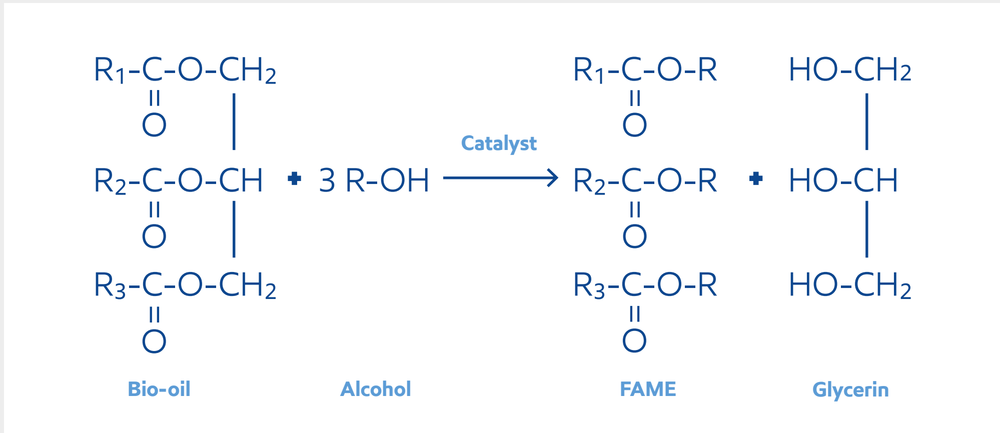
Differences in processing and feedstocks result in varying levels of contamination (see below) and different low temperature properties.

Biodiesel from SME (Soy Methyl Ester), derived from soybean oil, is most commonly available in the US. RME (Rapeseed Methyl Ester) derived from rapeseed oil, is the most common biodiesel blendstock available in Europe. PME (Palm Methyl Ester) derived from palm oil, is the most common biodiesel blendstock available in Asia.

FAME is more expensive to produce than conventional diesel due to the typically smaller scale of production and the increased effort of feedstock collation.

Unlike conventional diesel, FAME is an oxygenate and this has implications in its application. Because FAME is chemically very different from conventional diesel, national and international standards have been developed for biodiesel, as described in the next paragraph.

Figure 28
Transesterification process producing biodiesel (FAME) from bio-oils



Source: ExxonMobil illustration.

Biodiesel has a role to play in reducing lifecycle GHG emissions from commercial fleets, with some limitations

03

Biodiesel standards

Specifications like EN 14214 in Europe and ASTM D6751 in US have been defined for biodiesel.

These specifications not only establish standards for sulfur content and cold temperature properties (cold filter plugging point and cloud point) but are also designed to control contaminants specific to the biodiesel production process (acid, glycerin content, presence of catalyst, presence of free alcohol and fatty acids), ensuring products blended with biodiesel are fit for use.

04

Biodiesel blending

Biodiesel has a place in the consideration set for commercial fleets. Its use as a blendstock, at least up to 5-7%, is a step adopted in many markets to reduce the carbon intensity of diesel fuel as a class.

Pure biodiesel is often referred to as B100. It is typically used as a diesel fuel blendstock for on and off-road applications. Such biodiesel blends are designated as BX, where X represents the percentage by volume of pure biodiesel contained in the blend (e.g., B5, B20).

In many markets, the level of bio-mandate targets or carbon intensity targets in low carbon fuel standards heavily incentivize producers to blend biofuels content into the diesel pool. FAME is a more affordable blendstock than renewable diesel (see following section) and hence is typically adopted earlier than renewable diesel to meet these targets.

In most markets, FAME blending is limited to help ensure compatibility with diesel vehicles. National or International standards like EN590 in Europe and ASTM D975 in US typically state an upper limit for FAME content (7% and 5% respectively). France recently changed its national fuel quality law to permit the sale of B10 under the EN16734 standard.[35]

Section Four

Biodiesel has a role to play in reducing lifecycle GHG emissions from commercial fleets, with some limitations

05
Higher biodiesel content blends

In markets like North America in many states/provinces, higher biodiesel content blends are preferred in warmer months, with use of conventional or lower biodiesel content blends in winter conditions. B5 is blended everywhere that blending facilities exist and in locations where there are incentives/mandates for higher biodiesel content blends (such as California and Illinois), levels up to B20 can be found. B11 is common in Illinois - even during the winter - due to the sales tax exemption for >10% FAME volume diesel.

B20 and B30 blends, where available, are more commonly used in road freight operations. These biodiesel blends are covered by their own specifications, such as ASTM D7467 in the US (B6-B20), CGSB-3.522 (B6-B20) in Canada, and EN 16709 (B20-30) in Europe. In a few markets, like Indonesia, in support of domestic production, governments mandate elevated FAME contents as high as 35-40%.

At FAME contents of B20 and above, particular care is required for storage and handling of the biodiesel product as FAME attracts water. The presence of free water can encourage microbial growth. In research conducted by ExxonMobil, operators have reported operational implications at FAME contents of 20% and above, including filter blocking. The actual experience of fleet operators may depend on factors such as the FAME quality, application, and operating conditions.[36]

Globally, the level of adoption of higher biodiesel content blends is relatively small, and primarily where incentives exist to offset the higher production price, making the product more attractive from a TCO comparison perspective.

Some markets have established specifications for the use of 100% biodiesel in land transport, e.g. EN14214. France has a relatively well-developed B100 market, supported by domestic agriculture and stimulated by local rapeseed methyl ester production. Financial incentives, the local production narrative and favorable treatment in Ultra-Low Emission Zones (ULEZ) under the Crit'Aire certificate system, have helped grow the market with truck manufacturers like Renault, which produce B100-compatible truck models.

06
Advantages of biodiesel

Biodiesel has some advantages for fleets. Firstly, it offers the potential to reduce fleet GHG emissions on a lifecycle basis compared to conventional diesel. The exact emissions reduction potential depends on several factors, including the feedstock and production method. Models recognized by policymakers vary by jurisdiction, but, for illustration, under the European Renewable Energy Directive, on a well to wheels basis, rapeseed-based FAME typically is estimated to have approximately half the carbon intensity of conventional diesel. This depends on the feedstock. For example, FAME from used cooking oil can have an estimated carbon intensity reduction, well to wheels, of greater than 80%.[22]

Secondly, biodiesel has good lubricity, offering additional protection against fuel pump wear. This means that ultra-low sulfur diesel blended with 2% or more FAME content typically does not require the addition of lubricity additive to meet the minimum lubricity level for road applications.

07
Biodiesel and tailpipe emissions

The implications of biodiesel for tailpipe emissions are less clear cut. Generally, compared with conventional diesel, B100 reduces engine-out particulate emissions, but increases engine-out NO_x emissions.[37]

The EMA (Truck and Engine Manufacturers Association)[38] highlights research indicating that when biodiesel fuel is used in diesel engines not having the latest emission controls, engine-out emissions of particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO) are less than those from engines using conventional diesel fuel. The studies also show that use of biodiesel fuel blends may increase emissions of nitrogen oxides (NO_x) from those same engines. Analyses by the EMA show that NO_x levels vary depending on the biodiesel blend used and the engine duty cycle employed.

The EMA's assessment concludes that any particulate matter, hydrocarbon, and carbon monoxide emission benefits from biodiesel will be significant only for that portion of the existing diesel fleet that is not equipped with exhaust aftertreatment systems. This section of the fleet will be larger in some less-developed countries than in other more advanced markets.

08
Truck and engine manufacturer perspective on biodiesel

Whilst generally accepting of lower levels of FAME blending, engine and truck manufacturers are less supportive of the broad use of elevated biodiesel blends, on balance preferring renewable diesel. Many are happy to support 100% renewable diesel but express concern about biodiesel blends, primarily above B20 and in some cases above B5. We encourage operators to refer to their owner's manual to determine what level of biodiesel-blended product is right for their fleet.

In their position paper[39] on the Renewable Energy Directive Fuels Quality Directive, ACEA, the European Automotive Manufacturers Association, expressed concerns about expanding the availability of B10, citing vehicle compatibility with using B10 diesel as a concern. Instead of B10, they recommended a greater focus on fully compatible drop-in renewable diesel (see Section 5) that can deliver lifecycle greenhouse gas emission reductions and which the whole fleet, old and new, can use.

Engine and truck manufacturers are also concerned about the impact of biodiesel on after treatment device longevity. This is due to trace levels of metals left over from processing and naturally occurring in the feedstocks, such as vegetable oils. In response, ASTM recently approved a new low metals grade of biodiesel with a total 4ppm upper limit for sodium, potassium, calcium, and magnesium, combined.[40] This is becoming more important as many jurisdictions, for example under the US EPA Clean Trucks Plan[41], require emissions standards to be met for a longer period of time when these engines operate on the road.

The Truck and Engine Manufacturers Association (EMA), representing world-wide manufacturers of ICE and on-highway medium- and heavy-duty vehicles, recently stated[34] its position that additional performance testing will determine whether fuels with higher biodiesel content are acceptable for use in the new near zero emission engine and aftertreatment systems or if specification changes are required to improve compatibility.

Some engines can tolerate B10-B30 blends. For instance, in 2016, PACCAR endorsed use of B20 in its MX-11 engine and all model years of its MX-13 engine, both legacy models and new equipment. This followed approval in PX-7 and PX-9 engine equipped medium duty truck models. PACCAR diesel engines are sold in heavy-duty trucks under the Kenworth and Peterbilt nameplates in North America. At the time this meant around 1 million Peterbilt and Kenworth medium- and heavy-duty trucks were approved for running B20 biodiesel blends.[42]

And some modern vehicles have been specifically designed to use B100. Examples include Renault Trucks with DTI5 and DTI8 engines, assuming the biodiesel 100% option is selected, which Renault indicate can be used with EN14214 standard biodiesel.

As part of their biodiesel journey, fleets considering using B100 or B10+ blends should check with the manufacturers of vehicles in their specific fleet when making decisions on their fueling choices and fuel choice compatibility.

Biodiesel has a role to play in reducing lifecycle GHG emissions from commercial fleets, with some limitations

09
Adapting to the use of biodiesel

The oxygenates and unsaturated molecules in fuels containing higher biodiesel contents (typically B20 and above) have implications for long-term storage stability, especially for product exposed to higher temperatures, due to the risks of polymerization and oxidation.

Cold temperature performance is another consideration. FAME typically has poorer low temperature properties than conventional diesel, resulting in an elevated risk of gelling in storage.

The oxygenates in FAME also mean it has elevated affinity toward moisture content than conventional diesel. High water content in biodiesel and conventional diesel can cause problems such as water accumulation and microbial growth in fuel tanks and transportation equipment. Together with impurities that can be present in biodiesel, this can give rise to the risk of filter blocking and increased vehicle and storage tank maintenance costs (see **Figure 29**). A by-product of microbial growth is production of acids, which can cause corrosion.

Contamination from unconverted feedstock (incomplete processing), trace chemicals and byproducts from manufacture (e.g., glycerin, soaps), water from the washing process, and naturally occurring impurities such as plant sterols that are carried along with the feedstocks, are largely controlled by B100 specification limits. However, they are an important product quality consideration when choosing a supplier. A premium grade of B100 (also known as "super-FAME") is preferred for truck use in France as this grade has been subject to additional filtration to remove impurities from FAME production. Buying from a trusted supplier, with good technical capabilities and product quality standards is crucial.

Users need to elevate housekeeping routines (water draw off and tank cleaning) and use heated tanks with circulation during cold weather. They are encouraged to have their tanks cleaned before switching from conventional diesel. Similarly, users likely need to reduce drain/service intervals for their vehicles when converting from conventional diesel to a fuel with elevated biodiesel content. Residual fuel system deposits may accumulate in fuel filters due to biodiesel's higher solvency; thus, vehicle filters may also need to be replaced more frequently, at least initially.

Finally, biodiesel has lower fuel efficiency due to reduced energy content vs. conventional diesel. B100 contains about 10% less energy on a volumetric basis compared with conventional diesel. Whilst this scales down for lower biodiesel content blends, this may translate to lower fuel economy and fleets should pilot usage first in their own operations and take this into consideration in final TCO calculations.

Figure 29
Use of elevated biodiesel blends requires consideration of potential operational implications

Potential Issues:
- Fuel system corrosion.
- Fuel decomposition.
- Filter blocking.

Potential Implications:
- Premature fuel filter failure.
- Decreased overall performance.
- Decrease in engine power.

Source: ExxonMobil.

10
The experience of biodiesel users

Experiences from commercial fleets using B100 or B20+ fuels have been mixed. Some fleets who have tried these solutions went on to abandon biodiesel as a solution. For instance, the US Military tried B20 and experienced problems with biodiesel oxidation, low-temperature operability, water separation, microbial growth, and material compatibility.[43] After many years working with B20, they ultimately concluded there were substantial unexpected costs and unintended consequences with B20 use. They indicated a preference for renewable diesel instead.

On the other hand, Transport for London announced a Biodiesel program in 2015 and by 2017 approximately one third of buses in London were operating on B20.[44]

And commercial freight carriers, like G&D Integrated, a specialized transportation and logistics services provider with more than 450 trucks and 20 facilities in North America announced in 2021 it was running its diesel-powered units year-round on B20.[45]

Restaurant chain McDonald's has also been a visible champion of biodiesel, building circular economy relationships with suppliers and haulers, incorporating the collection and processing of used cooking oil from its chain. For instance, McDonald's UK aims to reach net zero emissions by 2040 for their entire business and value chain. McDonald's has used its own used cooking oil as a feedstock for biodiesel production, collaborating with its hauler Martin Brower, to run many McDonald's branded trucks on biodiesel since 2007. According to its Corporate Social Responsibility Report, Martin Brower has over 100 trucks operating in France with B100 and its entire UAE operation has shifted over to B100.[46]

Beyond buses and commercial trucking, train operating companies are also exploring biodiesel. For instance, in 2021, SNCF announced a pilot of B100 (RME) made in France on 15 Regiolis trains on the Paris-Granville line. They declared the results conclusive and in July 2022 the Normandy Regional Council approved the continued use of this product.[47]

So, fleets in a number of countries have shown that using biodiesel at blend rates of B20 and above, up to and including B100, is possible but it is evident that the quality of biodiesel used is critical, housekeeping disciplines for storage are essential, and vehicle compatibility requires close scrutiny.

Figure 30
Benefits of Esso Diesel Efficient™ B20 fuels technology in reducing microbial growth in B20 fuels

ExxonMobil's proprietary additive technology mitigates the growth of microbial growth in B20 Fuels

Unadditized B20
Week 11
mold widely distributed

Esso Diesel Efficient™ B20
Week 11
flat interphase, clear fuel

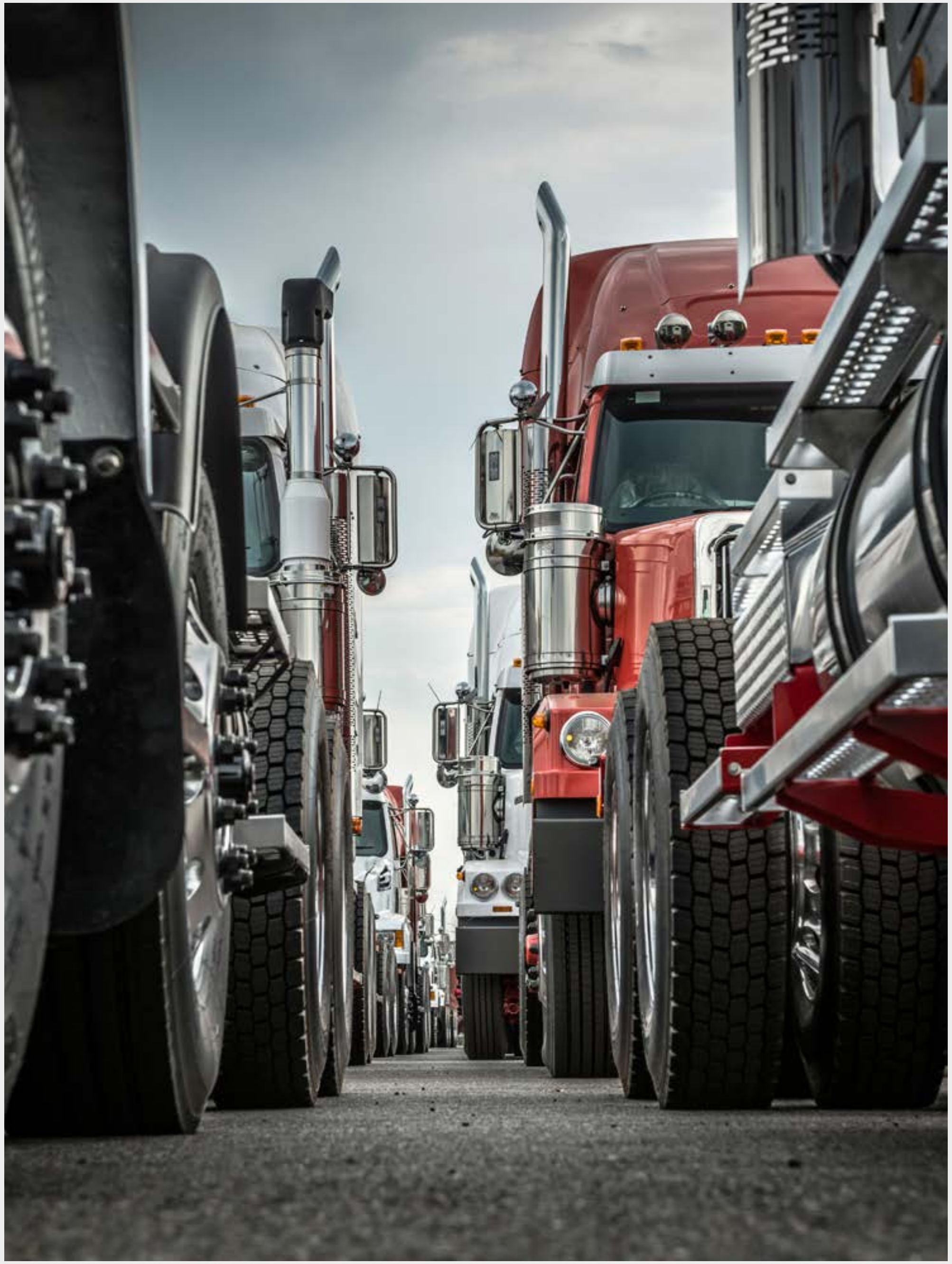
Source: ExxonMobil Research.

11
The benefits of performance technology in biodiesel

Some of the challenges associated with biodiesel blends can be addressed with additive technology. As with conventional diesel, deposits build up in injection systems using unadditized biodiesel, impacting fuel efficiency and engine out emissions (including NO_x & particulates) over time. The right detergent-based technology can help clean up these deposits, ensuring high pressure, precision direct injection systems operate as they should and optimizing fuel efficiency performance vs unadditized B20.[48]

ExxonMobil has also demonstrated the incremental benefits from its performance additive technology for storage stability, water handling, reducing microbial growth and reducing filter blocking vs unadditized B20 (see **Figure 30**). Consequently, ExxonMobil is supplying Esso or Mobil branded Biodiesel Efficient™ B20 fuel at select terminals in North America and Belgium to help meet the needs of strategic customers, incorporating the same performance additive technology which underpins its global Esso, Mobil and Exxon branded Diesel Efficient™ fuel product line.

> "Fleets in a number of countries have shown that using biodiesel at blend rates of B20 and above is possible but it is evident that the quality of biodiesel used is critical."



Section Four in Brief

Biodiesel has a role to play in reducing lifecycle GHG emissions from commercial fleets, with some limitations

- Biodiesel (technically FAME) has a role to play as part of reducing lifecycle GHG emissions from commercial fleets, representing a lower capital investment pathway, relative to many other alternatives, and more frequently deployed by industry to date.
- These solutions continue to have their place in the transport energy portfolio but are reaching blend limitations.
- Blending of biodiesel in conventional diesel at up to 5-7% by volume has been shown to be suitable for most applications without significant compromise.
- B20 can be used in compatible vehicles. Fleet managers must weigh several factors before proceeding with B20 for the first time and they must be integrated into overall TCO assessments. Where B20 is used, we recommend the use of the right performance additive technology as part of a fleet's operational strategy.
- Some commercial operators may feel neat biodiesel, B100, has its place in their strategy portfolio. This requires significant thought, careful piloting and consideration of the overall costs and benefits.
- B20 and B100 can contribute to lower lifecycle GHG emissions, but implications for fleet efficiency and productivity are important considerations and not all fleets will reach the same conclusions. A trusted supplier, with a relentless focus on product quality, is critical. Also crucial is operational commitment to manage biodiesel introduction carefully, allied with the right housekeeping and optimized servicing regimes.

Renewable diesel is an emerging solution for reductions in lifecycle GHG emissions from commercial fleets with fewer compromises

01
What is renewable diesel?

An alternative biofuel offer is emerging for land transportation that offers comparable lifecycle emissions reductions without some of the potential operational compromises associated with biodiesel. This is known as renewable diesel but is also referred to as HDRD (Hydrogenation-Derived Renewable Diesel) in North America, and HVO (Hydrogenated Vegetable Oil) in Europe. In Asia, the terms renewable diesel and HVO are becoming more recognized. We see this product gaining traction in commercial land transport and offering an attractive pathway for fleets who wish to reduce their carbon footprints ahead of, or in line with, legislative timetables.

Renewable diesel, while made from bio-feedstocks, undergoes a completely different transformation process to that involved in biodiesel production.

Chemically, renewable diesel is similar to conventional diesel but with a lower aromatic content. Critically, production largely eliminates the oxygenates, which drive many of the challenges of biodiesel. So renewable diesel can be used as a drop-in fuel, even in neat form in many vehicles. It has high storage stability and, depending on the production pathway, can offer the potential for great low temperature performance.

02
Renewable diesel production

There are different potential pathways to renewable diesel production. The most common pathway, driving production scaling today, is through hydro-processing of the bio-feeds, which come from similar sources to biodiesel.

a) Hydro-Processing Path to Renewable Diesel

Three key processes (decarboxylation, decarbonylation and hydrodeoxygenation) combine to convert the feedstocks. Dependent on the exact production methods deployed, the hydro-processing pathway (see **Figures 31**[49] **and 32**) can produce a paraffinic, high cetane hydrocarbon diesel, typically with excellent stability and cold flow properties. That being said, renewable diesel producers have different capabilities and some differences in the processes they adopt. Not all renewable diesel is produced to optimize cold flow performance or fractionated to the same degree.

Investment in biofuels is growing and shifting to hydro-treating / HEFA (Hydrotreated Esterified Fatty Acids) pathways to produce renewable diesel (RD) and sustainable aviation fuel (SAF).

While more capital intensive, the resultant renewable diesel can be used as a higher percentage blend stock or in neat 100% renewable diesel form. This opens a route for further lifecycle GHG emissions reduction potential versus conventional diesel in existing vehicles (see later in this section).

b) Co-Processing

Another pathway for renewable diesel production is co-processing. It is the simultaneous transformation of renewable feedstocks with conventional crude through manufacturing process units to produce intermediate or final products with renewable content. This can represent an effective option to drive the societal goal of lowering greenhouse gas emissions.

Co-processing at existing facilities has benefits versus standalone production, allowing existing facilities to produce volumes of product with renewable content at the scale and potential speed needed to support society's growing goals. In this pathway a proportion of end distillate production can be designated as renewable diesel.

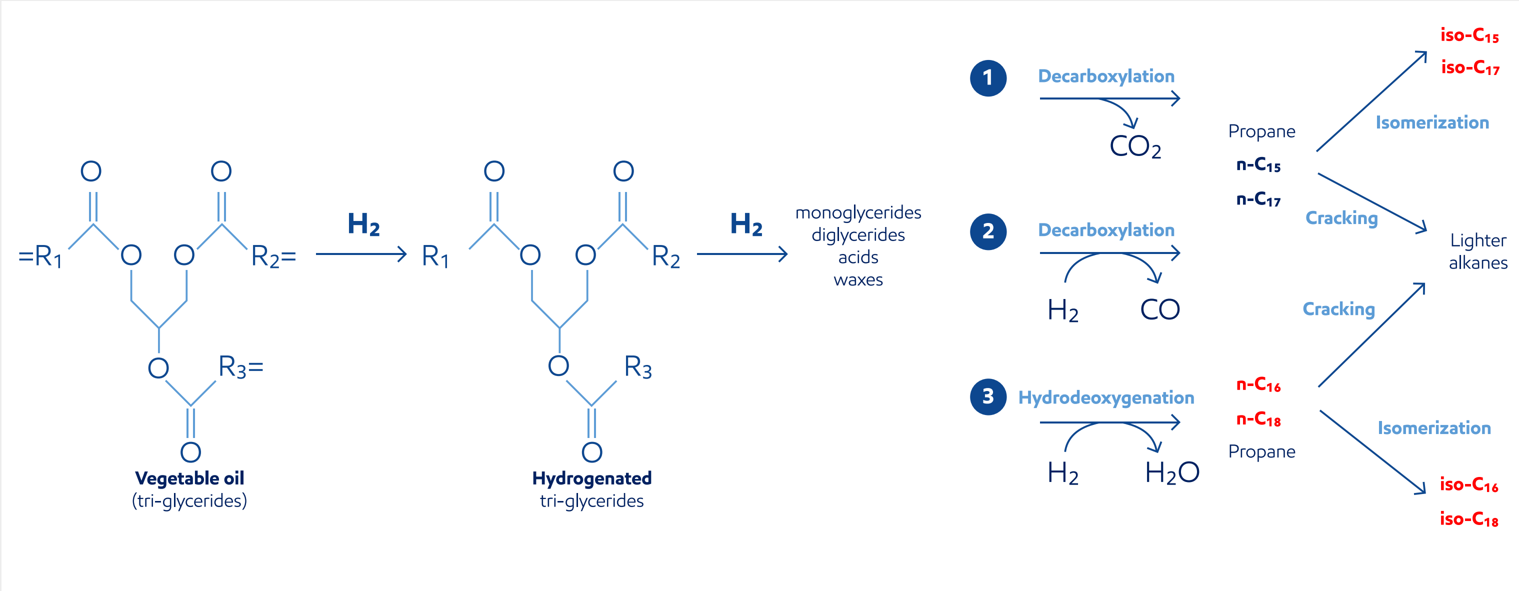
Co-processing depends on policy and prevailing regulatory frameworks. Policymakers have a role in defining the methodologies and protocols governing renewable diesel designation and carbon intensity/footprint value of co-processed product. These guidelines must be lifecycle based, technology neutral, and grounded in sound science.

Amongst the benefits of co-processing, is that it allows increased supply of renewable fuels at lower levels of investment in pre-existing facilities.

ExxonMobil is already working to adopt this pathway in locations like its Gravenchon refinery in France. In Canada, Imperial Oil (an ExxonMobil majority-owned affiliate) has successfully piloted co-processing[50] at its refineries, using bio feedstock alongside conventional feed to produce co-processed commercial fuels.

Figure 31
Molecular redesign to produce renewable diesel via hydrotreating[49]

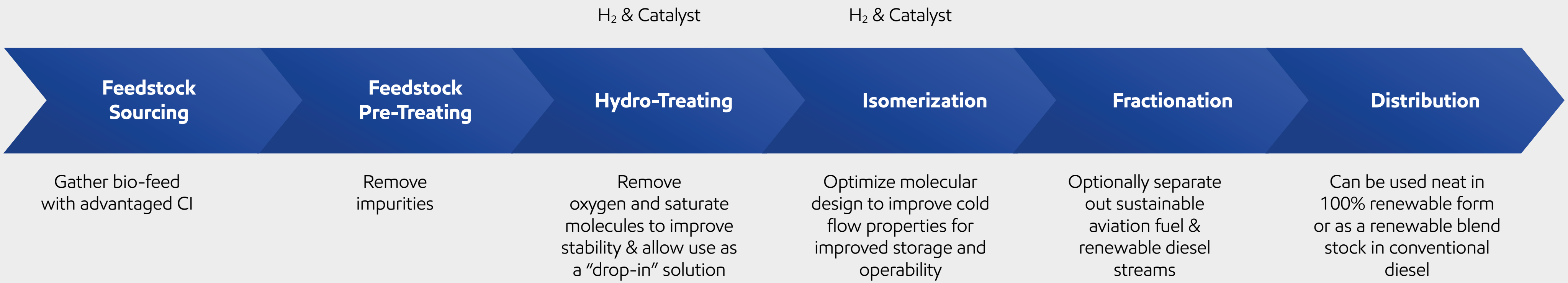
- The most common way to produce renewable diesel is hydro-treating or hydro-processing.
- **Hydro-processing** saturates double bonds & removes oxygen from the tri-gylcerides in vegetable oil, the most common feedstock.
- It does this via three key pathways, **decarboylation, decarbonylation & hydrodeoxygenation**.



Source: Illustration derived from Huber et al 2007.[49]

Figure 32
Simplified renewable diesel production process flow (bio-feed hydro-processing pathway)

How is Renewable Diesel Produced?



Source: ExxonMobil illustration.

c) Biomass Gasification

Whilst not in scale production today, another emerging future pathway to renewable diesel is biomass gasification. This is a process that converts biomass into syngas (a mixture of carbon monoxide and hydrogen). This is achieved by reacting the feedstock material at high temperatures (typically >700° C), without combustion, controlling the presence of oxygen and/or steam in the reaction. Syngas can be turned into synthetic liquid hydrocarbon fuels, via the Fischer Tropsch process. When this process is incorporated with carbon capture and storage (CCS), the lifecycle carbon intensity of the renewable diesel produced is very attractive (and can even potentially result in negative WTW GHG emissions, i.e. removing more CO_2 from the atmosphere than is produced upon combustion).[51] Gasification with CCS is an example of BECCS (Bioenergy with carbon capture and sequestration).

Whilst more energy intensive than existing hydro-processing pathways, one of the benefits of gasification is it reduces reliance on first generation bio-feeds and opens up second generation cellulosic materials (see Section 3, sub-section 3d). Furthermore, as noted above, it has the potential to achieve negative WTW GHG emission pathways that could further help societal GHG emission reduction ambitions.

More capital intense pathways like BECCS are expected to come to market slower and later than HEFA pathways but likely to become attractive based on lower effective feedstock costs and higher CO_2 abated so, over time, a much bigger role for gasification is anticipated, depending on supportive regulatory developments.

d) Pyrolysis

One additional process that looks attractive longer-term is pyrolysis. In this process, biomass is heated rapidly at high temperature (500-700C) in an oxygen-free environment. Vapors are cooled and condensed into a liquid pyrolysis oil (also known as Bio-Pyoil), which can be used to produce renewable fuels.

03
The growth in renewable diesel production

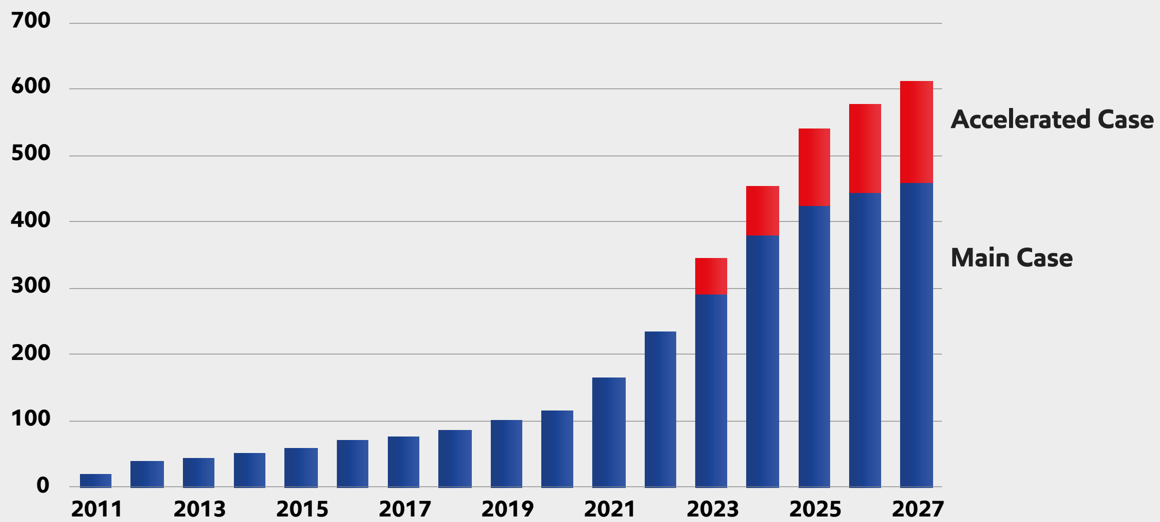
Driven to date primarily by the hydro-processing pathway, renewable diesel production is growing fast globally with new capacity coming on stream in North America, Europe, and Asia Pacific (see **Figure 33**).[52]

IEA projections (accelerated and main case) depend on different potential policy pathways.

As production scales, renewable diesel consumption is growing, including commercial sales of renewable diesel blends or 100% renewable diesel (also known as R100 or HVO100) for off- and on-road applications via in-yard and retail/truck stop channels. In the Netherlands there are now over 100 public access stations[53] selling renewable diesel. In California, supported by incentives and the Californian LCFS standard, the renewable diesel network is growing fast and approaching 600 stations by end April 2024.[54]

Unlike in the Netherlands and California, in some markets, regulators have restrictions on the sale of renewable diesel. The use of renewable diesel in Germany, for example, in commercial fleets was restricted until recently for testing purposes. In March 2024, The German Bundesrat amended regulations to allow HVO100 sales.[55] In markets like Belgium and France, usage is restricted to captive fleets and in-yard sales. As confidence in renewable diesel as a solution grows, these restrictions are expected to ease.

Figure 33
IEA projection of global renewable diesel production through 2027 (KBD)[52]



Source: IEA analysis.[52]

Renewable diesel is an emerging solution for reductions in lifecycle GHG emissions from commercial fleets with fewer compromises

04
Renewable diesel production, a case study – Strathcona

Recognizing the need for solutions for reducing GHG emissions in heavy transportation in Canada, Imperial Oil, an ExxonMobil majority-owned affiliate, is building a world-class renewable diesel facility at its Strathcona refinery in Alberta.[56,57,58]

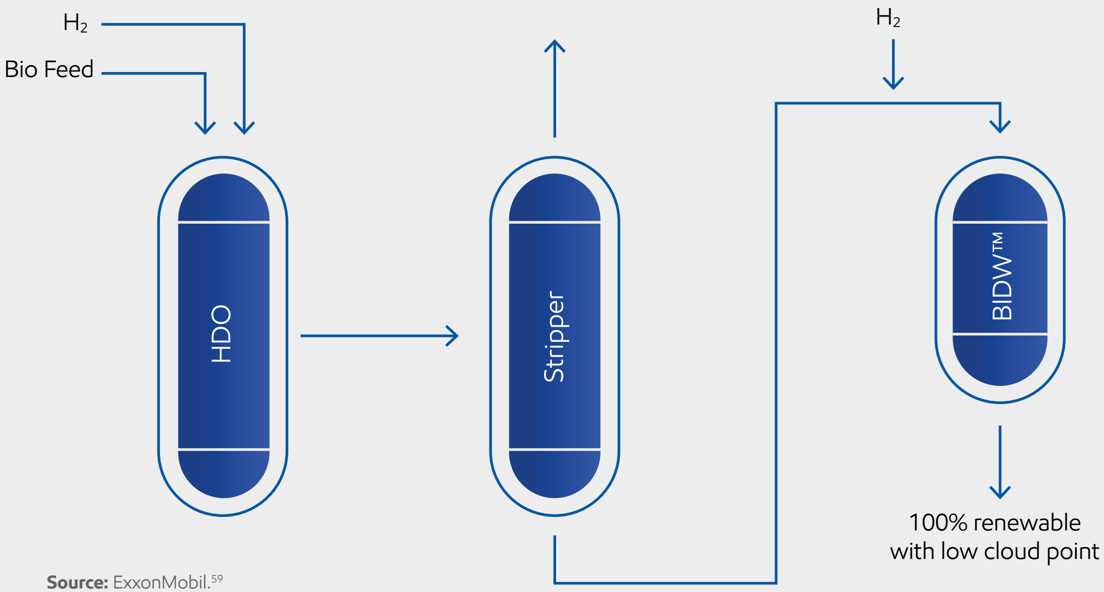
This cutting-edge facility will use locally-sourced bio-feedstock, supplemented by blue hydrogen with carbon capture and storage technology, to create lower-emission renewable diesel that functions similarly to its traditional diesel counterpart. When completed, the project is expected to have a capacity of more than 1 billion liters renewable diesel annually.

Not all renewable diesel is the same. Strathcona will benefit from ExxonMobil's proprietary catalyst technology, optimizing yields and delivering excellent cold temperature properties. The benefits of ExxonMobil's renewable diesel technology are summarized in **Figure 34 and 35**.[59]

Strathcona Refinery renewable diesel project

Figure 34
ExxonMobil's proprietary renewable diesel production technology advantages[59]

EMRD™ process



Source: ExxonMobil.[59]

Figure 35

ExxonMobil's proprietary renewable diesel production technology advantages[59]

High yield

- Two stage process has a higher diesel yield versus a single stage process.
- BIDW dewaxing catalyst has exceptional ability at deep delta cloud to retain diesel product and avoid cracking.

Operating flexibility

- Two stage process design allows for separate control of hydrotreating and dewaxing operations.
- A separate hydrotreating step enables better control, optimization, and flexibility compared to a single stage process, with the ability to remove contaminants before the dewaxing catalyst.

Efficient process design

- BIDW dewaxing catalyst has a high selectivity to isomerization, which consumes less H_2 than cracking.
- Improved process design, unit operations, and technical support when hydrotreating and dewaxing operations are provided by a single solution provider.

EMRD™ process technology configuration

- **Stage 1**
  Hydrodeoxygenation (HDO) step to convert triglycerides to n-paraffins.
- **Stage 2**
  Selective isomerization of the n-paraffins to iso-paraffins to improve cold flow properties.
- **Catalyst**
  The EMRD™ process utilizes ExxonMobil's BIDW dewaxing catalyst suite.

Advantages

- Two stage process provides flexibility to adjust operating conditions as needed for changing objectives.
- Handles variations in product cold flow properties due to different feed types or to address new requirements.
- Extended dewaxing catalyst lifetime due to customized conditions and contaminant control.
- Potential to produce jet if fractionation is added.
- EMRD process technology enables operational costs to be lowered through reduced hydrogen consumption in the dewaxing step due to the selectivity of BIDW™ to isomerization rather than cracking.
- EMRD process technology meets operational requirements while minimizing equipment sizing and capital costs.

Services include

- Initial consultations and proposal development.
- Basic engineering package, including design specifications.
- Technical support during FEED, and EPC stages.
- Technology training, catalyst loading and start-up support.
- Unit monitoring support.

Source: ExxonMobil.[59]

05 Renewable diesel specifications

Unlike for biodiesel, in North America there is currently no separate renewable diesel specification. Renewable diesel must meet the diesel specification of ASTM D975.

ASTM D975 was not designed with renewable diesel in mind — it just so happens that renewable diesel meets the requirements. Any renewable diesel (or blends) sold in North America must at a minimum meet ASTM D975 requirements.

By contrast, in Europe, EN15940, a paraffinic diesel specification, has been established, which defines the quality requirements of renewable diesel and other paraffinic fuels such as Gas-to-Liquid (GTL) diesel.

In practice, in North America, most purchasers will create an internal purchase specification that combines the D975 requirements with some of the more restrictive requirements from EN 15940. Common additional purchaser requirements are a maximum aromatics content, density range, and cold flow requirements.

Renewable diesel meeting EN15940 also has higher cetane number and lower density than conventional diesel due to its lower aromatic content.

In Asia Pacific, renewable diesel is currently generally produced to meet European or North American standards as local demand currently remains limited by lack of supportive policy.

Renewable diesel is an emerging solution for reductions in lifecycle GHG emissions from commercial fleets with fewer compromises

06
Feedstocks and carbon intensity of renewable diesel

As with biodiesel, the carbon intensity of renewable diesel depends on the feedstock, its source, the transportation of feedstock, the production process, and the transportation of the finished product.

Models, such as Argonne National Laboratory's GREET model, help guide calculation of estimated renewable diesel carbon intensity based on feedstock and pathway.[60]

Production from non-edible, waste-based feedstocks including used cooking oil, typically offer lower carbon intensities relative to production from other feedstocks. Calculations and estimates vary between models and across jurisdictions but, by way of illustration, EU's RED II (Renewable Energy Directive II) assign to renewable diesel from used cooking oil a default carbon intensity reduction vs conventional diesel of 83% and a typical reduction of 87%.[22]

The carbon intensity of renewable diesel is dependent upon production pathways. Lower carbon intensities can be achieved when using lower GHG emission H_2 in hydrotreating or gasification pathways and/or using gasification pathways in conjunction with CCS.[60,61]

07
Renewable diesel and tailpipe criteria pollutant emissions

Research by CARB highlighted that renewable diesel fuel's high cetane number and low aromatic content can result in lower NO_x emission levels for pre-2010 on-highway and pre-Tier 4 non-road engines compared with those from conventional diesel fuels.[37,38] South-West Research Institute (SWRI) reported in 2023 that 100% renewable diesel fuels significantly reduced soot loading rates on the Diesel Particulate Filter (DPF). They highlighted that this would likely lead in turn to a lower active regeneration frequency for the DPF under part-load transient duty cycles, the implication being less fuel consumption associated with active regeneration, and possibly improved durability of the downstream SCR system due to less high temperature exposure.[62]

08
Renewable diesel blends

Bio-mandates in Europe, and low carbon fuel standards in California, Washington, Oregon, New Mexico and British Columbia mean that renewable diesel is being used as a blend stock for compliance purposes in many markets.

For end customers renewable diesel blends may offer an attractive pathway to fleets looking to lower their operational carbon intensity. In North America, the percentage of renewable diesel blended into conventional diesel is recognized by the naming convention RX, where X represents the volume percentage of the renewable diesel that has been blended. Accordingly, R30 represents a 30% by volume blend of renewable diesel in conventional diesel.

In Europe, where renewable diesel is also referred to as HVO (Hydrotreated Vegetable Oil), the product is more typically classified as HVOX, for example HVO30, a 30% by volume blend of renewable diesel in conventional diesel. Asia Pacific typically follows the North America convention.

The density of renewable diesel in Europe is typically around 780 kg/m^3 and hence lower than allowed in the EN590 diesel fuel specification. Accordingly, this may limit the percentage of renewable diesel, which can be blended to around 30% or less. This is dependent on the actual density of the conventional diesel used, if the resultant blend is to meet the higher EN590 minimum density specification.

In addition to its production plans in Canada, ExxonMobil currently has branded renewable diesel offers in several markets globally, including the Netherlands, the UK, Singapore, and Italy, with plans for further introductions in other markets in collaboration with strategic customers (see **Figure 36**).

Figure 36
Examples of renewable diesel product deployments by ExxonMobil affiliates & brand partners globally

Product availability as of August 29th 2024 except as otherwise noted. Find more information on your regional Esso or Mobil website.

*Product not presently available as part of our fuel product offerings; expected to be available in 2025.

Source: ExxonMobil.

Renewable diesel is an emerging solution for reductions in lifecycle GHG emissions from commercial fleets with fewer compromises

09
The vehicle and engine manufacturer perspective on using 100% renewable diesel

Its molecular make up means 100% renewable diesel (R100) is a superior product for use in modern trucks vs. 100% biodiesel (B100) and many engine and vehicle manufacturers support R100 use in regular production engines.

In 2016 and 2017, Cummins, for instance, confirmed the compatibility of 100% renewable diesel meeting EN15940 with Euro 6 engine technology (Cummins F3.8, B4.5, B6.7 and L9 engines) after an extensive test program running on 100% HVO renewable diesel meeting EN15940. This was followed by approval in August 2023 of use of R100 in all its larger industrial high-horsepower engines.[63]

Also in 2016, Mercedes-Benz Trucks approved the use of renewable diesel (HVO) in the US for trucks fitted with its in-line six-cylinder engine variants of the Mercedes-Benz OM 470, OM 471 (first generation) and OM 936 as well as the in-line four-cylinder variants of the OM 934 meeting the Euro VI emissions standard.[64]

In 2015 Volvo Trucks North America approved the use of renewable diesel in all their proprietary engines and more recently announced the use of renewable diesel as factory fill in their diesel-powered trucks.[65] In Europe in 2015, after significant testing, Volvo certified all its Euro V engines for use with renewable diesel and EN15940 HVO100 is certified for all new Euro VI Volvo truck engines with no engine issues or service interval changes.[66]

ACEA, representing European vehicle manufacturers, is more favorable of renewable diesel than biodiesel.[67] The international Truck and Engine Manufacturers Association (EMA) acknowledges that renewable diesel fuels "show great promise". It highlights similarity to conventional petroleum-based diesel fuel, eliminating certain concerns with biodiesel and other properties such as high cetane and low aromatic content that may be advantageous.[68]

10
Other considerations in using renewable diesel

European renewable diesel meeting EN15940 has a lower density and slightly lower energy content so some fleets may see a small reduction in fuel efficiency, likely to be imperceptible in blends, but potentially noticeable when using R100.

Relative to biodiesel, the main challenge renewable diesel may face is cost. Even for a relatively small production capacity, renewable diesel production start-up requires more capital investment than bringing biodiesel production on-stream. Even absent of investment cost, renewable diesel is more expensive than biodiesel given the extra processing steps.

However, in many markets, bio-mandates, low carbon fuel standard credits and other regulatory incentives make renewable diesel a more attractive commercial proposition.

Given it can be used without the need to buy new vehicles, make fleet or storage adaptations, or reduce vehicle service intervals, renewable diesel offers the potential for reduction in lifecycle GHG emissions (see 6. above) versus conventional diesel, and can leverage existing infrastructure, renewable diesel can be an attractive proposition.

It also offers potential as a flexible turn-key solution for use in trucks for specific end customers with more ambitious plans to reduce lifecycle GHG emissions. This is a significant factor amongst early adopters.

Renewable diesel is an emerging solution for reductions in lifecycle GHG emissions from commercial fleets with fewer compromises

11

Adoption of renewable diesel to reduce commercial transport GHG emissions

To meet their own GHG emissions reduction goals, and those of the companies whose goods they are moving, many fleets globally are seeing renewable diesel as an attractive proposition. Publicly-announced examples of use and/or trial of renewable diesel across different countries include:

Benelux

- Logistics specialist, H. Essers is using HVO100 as part of an insetting program for their shippers, working with shippers like Nike.[69]
- Soft drinks company Coca Cola Europacific Partners announced a collaboration with its local transport suppliers in the Netherlands (Van Rijen, Zandbergen, Snel Logistics Solutions, and T-Trex) to run their truck fleet on HVO100.[70]
- Restaurant chain McDonalds, announced a collaboration with logistics partner Havi on circular recycling of used cooking oil into HVO100.[71]
- Package delivery company Post NL is leveraging palm-free HVO100.[72]

UK

- Soft drinks company, Coca Cola EuroPacific Partners, announced[73] in 2022 it is working with MJD Group to use HVO100 for their truck operations.
- Competing soft drinks company PepsiCo UK announced in Nov 2022[74] it will power more than 1M miles of truck journeys each year with used cooking oil based renewable diesel, working with its haulage partner, Pollock (Scotrans). The announcement states that HVO will replace diesel in trucks travelling between the Quaker Oat mill in Cupar and Leicester, home of Pepsico subsidiary Walkers.
- Mining company and plasterboard manufacturer British Gypsum announced in October 2022[75] plans to convert 40% of its UK fleet to renewable diesel (HVO). British Gypsum is part of Saint Gobain.

US

- Oregon-based logistics company Titan Freight Systems announced in 2021 the switch to renewable diesel across its operations with favorable TCO outcomes without the need to make any vehicle or infrastructure modifications.[76]
- In November 2022, truck leasing company, Penske, announced[77] availability of renewable diesel across 32 refueling locations in California, noting it found an overall net positive effect on the vehicles related to renewable diesel, including reduced maintenance-related issues along with the added benefits of lower overall emissions.

Singapore

- In 2023, teaming up with ExxonMobil, secured logistics company, Certis, became the first organization in Singapore to use Esso Renewable Diesel R20 (R20), trialing the 20% renewable diesel blend across a fleet of ten vehicles.[78]

> " HVO100 is a very viable alternative to traditional Diesel fuel; it is the best alternative that we can think of until 2030, and still a very good one till 2035 — as these trucks will last long. "

CEO, automotive logistics specialist, Netherlands[79]

> " I am an evangelist for HVO100. There are absolutely no barriers to adoption. "

Fleet manager, Public Fleet, California[79]

> CSG and environmental aspirations of the customer are big factors. The customer is really important. They are the ones who are going to pay for you to invest in these things ... Renewable diesel is the lowest risk. It is not a completely different truck. It's not a significant capital investment ... If you have got any uncertainty ... that feels like the safest thing to do. If you are running overnight vehicles on your primary network and you are going to the other side of the country, quite a few of the other options are not viable for you. Going to these fuels feels like the safest option.

Manager, Large Truck Fleet for major brand, UK[80]

> 1st generation biodiesel comes with constraints. Maintenance of trucks is different – a lot of engines are ready to use but the maintenance cost goes up. It requires a dedicated tank which is a constraint. 10-15% of bulk fuel is HVO100 today ... If the customer is ready to pay a little more for benefit of decarbonization, it is simple and efficient. The big difference is HVO is miscible so we can use the same tank and periodically drop in the HVO ... there is no impact on maintenance and no extra consumption whereas for 1st gen biodiesel we saw over-consumption.

Purchasing Director, Large France-based European Specialist Logistics Service provider[80]

> Biofuel for us is an extremely good way for us to go to reduce our carbon footprint. For example, Sweden has been using HVO for quite a while now and we are looking at it for other countries too. It is interesting because it doesn't imply additional investments as you can use it with your diesel trucks. And if you don't have access to HVO then you can just use diesel either way .... We did tests, several of them for quite a long time now – it is going pretty well.

Procurement Manager, Large European Dairy Group[80]

Figure 37
The end user experience with renewable diesel

a) On-Road Experience

To share with you a wider range of feedback, ExxonMobil collaborated with Frost and Sullivan to interview 15 commercial truck fleets who have used renewable diesel in their operations in the US and various European markets.[79]

Overall Experience:
Frost and Sullivan reported that experience of these commercial fleets with renewable diesel was very promising. Each fleet is different (operating varying fleets with a range of duty cycles in a range of markets) and their perspectives unsurprisingly varied to some degree. But there were common themes to their feedback.

Efficiency:

- Usually, no difference in fuel consumption.
- Some users report slightly lower, or slightly higher consumption.

Performance:

- Reports on performance are good.

Emissions:

- Reports of fewer regenerations, reduced DEF consumption and longer after-treatment life in modern diesel trucks. Reduced tailpipe emissions (NO_x and Particulate Matter) in older trucks.

Handling and User Experience:

- Some report favorably on no odor / no smell of the exhaust gases, and lower engine noise by operators whose vehicles are idling or operated in a confined environment.
- Storage experience is excellent. No algae / no bacteria in contrast to biodiesel.

They used Renewable Diesel as part of an Integrated Strategy:

- The fleets' choice to use renewable diesel does not stand-alone, but part of their broader sustainability plan covering installations, routes optimization, vehicles specs and a (relatively) methodical review of different fuel / powertrain alternatives, based on suitability of solution.

They regard Renewable Diesel and Biodiesel as complementary, not competing:

- Biodiesel use is essentially limited to blends, limiting scalability. Their perception of biodiesel's reputation appears to be a potential deterrent from both a user's and the public's standpoint. Renewable Diesel is seen as drop in fuel which means scalability, can be used neat, and can be sourced from waste products.
- Renewable Diesel may be preferred over Renewable Natural Gas as the latter requires special equipment (truck, refueling), and implies an additional technology diversity that is particularly unwelcome in a period in which fleets will introduce BEV; again, an advantage for HVO100.

Most continued to use Renewable Diesel post an initial trial period:

- Post trial adoption was ~70% in fleets interviewed, with non-adopters pursuing a focus on other solutions, like battery electric vehicles, and increased focus on intermodal operations, or a pivot towards sustainable aviation fuel in wider operations.

b) Off-Road Application

Off-road, ExxonMobil recently collaborated with Finning, the world's largest Caterpillar dealer, to test the use of renewable diesel in haul truck operations as shown in **Figure 38**.[81]

Figure 38
Renewable diesel case study – haul trucks in Alberta, Canada

- Imperial Oil collaborated with the Finning, the world's largest Caterpillar dealer on the potential for renewable diesel as a practical solution for helping the Canadian mining sector's productivity and lower lifecycle GHG emission ambitions.
- They worked together to trial renewable diesel in CAT haul trucks at the Kearl oilsands mine in Alberta.
- The results confirmed that this equipment can operate on a fully renewable fuel, with similar equipment power and performance.*



* All trial results and comparisons throughout are renewable diesel compared to conventional diesel fuel. Actual benefits will vary depending on factors such as vehicle/engine type, driving style and diesel fuel previously used. Consult the original equipment manufacturer (OEM) for guidance on compatibility with renewable diesel.

Source: Imperial Oil & Finning Trial.[81]

12

Enablers for scaling renewable diesel adoption

Renewable diesel is an emerging solution for reductions in lifecycle GHG emissions from commercial fleets with fewer compromises

Amongst managers of medium to large heavy-duty commercial fleets, renewable diesel's lifecycle GHG emission reduction potential and performance are perceived as the key reasons to consider switching. However, there are barriers that are commonly highlighted around biofuels for land transport (see **Figure 39**). These can be linked back to different dimensions of the productivity, efficiency, sustainability model for land transport (see **Figure 20**):

Productivity (uptime and reliability)

- Limited network of / access to biofuels solutions "where and when I need them."
- Engine / Truck manufacturer acceptance and implications for warranties.
- Confidence in performance.
- Implications for maintenance intervals.

Efficiency (cost/Ton mile):

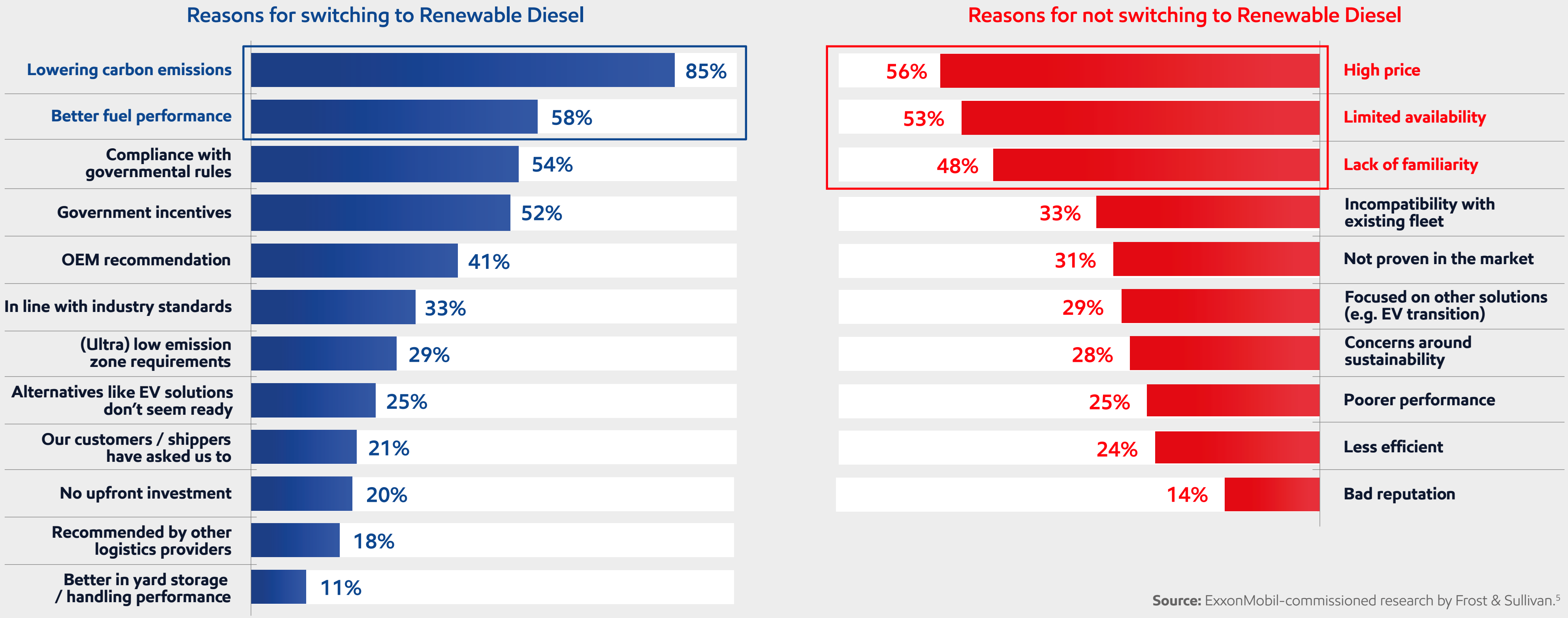
- Price and TCO competitiveness with ZEV solutions and/or conventional diesel.

Sustainability

- Sustainable sourcing of biofuels.
- Traceability of claims around emissions and the percentage of renewable fuel content.

Figure 39
Renewable Diesel: Reasons for and against switching[5]

Please rank the top 5 potential reasons that would make you switch to HVO / Renewable Diesel and the top 5 reasons you would not consider switching



Source: ExxonMobil-commissioned research by Frost & Sullivan.[5]

Whilst many fleets have navigated these kinds of questions, we share our thoughts for those who are still thinking through the issues.

a) Accessibility — Opening up renewable diesel in restricted markets

Not all markets support the sale of biofuels like renewable diesel (HVO) in public access stations. Some, like France, restrict sales to captive fleets, with in-yard fueling. This limits the potential for fleets with a mix of use-cases including on-road fueling to maximize usage of biofuels should they wish. In some markets, like Germany, as of 2023, use of renewable diesel remained prohibited with the exception of testing purposes. In 2024, the German regulations were amended to allow HVO100 sales.

We believe this restricts the potential for fleets seeking to accelerate their GHG emissions reductions to do so and encourage regulators to review these restrictions.

b) Infrastructure costs — The potential for mass balance solutions for fleets

Today, renewable diesel sales are mainly limited to segregated storage/distribution. We see no reason why renewable diesel could not be sold in the same way as say renewable natural gas or renewable electricity, leveraging grid/gas network systems and effective verification and traceability.

We are willing to work with third party assurance schemes to build out systems to support such applications.

c) Warranties — Engine / Truck manufacturer acceptance of renewable diesel

A rising proportion of truck models are approved for using renewable diesel.

Renewable Diesel is widely acceptable at blends of up to R30 (30% by volume) as being interchangeable with conventional diesel. Many newer engine platforms have been approved for use with R100, so long as the finished product meets industry diesel standards.

ExxonMobil is working with equipment manufacturers and distributors in off-road sector to demonstrate performance of RD and BD blends.

d) Traceability along the supply chain — The rise of assurance schemes

We support the development of reassurance schemes which provide an independent oversight of biofuels suppliers. We think this can add confidence to biofuels as a solution. Industry associations, public-private collaborations, and/or consultancies may step in to provide this kind of service.

An example is the Zemo Partnership in the UK and its Renewable Fuel Assurance Scheme (RFAS). Zemo offers a standardized process and third party audit of RFAS Renewable Fuel Declarations. This oversight gives confidence in sourcing, lifecycle GHG emissions savings and ensuring the renewable nature of product received.[82]

e) Confidence in performance — Differentiation via performance technology

We believe that the growing experience of fleets using renewable diesel, and sharing some of their learnings in this white paper, should build confidence over time.

As in Europe, defining a specification for renewable diesel in US should add confidence to the renewable diesel proposition and lock in performance differences compared with conventional diesel.

ExxonMobil testing shows that, as with conventional diesel, renewable diesel can leave deposits in fuel injection system which can impact fuel efficiency and engine out emissions over time.

These deposits can be cleaned up with the right performance additive technology, which offers extra protection against deposits and corrosion, adding confidence to adoption of renewable diesel as a portfolio solution to reduce lifecycle GHG emissions from commercial fleets.

f) Affordability and TCO — The expansion of bio-mandates and low carbon fuel standards

Biofuels like renewable diesel are inherently more expensive to produce due to the complexity of aggregation of feed stocks, production scale, and logistics. Without policy support to level the playing field, the cost of biofuels makes adoption by fleets a less affordable proposition in comparison to conventional fuels.

Markets like California and British Columbia have significantly incentivized biofuels production by introduction of LCFS programs.

In Europe, under REDII and the associated country mandates, bio-blending contributes towards compliance and mandate levels are rising. This is allowing renewable diesel to be made available on a more competitive basis versus conventional diesel. As noted above, The Netherlands now has more than 100 public access stations selling renewable diesel HVO100[53].

We continue to encourage governments for supportive policy which incentivizes investment and innovation to provide solutions to the marketplace.

As the playing field is levelled, adoption and production of lower GHG emission fuels grows as we have seen across many markets. This also helps lower GHG emission fuel accessibility.

Section Five in Brief

Renewable diesel is an emerging solution for reductions in lifecycle GHG emissions from commercial fleets with fewer compromises

- Renewable Diesel offers an emerging solution for fleet lifecycle GHG emission reductions with many advantages.
- Renewable Diesel is different from biodiesel, being chemically similar to conventional diesel and without the oxygenates which give rise to many of biodiesel's drawbacks.
- There are different pathways to renewable diesel. Today, renewable diesel is predominantly produced by hydrotreating bio-feeds. Some is produced via co-processing. Gasification with carbon capture and storage of cellulosic bio-feeds offers potential as an attractive future pathway to lower carbon intensity renewable diesel.
- Renewable diesel production is growing rapidly, including co-processing operations, such as at ExxonMobil's Gravenchon refinery in France, and the startup of a large-scale renewable diesel unit at Imperial Oil's Strathcona Refinery in Canada.
- Renewable diesel can be blended at higher percentages than biodiesel, whist still meeting existing diesel specifications and the needs of existing fleets. A number of fleets are taking advantage of R20-30 blends to reduce lifecycle GHG emissions as a drop-in solution.
- As many vehicle/engine manufacturers are now accepting of 100% renewable diesel for use in modern lower emission diesel engines, R100 is increasingly part of the plans established by fleets and brands to meet fleet GHG emission targets as a drop-in solution without associated capital investments.
- Many opportunities exist to accelerate the adoption of renewable diesel in markets around the world. A collaborative approach across the ecosystem, between producers, marketers, regulators, assurance schemes, commercial fleets, and shippers, is a key enabler.

Summary

Planning your journey to lower emission operations

Forward-thinking fleet managers will already be evaluating their options for reducing fleet emissions. However, what is clear is that for most operators there won't be a single route towards lower GHG emissions from their operations.

As we've already seen, mixed fleets and complex operational patterns will require a range of solutions, now and in the future. From additized diesel to new vehicles running on novel fuel formulations, the range of options is large and increasingly complex. Also, fleet managers may choose a staged progression between choices over time as infrastructure is built and regulatory policies evolve.

ExxonMobil therefore suggests that fleet managers assess their short- to long-term options to help devise a path that meets both their operational requirements and emission reduction goals.

With this in mind, operators should generally first look at relatively simple measures that can be implemented today, and can make a difference, including:

- A renewed focus on fuel efficient driving practices, underpinned by driver training.
- Running the fleet on detergent-additized diesel.
- Use of high-performance lubricants.

Based on this foundation, fleet managers will typically go a step further, by:

- Establishing fuel efficiency and GHG emissions goals.
- Increasing emphasis on data analytics and telematics.
- Enhancing attention to reducing empty miles driven.

Taken together, these measures can help enhance fleets' day-to-day operations, improve efficiency, lower operating costs and lower emissions per mile driven.

From there, fleet managers could establish a roadmap for progressive adoption of lower-emission technologies, which are increasingly playing a role in helping meet their GHG emissions targets. These include:

- Accelerating the replacement of older, less fuel efficient tractors with higher tailpipe emissions.
- Considering biodiesel blends or renewable diesel to lower lifecycle GHG emissions from the diesel fleet.
- Evaluating alternatives like battery electric, bio-LNG or hydrogen-powered vehicles.

There are pros and cons to all options, so fleet managers will need to fully assess the alternatives – in terms of availability, cost, and suitability – before choosing the best combination for their specific fleet. The determining factors may change over time, so it will be important to reassess decisions as technologies evolve.

For the longer-term, managers can start to replace portions of their fleet with new vehicles designed to run on lower-emission fuel options. Some operations will be more suitable than others for this transition. Fleet managers will consider a number of factors, including:

- Sustainability goals, with a particular emphasis on achieving emissions targets, and the speed of the fleet's transition plan.
- Lighter-duty vs. heavier-duty.
- Operating range/routing.

Due to the complexities involved, and the potential operational ramifications if sub-optimal decisions are made, it is essential that fleet managers work with technology suppliers that have a proven track record of supporting their customers with the fuel options they need, when and where they need them.

Comparing solutions for commercial fleets

We realize all this is a lot to take in, so we have summarized below a high-level directional comparison between conventional diesel, biodiesel, and renewable diesel options available to commercial fleets today (see **Figure 40**).[83]

Figure 40
Directional comparison of different diesel solutions[83]

Directional

Diesels Compared	Conventional Diesel	Additized Diesel[(a)]	Biodiesel (B100)[(b)]	Renewable Diesel (R100)[(c)]
European Specification	EN590	EN590	EN14214	EN15940
US Specification	ASTM D975	ASTM D975	ASTM D6751	Per Diesel
Vehicle Compatibilty[(d)]	All Diesel	All Diesel	Adapt/Change	Good % Compatibility
Cetane	Baseline	Baseline	Similar or Better	Best
Cold Flow Properties	Baseline	Baseline	Usually Inferior	Similar to Diesel
Storage & Handling	Baseline	Baseline	Adaptation Required	Better
Fuel Efficiency	Baseline	Improved	Lowest	Lower[(e)]
Engine Out NO_x Emissions	Baseline	Lower	Higher	Similar or Lower
Lifecycle GHG Emission Saving Potential[(f)]	Baseline	Baseline	Better	Better

(Results vary dependent on fleets, specific fuels, feedstock & production methods and fleet operating practices)

Source: ExxonMobil analysis.

a) Modelled off Esso Diesel Efficient™ fuel. Other additised diesel fuels may have different formulations and properties. Esso Diesel Efficient™ fuel benefits are based on internal and third-party vehicle engine testing, laboratory testing, and/or industry or other scientific literature. Basis for comparison for all claims is versus Esso™ unadditised diesel. Vehicle type, engine type, driving behavior, and other factors also impact fuel and vehicle performance, emissions, and fuel economy. Esso Diesel Efficient™ fuel may be used in all heavy-duty and light-duty vehicles, but results may vary. Fuel economy testing was performed in the UK using road-trucks (Euro III and Euro V specifications). Product offerings and availability vary by region.
b) Product specifications including cetane vary according to local regulations. Depends on supplier & quality level. Properties shown assume EN14214 vs EN590. Note D6751 is primarily designed to be a specification for use of B100 as a blendstock.
c) Product specifications including cetane vary according to local regulations. Depends on supplier & quality level. Properties shown assume EN15940 specification renewable diesel vs EN590 diesel.
d) Check with vehicle manufacturer for specific models.
e) Actual experiences of commercial fleets with renewable diesel may vary with some fleets reporting no difference in consumption.
f) Additised diesel with the potential to improve fuel economy can help reduce CO_2 tailpipe emissions per mile driven. Indicated lifecycle emissions for biodiesel and renewable diesel are based on biofuel content. Depends on feedstock, production method & policy. For our qualitative GHG comparisons, EU Renewable Energy Directive (2018/2001/EU) ANNEX V has been used to compare the greenhouse gas emission saving default values vs conventional diesel for 100% biodiesel & 100% renewable diesel from comparable used cooking oil feedstock sources.

A vision for the future

At ExxonMobil, we develop and deploy technology solutions that help meet society's needs. Today, that means providing products that are needed for modern life, reducing our own greenhouse gas emissions and developing technologies to advance a lower-GHG emissions future. For more detail on our corporation's plans we draw your attention to our Advancing Climate Solutions Report.[84]

We're pursuing more than $20 billion in lower-emission investments from 2022 through 2027 across a number of sectors, technologies and geographies. About 50% of our lower-emission investments are targeted at reducing emissions from operated assets, with the balance going toward reducing the emissions of other companies. We're focused on customers in the heavy industry, power generation, and commercial transportation sectors. These sectors provide great economic value and generate significant emissions that aren't easy to cut. Together, these sectors account for about 80% of energy-related CO_2 emissions today. Carbon capture and storage, hydrogen, biofuels, and lithium align with our capabilities and have the potential to make a big difference in these hard-to decarbonize sectors.

With advancements in technology and the clear and consistent government policies that support needed investments and the development of market-driven mechanisms, ExxonMobil aims to achieve net-zero Scope 1 and Scope 2 greenhouse gas (GHG) emissions in our operated assets by 2050, backed by a comprehensive approach centered on developing detailed emission reduction roadmaps for major operated assets.

Our land fuels business

Our Product Solutions land fuels business currently markets lower emission fuels in multiple countries around the world such as the US and Canada in North America, to the UK and the Netherlands in EAME, to Singapore and Indonesia in Asia Pacific. We are excited about our plans and the ecosystem collaborations that are enabling them and look forward to continuing the productive conversations, which can lead to lower lifecycle GHG emissions solutions in the sector.

To learn more about our land fuels plans, we invite you to follow our ExxonMobil Global Land Fuels LinkedIn page so we can share ecosystem developments, input from those we work with and updates on product solutions we are bringing to market.

We look forward to hearing from you.

You can follow ExxonMobil Global Land Fuels on LinkedIn.

Appendix

Definitions

Fuel Terminology

Biodiesel (B100): Renewable, biodegradable form of diesel typically manufactured by trans-esterification of plant oils, waste oils and/or animal fats (tallow). Also known as FAME (Fatty Acid Methyl Ester). The product is not hydrotreated before blending and contains oxygen.

Biofuel: Fuel produced from biomass, including waste vegetable oils and animal fats (such as used cooking oil). Examples include Biodiesel, Renewable Diesel, Renewable Natural Gas etc.

Biomass: A feedstock comprised of organic matter derived from living or recently living organisms; e.g. wood, crops, algae.

Bx: Biodiesel blend into conventional diesel at x vol% biodiesel, e.g. B10.

Compressed Natural Gas (CNG) and Liquified Natural Gas (LNG): Natural gas stored in compressed gaseous form and liquified form, respectively.

eFuels: Broad category of synthetic fuels that includes fuel produced from green H_2 which is combined with CO. The CO comes from CO_2, either from direct air capture or from a point source. The Point source is generally biogenic for a lower CI. The fuels produced include methane, methanol, ethanol, gasoline, jet, diesel, or various chemicals. This procedure is now commonly known by the terms Power-to-X (PtX), Power-to-Liquids (PtL) and Power-to-Gas (PtG).

H_2 (Hydrogen): Fuel used for land transportation in ICE engines or more commonly in fuel cell electric vehicles (FCEV). Like natural gas, hydrogen can be stored in compressed or liquified form. The carbon intensity of H_2 is influenced by the production process and colors are often used as a shorthand for the production pathway, e.g. Grey H_2, from natural gas SMR (steam methane reformation), Blue H_2 from SMR or ATR (autothermal reformation) with Carbon Capture and Storage (CCS), Green H_2 from electrolysis of water using green electricity (e.g. solar, wind, geothermal, hydro-power), Pink H_2 from electrolysis of water using nuclear power.

Liquefied Petroleum Gas (LPG): Fuel gas in liquified form, principally propane and/or butane.

Renewable Diesel (RD, R100): Drop-in form of diesel, made from same feedstocks as biodiesel (vegetable oil, waste, residues). Primarily produced through hydro-processing edible and waste oils but can be produced through pathways like gasification. The hydro-processing step removes impurities and oxygenates which means, unlike biodiesel, it can be used more interchangeably with conventional diesel, and has good cold weather performance. Also known as **HDRD** (Hydrogenation-Derived Renewable Diesel), and **HVO** (Hydro-treated Vegetable Oil).

Renewable Energy: Energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.[28]

Renewable Fuel: Renewable fuels include liquid and gaseous fuels and electricity derived from renewable biomass energy sources. Examples include ethanol, biodiesel, cellulosic diesel and compressed natural gas and electricity from renewable biomass.[85]

Renewable Natural Gas (RNG): Also known as biogas, RNG is a renewable form of natural gas (primarily methane) usually captured from anaerobic digestion in a landfill or from livestock manure. Can be used for land transport.

Rx: Renewable diesel blend into conventional diesel at x vol% renewable diesel, e.g. R30.

Biofuels Production Related Terminology

BECCS: Bioenergy with carbon capture and sequestration (CCS). Gasification with CCS is an example.

Cellulosic feed: Feedstock that contains cellulose including forestry waste, agricultural waste, and municipal solid waste (MSW). Can be used for gasification or pyrolysis.

Co-processing: Utilization of bio-feedstock in conjunction with traditional crude oil / petroleum feedstock in fuel production to help reduce the overall carbon intensity of the end-products produced. The bio-feed can be inserted at different points in the production process (e.g. hydro-treating) depending on the refinery configuration and the desired products.

Gasification: Process that converts biomass into syngas (mixture of carbon monoxide, and hydrogen. This is achieved by reacting the feedstock material at high temperatures (typically >700°C), without combustion, controlling the presence of oxygen and/or steam in the reaction. Syngas can be turned into synthetic liquid hydrocarbon fuels, via the Fischer Tropsch process.

Hydro-processing: Refining process, using hydrogen in the presence of catalyst, to remove sulfur and oxygen from fuel products.

Pyrolysis: Process in which biomass is heated rapidly at high temperature (500-700C) in an oxygen-free environment. Vapors are cooled and condensed into a liquid pyrolysis oil (also known as Bio-Pyoil) which can be used to produce renewable fuels.

Commercial Transport Terminology

Battery Electric Vehicle (EV): Electric vehicle powered by a rechargeable battery.

Fuel Cell Electric Vehicle (FCEV): Electric vehicle that uses a fuel cell, sometimes in combination with a small battery or supercapacitor, to power its onboard electric motor. Fuel cells in vehicles generate electricity generally using oxygen from the air and compressed hydrogen.

Heavy-Duty (HD): Category of heavy road transportation, typically for commercial carriage of freight.

Intermodal: Use of successive modes of transport (e.g., ocean ship, inland waterway, air, rail, trucking) to move goods within one and the same loading unit without handling of the goods themselves when changing modes.

Internal Combustion Engine (ICE): Engine in which fuels are burned (e.g., gasoline, diesel) through spark ignition or compression to release energy and cause motion.

Light-Duty (LD): Category of lighter road transportation, primarily 2-4 wheelers including motorbikes, cars and small vans.

Medium-Duty (MD): Category of road transportation at intermediate load levels, including smaller buses and trucks.

Total Cost of Ownership (TCO): Estimate of the expenses associated with purchasing, deploying, operating, maintaining and retiring a product or piece of equipment, across the product's entire lifecycle. TCO can be calculated as the initial purchase price plus costs of operation across the asset lifespan and takes into account resale value. It is key measure used by commercial transport companies in selecting between vehicles and fueling choices.

Vehicle Emissions Control Terminology

Diesel Exhaust Fluid (DEF): DEF is a liquid used to reduce the amount of air pollution created by a diesel engine. Specifically, DEF is an aqueous urea solution made with 32.5% urea and 67.5% deionized water. DEF is consumed in a selective catalytic reduction (SCR) that lowers the concentration of nitrogen oxides (NO_x) in the diesel exhaust emissions from a diesel engine. DEF is widely marketed under the trade name AdBlue™.

Diesel Oxidation Catalysts (DOCs): Exhaust aftertreatment devices reducing tailpipe emissions from diesel fueled vehicles and equipment. Generally, consist of a precious metal coated flow-through honeycomb structure contained in a stainless-steel housing. As hot diesel exhaust flows through the honeycomb structure, the precious metal coating causes a catalytic reaction breaking down pollutants into less harmful components. DOCs promote oxidation of exhaust gas components - carbon monoxide (CO), hydrocarbons (HC), and the organic fraction of diesel particulates (OF). In modern diesel aftertreatment systems, an important function of the DOC is to oxidize nitric oxide (NO) to nitrogen dioxide (NO_2), a gas needed to support the performance of DPFs and SCR catalysts used for NO_x reduction.

Diesel Particulate Filter (DPF): Filter that captures and stores exhaust soot to reduce tailpipe emissions from diesel engines. DPFs only have a finite capacity, so trapped particulates are periodically 'burned off' to regenerate the DPF, reducing the harmful exhaust emission and helps to prevent black smoke emissions during acceleration.

Exhaust Gas Recirculation (EGR): Technique to reduce NO_x tailpipe emissions. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. The exhaust gas displaces atmospheric air, reducing O_2 in the combustion chamber, in turn reducing the amount of fuel that can burn in the cylinder, thereby reducing peak in-cylinder temperatures. The amount of recirculated exhaust gas varies with the engine operating parameters. In modern diesel engines, the EGR gas is usually cooled with a heat exchanger to allow the introduction of a greater mass of recirculated gas.

Selective Catalytic Reduction (SCR): Technique for reducing nitrogen oxide (NO_x) tailpipe emissions from diesel engines. Static mixers are widely used in SCR systems before reactors to promote the mixing of ammonia and exhaust streams.

Emissions Related Terminology

Assurance Scheme: Independent program which audits renewable fuel claims including feedstock origin and GHG emissions reductions through the supply chain. Examples include the Renewable Fuels Assurance Scheme (RFAS), run by the Zemo Partnership in the UK.

Carbon Intensity (CI): Measure of lifecycle GHG emissions, expressed in units of CO_2 equivalent (CO_2e) emissions per unit of energy. It is usually expressed per megajoule of energy. CO_2e is used to normalize Greenhouse Gases such as methane to a recognized Global Warming Potential (GWP) value by applying universally accepted conversion factors. It is a measure of the GHG potential of all emissions, not just CO_2.

Greenhouse gas emissions (GHG): Emissions expressed in CO_2e, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (NO_x).

GREET: The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET™) suite of models developed by The Department of Energy's Argonne National Laboratory. These models are a publicly available tool to assess lifecycle emissions associated with a wide range of energy sources and production pathways.

Indirect Land Use Change (ILUC): Occurs when cultivation of crops for biofuels, bioliquids and biomass fuels displace traditional production of crops for food and feed purposes. This additional demand may increase the pressure on land and can lead to the extension of agricultural land into areas with high carbon stock such as forests, wetlands and peat land causing additional lifecycle GHG emissions.[86]

Life Cycle Assessment (LCA): A life cycle assessment (LCA) is a holistic method to assess environmental aspects and quantify potential environmental impacts throughout a product's defined life cycle.

Lower Emission Fuel (LEF): Fuel which has lower lifecycle GHG emissions compared to conventional fuel as measured by lifecycle analysis.

Tank To Wheels Emissions (TTW): GHG emissions, expressed in CO_2e/MJ, from the use (combustion) phase of a fuel - also known as vehicle exhaust or tailpipe emissions.

Well To Tank Emissions (WTT): GHG emissions, expressed in CO_2e/MJ, associated with fuel production and distribution to the end user vehicle refueling point.

Well To Wheels Emissions (WTW): Full lifecycle assessed fuel GHG emissions, expressed in CO_2e/MJ.

Zero Emissions Vehicle (ZEV): Vehicle which emits no CO_2, particulates, or NO_x from the exhaust/tailpipe. Battery Electric Vehicles and Fuel Cell Electric Vehicles are classed as Zero Emissions Vehicles.

References

1 Mobility Reimagined, on the road to lower GHG emissions (2023).

2 IEA Global EV Outlook 2022.

3 "Former Life of the Electric Car" Scientific American 303, 2, 51 (August 2010).

4 2021 average marginal costs per mile. American Transportation Research Institute's (ATRI) Report Operating Costs of Trucking.

5 ExxonMobil commissioned research by Frost & Sullivan of 157 fleets with 50+ heavy-duty trucks across UK, Germany, Benelux, France, Norway and Italy – 4Q23-1Q24.

6 IEA CO_2 Emissions in 2022 Report, IEA Tracking Transport Tracking 2023.

7 ExxonMobil Gobal Outlook Our View to 2050 (2023).

8 World Economic Forum 2016.

9 Road freight activity forecast 2050 | Statista.

10 NACFE 2022 Annual Fleet Fuel Study.

11 ExxonMobil analysis of interviews and various sources (including NAFCE, British Retail Consortium Net Zero Logistics Report, 2021)

12 Fuel Efficiency Technology in European Heavy-Duty Vehicles: Baseline and Potential for the 2020–2030 Time Frame Oscar Delgado, Felipe Rodríguez, and Rachel Muncrief. July 2017.

13 See for example TransportPolicy.net.

14 Omidvarborna; et al. (2014). "Characterization of particulate matter emitted from transit buses fueled with B20 in idle modes". Journal of Environmental Chemical Engineering.

15 Council Directive 93/12/EEC of 23 March 1993 relating to the sulfur content of certain liquid fuels.

16 Council Directive 1999/32/EC of 26 April 1999 relating to a reduction in the sulfur content of certain liquid fuels and amending Directive 93/12/EEC".

17 The Sulphur Campaign | UNEP - UN Environment Programme.

18 ExxonMobil Commercial fleet card reseller's research of 186 customers in 2022 across multiple countries in Europe.

19 Benefits apply to Mobil or Esso Diesel Efficient™ branded fuel compared to diesel fuel without detergent additive with the same level of renewable content. Actual benefits will vary depending on factors such as vehicle/engine type, driving style, diesel fuel previously used, and other factors. Concentration and availability of our proprietary additive package may vary based upon factors beyond our control. Product offerings and availability vary by region.

20 See UN Theme Report on Energy Transition "Towards the Achievement of SDG7 and net-zero emissions, 2021.

21 JEC Well to Wheels Methodology JEC is a collaboration of JRC, EUCAR and CONCAWE. JRC, 2015, European Commission, Joint Research Centre, IET,Sustainable Transport Unit, Marelli, L., Padella, M., Edwards, R., Moro, A., Kousoulidou, M., Giuntoli, J., Baxter, D., Vorkapic, V., Agostini, A., O'Connell, A., Lonza, L., 'The impact of Biofuels on transport and environment, and their connection to the agricultural development in Europe'. Report prepared by JRC-IET for the European Parliament.

22 For emissions factors for biofuels like biodiesel, HVO, renewable natural gas or biomethane, see, for example, Renewable Energy Directive 2018/2001/EU Annex V.

23 IEA Electric Market Report 2023.

24 See for instance, Unlocking hydrogen's power for long-haul freight transport | McKinsey (Aug 2022).

25 Imperial Newsroom - FLO teams with Imperial to support Canada's emissions reduction goals (imperialoil.ca).

26 ExxonMobil drilling first lithium well in Arkansas, aims to be a leading supplier for electric vehicles by 2030.

27 Low-carbon hydrogen: Fueling our Baytown facilities and our net-zero ambition | ExxonMobil.

28 See for example Revised Renewable Energy Directive (EU/2023/2413).

29 https://nature.berkeley.edu/classes/es196/projects/2007final/MillerJ.pdf.

30 US National Restaurant Association Report 2020.

31 See for instance, AHDB, an introduction to cover crops.

32 Cover Crop Fact Sheet 2018 (usda.gov) & Cover Crop Trends, Programs, and Practices in the US (2021) (usda.gov).

33 See for example, Underutilized Feedstocks Are Key To Renewable Fuels Growth (oliverwyman.com).

34 See for instance Prabakaran et al 2023. "Algae biofuel: A futuristic, sustainable, renewable and green fuel for I.C. engines".

35 B10 diesel fuel: vehicle compatibility list - ACEA - European Automobile Manufacturers' Association.

36 ExxonMobil-commissioned research of mining operators in Indonesia, 2023.

37 CARB "Biodiesel Characterization and NO_x Mitigation Study" October 2011.

38 EMA - Facts You Should Know About Biomass-Based Diesel - March 2023.

39 ACEA Position Paper on RED FQD, Nov 2022.

40 See latest ASTM D6751 standards.

41 Heavy-Duty 2027 and Beyond (www.epa.gov).

42 Biodiesel Magazine, Jan 2016.

43 For example, USAF Experience with Biodiesel Blends (B20). Emilio Alfaro Presentation to ASTM Dec 2017. U.S. Army and Department of Defense Interim Report May 2014.

44 London Mayor Biodiesel Report 2016.

45 Commercial Carrier Journal, March 2021.

46 McDonalds press releases and Martin Brower 2022 CSR Report.

47 SCNF Update Jan 2023 (SCNF.com).

48 See Mobil Diesel Efficient for details on additive technology benefits as applied to conventional diesel. Product offerings and availability vary by region.

49 George Huber et al, 2007.

50 Imperial announces progress with RD project, coprocessing trials | Biomass Magazine.

51 See for example Shahbaz et al. Oct 2021. A comprehensive review of biomass based thermochemical conversion technologies integrated with CO_2 capture and utilization within BECCS networks.

52 IEA Renewables 2022 Report (Dec 2022).

53 HVO 100 Stations in Netherlands (glpautogas.info).

54 Alternative Fuels Data Center: Alternative Fueling Station Locator (energy.gov).

55 Argus Media (March 2024) Germany allows HVO100, B10 diesel at public pumps.

56 Low Carbon Solutions | ExxonMobil.

57 ExxonMobil 2023 - The-road-to-renewable-fuel.

58 Imperial Oil Canada - Renewable Diesel.

59 EMRD™ renewable diesel process technology | ExxonMobil Product Solutions (exxonmobilchemical.com).

60 For more about the GREET model, see GREET | Department of Energy, GREET: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model | Department of Energy.

61 ACS.org. Hui Xu et al May 2022 "Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States".

62 Characterization of Fuel Impacts on Heavy-Duty Low NO_x Emission Engines - CRC Final Report - July 2023.

63 See Cummins Press Release May 2017, Cummins Press Release Aug 2023.

64 Biodiesel Magazine, Feb 2016.

65 Volvo Trucks Press Release (2015), truckinginfo.com (June 2015), Volvo Trucks press Release (April 2024).

66 ZEMO Renewable Fuels Guide.

67 ACEA Position Paper on RED FQD, Nov 2022.

68 Facts You Should Know About Biomass-Based Diesel (EMA) 2023.

69 H.Essers HVO100 Insetting.

70 Coca Cola NL Press Release Feb 2022.

71 FoodBev Media 2020.

72 Post NL Sustainability News.

73 CCEP Press Release.

74 Commercial Fleet, 2022.

75 British Gypsum Press Release 2022.

76 TITAN Freight Systems Goes Renewable.

77 Penske Press Release Nov 2022.

78 Certis Group first to trial renewable diesel in Singapore.

79 ExxonMobil-commissioned research by Frost and Sullivan in 4Q23. Frost and Sullivan interviewed 15 commercial trucking fleets who have used Renewable Diesel in their fleet operations.

80 Direct ExxonMobil interviews of representatives of large heavy-duty European fleets in 2Q2024.

81 For further background please see ExxonMobil Global Land Fuels LinkedIn.

82 Renewable Fuels Assurance Scheme | Fuels | Zemo Partnership.

83 (a) Modelled off Esso Diesel Efficient™ fuel. Other additised diesel fuels may have different formulations and properties. Esso Diesel Efficient™ fuel benefits are based on internal and third-party vehicle engine testing, laboratory testing, and/or industry or other scientific literature. Basis for comparison for all claims is versus Esso™ unadditised Diesel. Vehicle type, engine type, driving behaviour, and other factors also impact fuel and vehicle performance, emissions, and fuel economy. Esso Diesel Efficient™ fuel may be used in all heavy-duty and light-duty vehicles, but results may vary. Fuel economy testing was performed in the UK using road-trucks (Euro III and Euro V specifications). Product offerings and availability vary by region. (b) Product specifications including cetane vary according to local regulations. Depends on supplier & quality level. Properties shown assume EN14214 vs EN590. (c) Product specifications vary, depending on supplier, quality level & local specifications. Properties shown assume EN15940 specification renewable diesel vs EN590 diesel. (d) Check with vehicle manufacturer for specific models. (e) Actual experiences of commercial fleets with renewable diesel vary with some reporting no difference in consumption. (f) Depends on feedstock, production method & policy. For our qualitative GHG comparisons, EU Renewable Energy Directive (2018/2001/EU) ANNEX V has been used to compare the greenhouse gas emission saving default values vs conventional diesel for 100% biodiesel & 100% renewable diesel from comparable used cooking oil feedstock sources.

84 ExxonMobil Advancing Climate Solutions Report, 2024.

85 Derived from US EPA Renewable Fuel Standard Program Overview.

86 See COMMISSION DELEGATED REGULATION (EU) 2019/807 of 13 March 2019 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council.

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