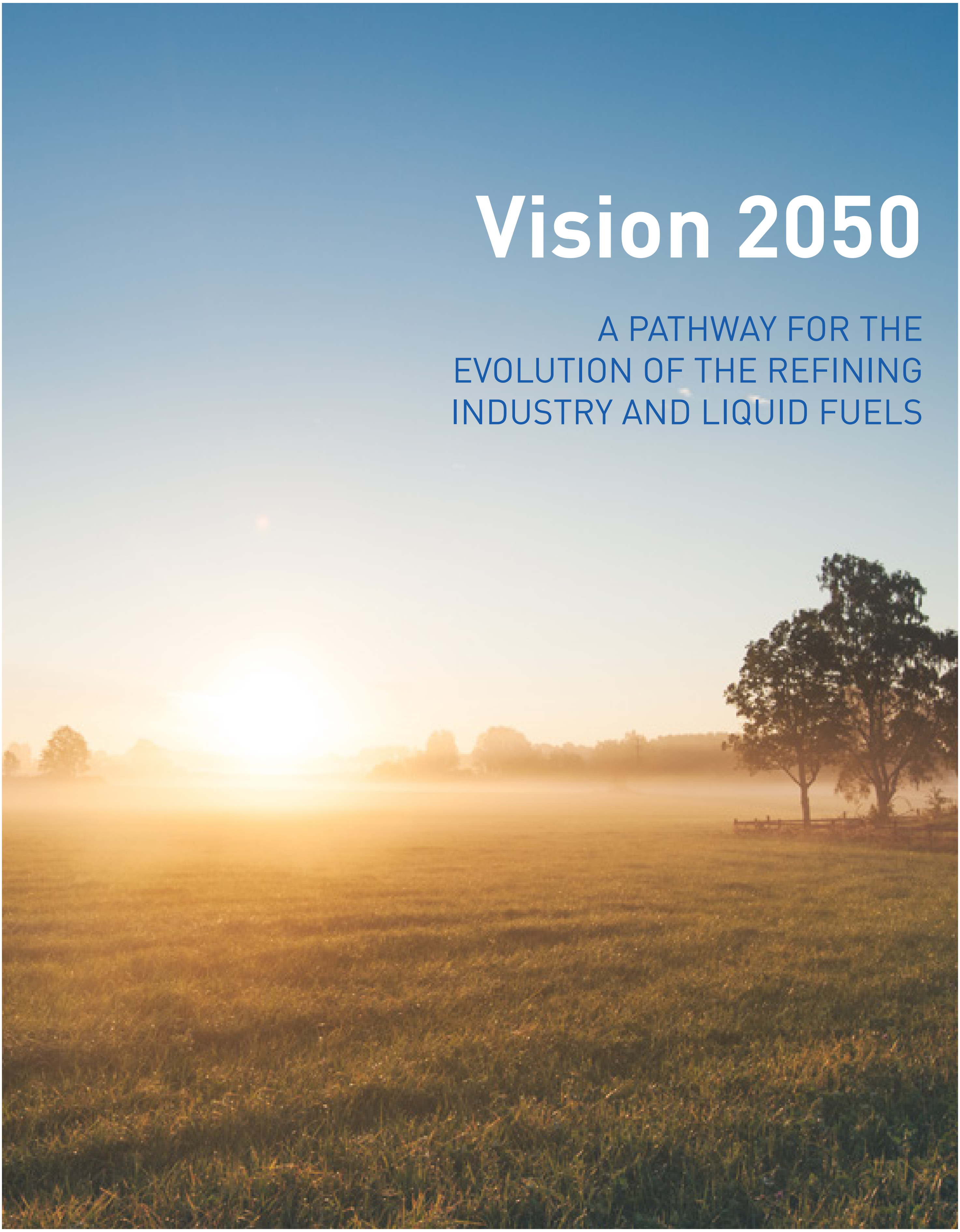

Vision 2050

A PATHWAY FOR THE EVOLUTION OF THE REFINING INDUSTRY AND LIQUID FUELS

FuelsEurope
REFINING PRODUCTS FOR OUR EVERYDAY LIFE

EXECUTIVE SUMMARY

The EU established a goal in the framework of the Paris Agreement to lead the world in addressing global climate change. The European refining and distribution industry is committed to contributing to the achievement of this objective.

The global demand for liquid hydrocarbons – as fuels for transport, as petrochemical feedstock and for other uses – is expected to increase until at least 2040. These products have an unrivalled energy density and are easy to transport, making them an ideal means to carry and store energy. While alternatives are being developed for some of their current uses (e.g. in passenger cars, where electrification is expected to play a major role), liquid hydrocarbons remain difficult to replace in heavy-duty and marine transport, in aviation and as a feedstock for the petrochemical industry.

It is therefore of great importance for the EU's energy and industrial value chain, as well as for its citizens, that the carbon emissions of liquid hydrocarbons be progressively reduced. The EU refining industry is well placed to evolve its business model consistently with this objective, by increasingly using combinations of new feedstocks – such as biomass and vegetable oils, waste and captured CO_2 in very efficient manufacturing. It can also expand its use of renewable electricity and hydrogen on-site and further exploit synergies with other industries in integrated clusters. The flexibility and resilience of the refining industry infrastructures, including those for the distribution of products, will allow this transformation to occur at a comparatively low cost and with immediate benefits in terms of CO_2 reduction.

The EU refining industry is already engaged in a low-carbon transition, through investments in R&D projects and the early deployment of new technologies. These technologies, which have already been proven at different technology readiness levels (TRL), need to be implemented at scale. Innovative solutions will allow the use of new feedstocks and will cut greenhouse gas (GHG) emissions from refineries as well as from the use of their products. In the process, the EU will develop and reinforce its global leadership in low-carbon technologies, which will be exported around the world where they are needed.

A view of the potential low-carbon pathways for the EU refining system has been developed by Concawe[1]. It shows that the adoption of technologies for reducing GHG emissions from refineries may achieve CO_2 savings by 2050 of close to 80% of their 1990 levels, at a minimum cost of €50,000 million. This view is not intended as a roadmap, as the CO_2 efficiency of existing facilities coupled with local and structural constraints will determine individual refineries' routes and implementation costs. But the low-carbon pathways still show the industry's potential contribution to the low-carbon transition.

A study prepared by Ricardo for Concawe, focusing on light-duty road transport in the EU, assesses, among others, the potential effects of the widespread use of low-carbon liquid fuels in highly-efficient conventional vehicles in a 50/50 combination with electrically-powered vehicles. It concludes that by 2050, GHG life-cycle emissions could potentially be reduced to less than 13% of their 2015 values. In Tank-to-Wheel terms, life-cycle emissions could be 90% lower than in 1990. When compared with a high electric vehicles (EVs) scenario (100% of vehicle registrations battery electric from 2040), Ricardo concludes that the two cases are approximately equivalent both in terms of GHG reductions and in their costs to end-users and society.

To unlock investments in low-carbon technologies, the policy framework should enable investors to be remunerated for their risk capital. The current regulations in energy and climate lack long-term predictability and stability, are sectoral rather than holistic and deviate too often from technology neutrality.

The following measures for an evolutionary trajectory of the regulations on fuels and vehicles could be proposed:

- In the short-term (until about 2030), regulatory adjustments or corrections to the existing regulatory framework (particularly the Renewable Energy Directive – RED II, and the Thank-to-Wheel-based (TTW) vehicle emission standards) should be made. These would stimulate the development and deployment of technologies for low-carbon fuels and efficient vehicles.
- In the medium-term (post 2030), a cross-sectoral approach across the economy with a single cost of carbon should be created. A move to a single CO_2 market within road transport would be a first step in this direction.
- In the longer term, a common CO_2 market across the whole economy should be taken in a cross-sectoral approach based on a single carbon price.

During the low-carbon transition, due to the high cost of innovative technologies, appropriate measures should be taken to safeguard the international competitiveness of EU industries and avoid the offshoring of manufacturing activities.

[1] The scientific and technical body of the European Petroleum Refining Industry.

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INTRODUCTION

In December 2015, an important step to change was taken at COP21 in Paris. The conference agreed to make efforts to limit the global temperature increase to "well below 2°C" above pre-industrial levels, and possibly to 1.5°C. The European Union (EU) is setting the pace with its Nationally Determined Contribution (NDC).

The EU has committed to several ambitious goals. It set a binding target of reducing greenhouse gas (GHG) emissions by at least 40% in 2030 compared to 1990. The European Commission is working in parallel on a long-term approach. A roadmap for 2050 was drafted in 2011 and is currently under review, calling for a reduction in GHG emissions by 80-95% in 2050 compared to 1990. The roadmap indicates ranges of GHG reduction for key economic sectors, including 83-87% for industry and 54-67% for transport. Achieving these ambitions while maintaining the competitiveness of its economy and the quality of life of its citizens represents an enormous challenge for the EU. In particular, this will require changes in the entire EU energy system and in consumer behaviour. It will depend on innovative solutions, which will require both the technological excellence to develop them and the means to fund the necessary investments.

EU'S NDC

The European Council agreed on a binding target for the EU and its Member State of at least 40% domestic reduction in greenhouse gases (GHG) emissions by 2030 compared to 1990, to be fulfilled jointly.

- The EU target consists of economy-wide absolute GHG reductions from 1990 emissions levels over the period 2021 till 2030.
- The inclusion of LULUCF into the 2030 mitigation framework will be established as soon as allowed.
- No contributions from international credits.

To achieve these challenging goals, the EU needs to apply all its resources and appeal to all stakeholders and sectors of society. It will need a holistic regulatory framework, effective policies and an industrial strategy to encourage industries to invest in a low-carbon economy and consumers to adopt low-carbon technologies.

The petroleum refining industry and the distribution network of oil products have been operating in Europe for well over 100 years. They have continuously evolved, adapting to market and regulatory demands while providing reliable and affordable energy, as well as many other products and services that are essential to society. The EU refining sector improved its average energy efficiency by about 13% between 1992 and 2014, despite using more energy intensive operations in order to produce cleaner fuels (see Annexes 1, EU law imposing GHG emissions reduction on the transport sector and 2A, The refining industry: An example of a positive evolution in the past and a key asset for the EU in the present).

The EU refining and distribution industry is already undergoing a transition, leveraging its technological excellence, entrepreneurial culture and approach to customers. Petroleum liquid fuels blended with biofuels are used in increasingly efficient vehicles, resulting in lower carbon emissions per kilometre, per passenger, and per unit of load. Service stations across Europe are progressively diversifying their customer offers both in terms of fuels and energy for vehicles and of services for drivers. Examples include the conversion of refineries to bio-refineries, the development of sustainable biofuels and hydrogen produced from renewable electricity. These are just the tip of the iceberg of the industry's extensive efforts and investments in R&D.

In addition to a reduction in CO_2 emissions, the EU energy strategy addresses air quality and the transition to a more circular economy: This implies maintaining the value of products, materials and resources in the economy for as long as possible and minimising the generation of waste. The EU refining industry is deeply engaged in these important areas, with innovations and initiatives that aim to improve air quality and minimise waste – or, when possible, re-use it.

The industry will continue to develop its assets and business models and to play its part in the energy transition. In the coming decades this will require very significant investments in low-carbon energy solutions. These efforts need to be accompanied by a policy framework based on the principles of technology neutrality, cost-effectiveness and free competition. As the cost of implementing low-carbon solutions is likely to be high, appropriate measures will be needed to safeguard the international competitiveness of EU industries. If this is not done, there is a risk that manufacturing activities could be offshored to countries with lower climate ambitions, which would result in an increase in product imports and lower security of supply.

This document presents a vision for the evolution of the EU refining industry. It analyses the future role of liquid fuels and other products in line with EU's climate change objectives for the longer term – to 2050 and beyond. It also discusses how the refineries can increase their efficiency and be integrated in a cluster of industries.

1.

THE EVOLUTION OF DEMAND FOR LIQUID HYDROCARBONS AND THE FUTURE ROLE OF LOW-CARBON LIQUID FUELS AND PRODUCTS

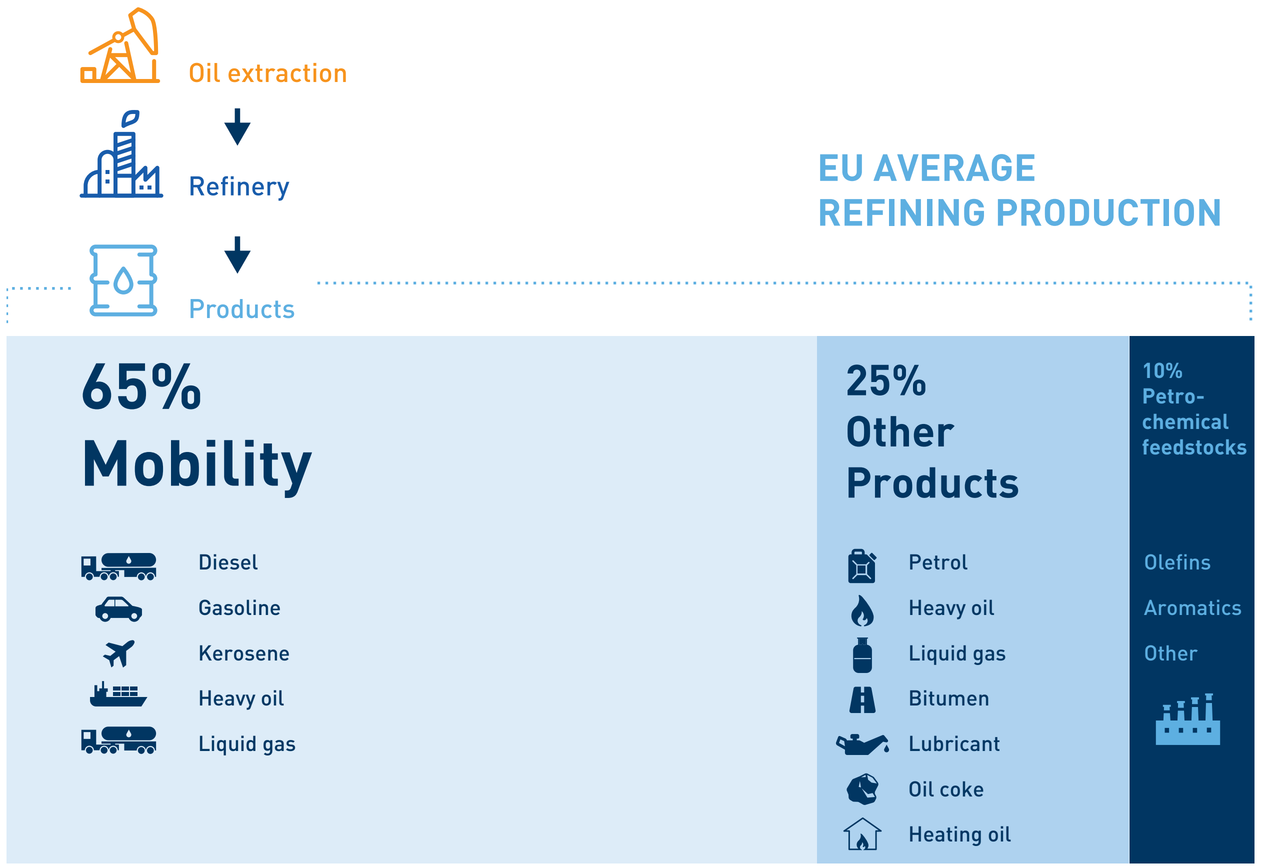
1.1. Demand trends

The refining of crude oil leads to a vast array of products that fulfil the needs of both citizens and businesses. About 65% of the crude oil processed in EU refineries is transformed into transport fuels, which are mostly liquid; about 10% goes to petrochemical feedstocks; and about 25% is employed for other products.

The evolution of oil demand will depend on a variety of factors. These include oil prices and the economic and social transitions in major centres of demand such as China and India. Another factor will be the speed at which disruptive technologies, replacement products and new business models emerge in transport and other sectors – for example, new models of car ownership, integrated transport systems, self-driving vehicles and urbanisation.

Demand for oil products will also feel an impact from policy measures aimed at addressing climate change (by reducing the emissions of greenhouse gases) and the risks linked to the emission of air pollutants. The implementation of these measures will be of growing importance mainly – but not only – in the transport sector. For example, fuel economy standards for cars and trucks introduced in China, the EU and the US will play a major role in the short-term in reducing or containing the growth of demand for mostly liquid fuels.

FIGURE 1: REFINING PRODUCTS

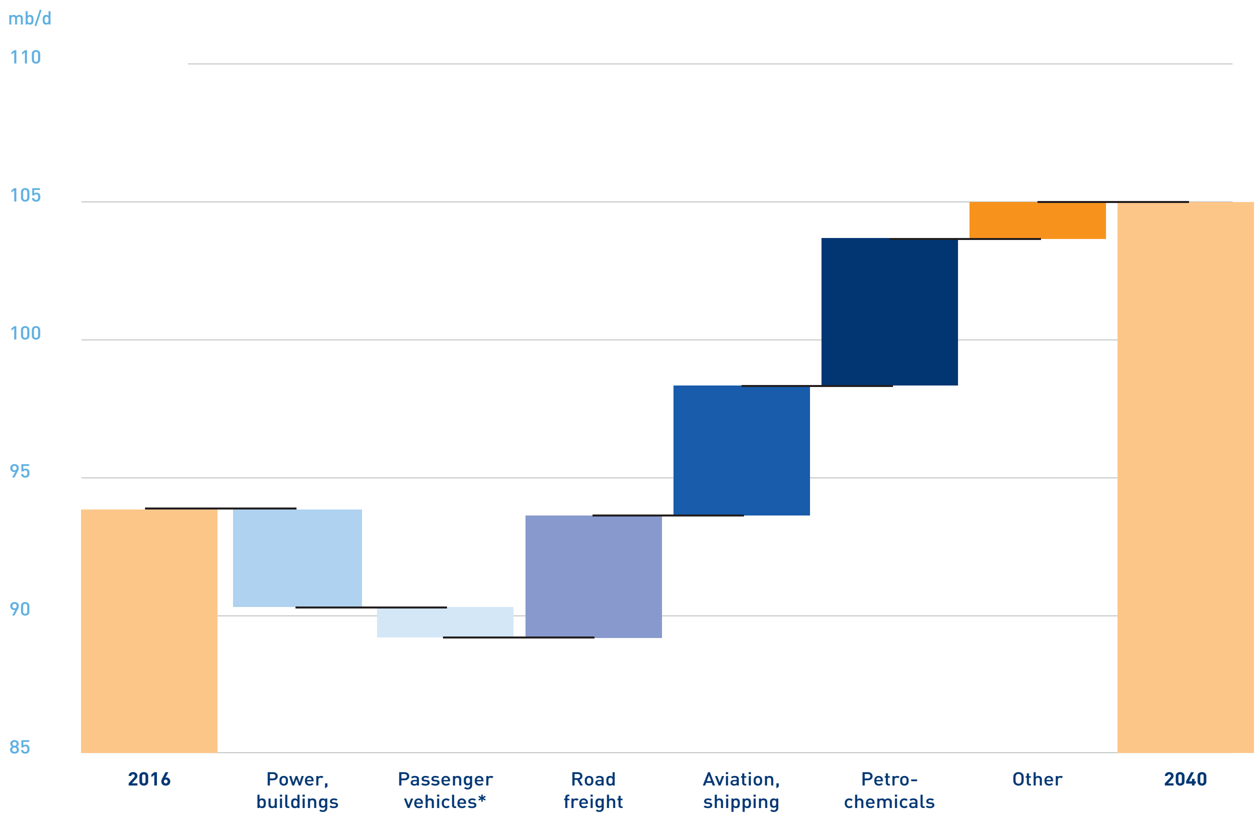


Source: Based on EUROSTAT, http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Consumption_of_oil_EU-28,_2015,_percentage.png and WoodMackenzie product markets long-term outlook H_2 2017 Demand in EU 28, NOR, CH, ISL for 2015.

According to the International Energy Agency (IEA), some specific sectors will continue to be mainly dependent on oil. In the World Energy Outlook (WEO) 2017, the New Policy Scenario[2] assumes continued growth in the global use of oil until 2040. This is because the decline in the use of oil in passenger vehicles, buildings and power generation will be more than offset by the growth in demand for petrochemicals, aviation, ships and trucks.

[2] The IEA WEO 2017 New Policy Scenario takes account of broad policy commitments and plans that have been announced by countries, even if the measures to implement these commitments have yet to be identified or announced. It is generally considered to be the central scenario, sitting between the moderate-change and radical-change scenarios for the energy system to meet the Paris objectives for climate change.

FIGURE 2: **CHANGES IN WORLD OIL DEMAND BY SECTOR IN THE NEW POLICIES SCENARIO**



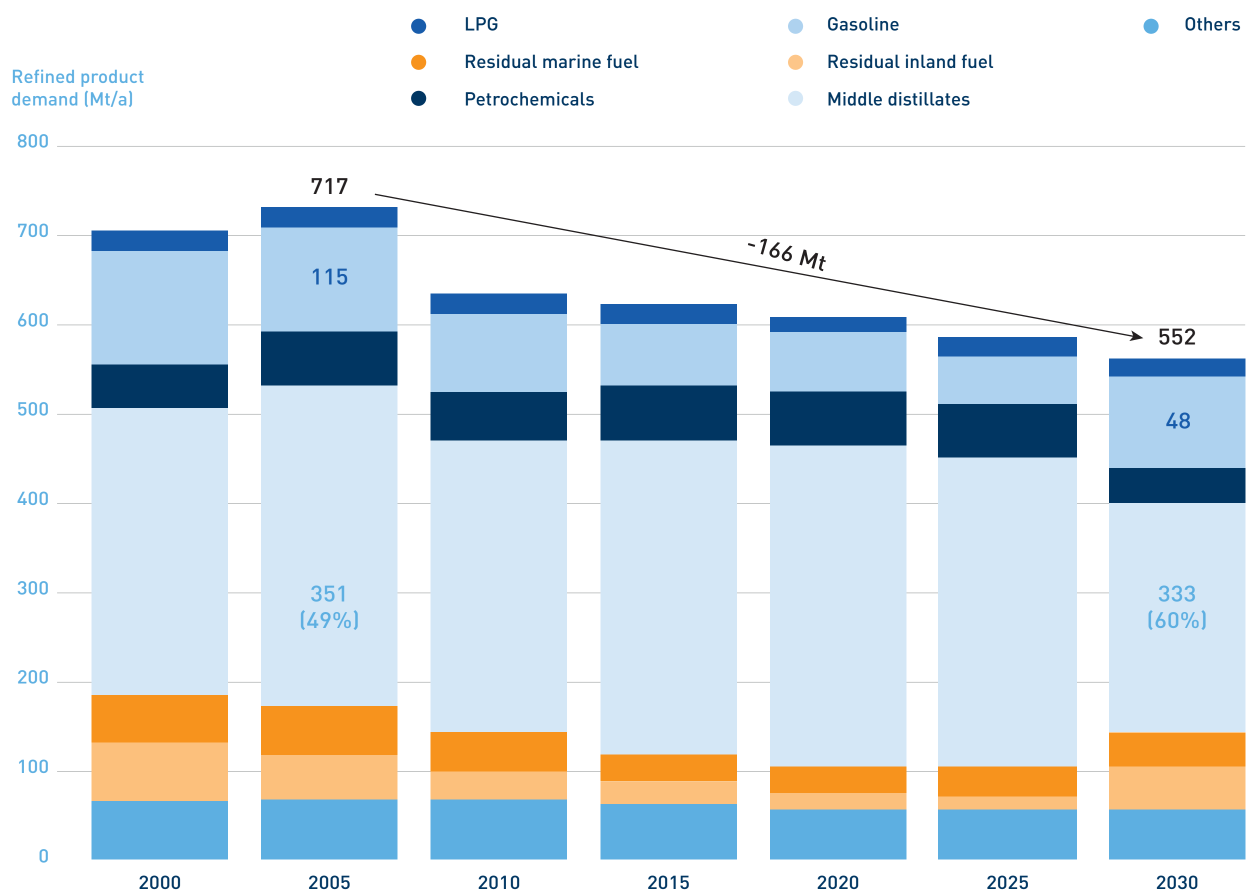
While the outlook for oil in power generation, buildings and passenger vehicles hints at a peak in oil demand, this is more than offset by rising demand in other sectors.

* Includes passengers cars, two/three wheels and buses.

Source: IEA, WEO 2017.

For Europe, the IEA WEO 2017 assumes that EU oil demand will decrease from 13mb/d in 2016 to between 5.7mb/d and 8.7mb/d by 2040. The largest reduction will be in transport, while there will be smaller decreases for hydrocarbon feedstocks (for petrochemicals, solvents, lubricants, waxes and bitumen). In 2015 Concawe and Wood Mackenzie forecast that demand for refined products (petroleum-based products plus biofuels) in the world was expected to decline until 2030. This decline is due to predicted efficiency gains in different transport sectors, the initial penetration of EVs into the passenger car fleet (based on JEC modelling) and a lower demand for heavy fuel oil for heating. A recent update to this forecast now suggests the reduction in demand will be more marked as in Figure 3.

FIGURE 3: **TOTAL DEMAND FOR REFINED PRODUCTS IN THE EU-27+2**

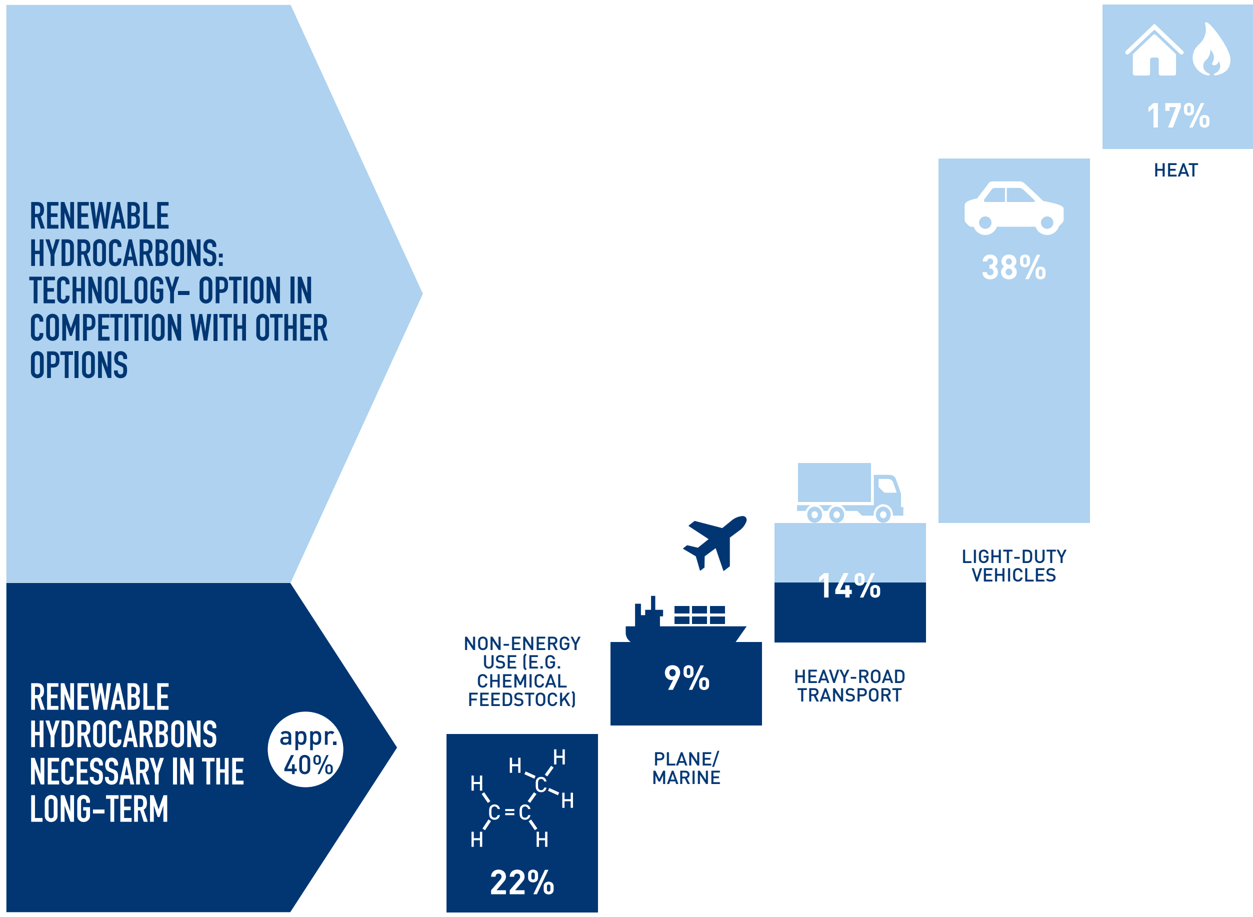


Source: Wood Mackenzie and Concawe.

Concawe is currently elaborating different scenarios for demand up to 2050. These will reflect different estimates of the change in demand for hydrocarbon products due to factors such as the following:

- A transition from predominantly oil-based products to low-carbon liquid hydrocarbons, including sustainable biofuels and e-fuels, as well as gaseous hydrocarbons such as liquefied natural gas (LNG) and compressed natural gas (CNG).
- The various balances of substitutes for petroleum hydrocarbons across different transport sectors: aviation, marine, rail, heavy- and light-duty road freight and passenger vehicles.
- Updated forecasts for the transition to more fuel-efficient vehicles, including hybrid vehicles with smaller, more efficient internal combustion engines (ICEs), as well as fully EVs (battery and hydrogen).

FIGURE 4: USE OF OIL PRODUCTS/HYDROCARBONS IN GERMANY 2016



Source: Prognos AG, Berlin.

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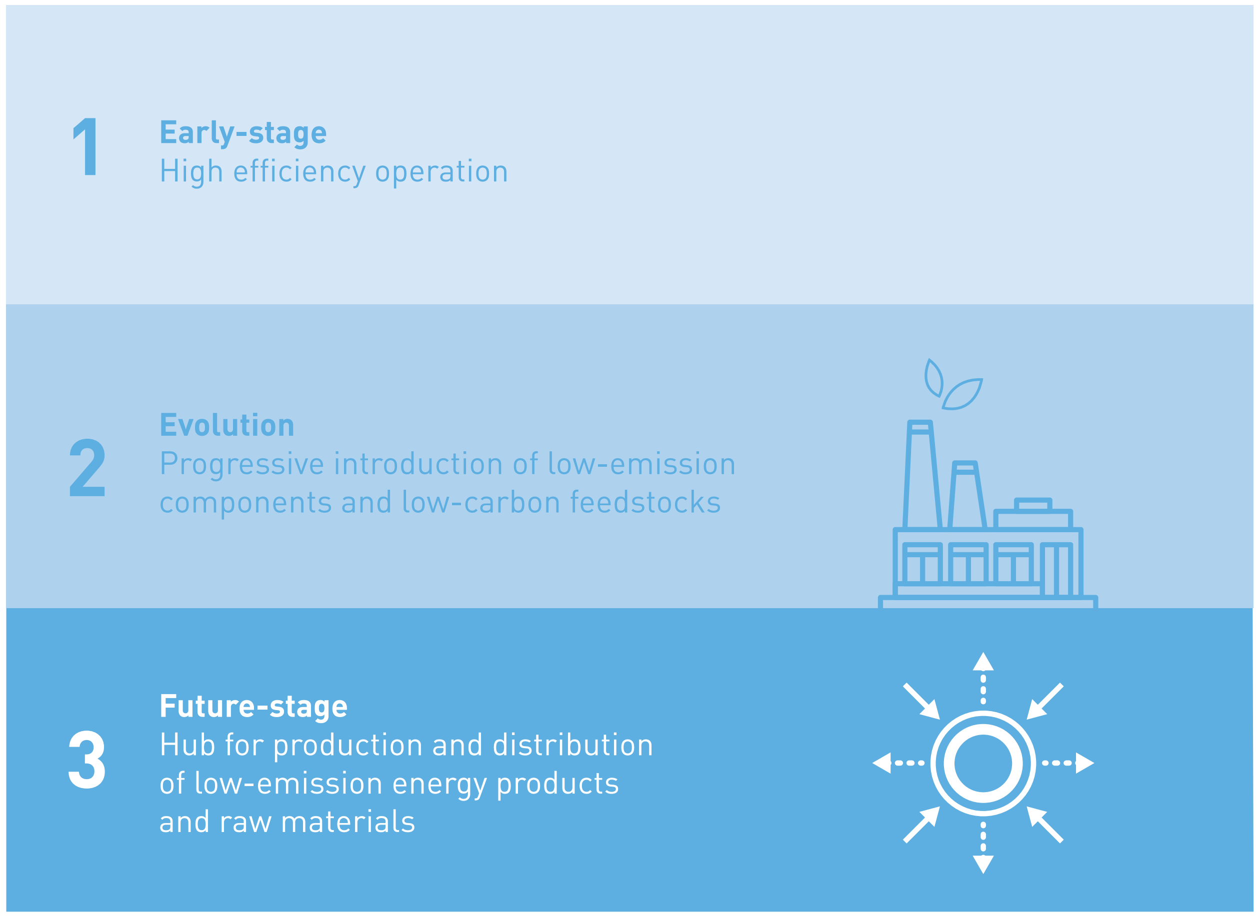
Taking stock of the above considerations, it can be assumed that the demand for refinery products will evolve in a manner similar to the Figure 4 on page 10, which shows the scenario for Germany.

In all likelihood, low-carbon liquids will be of vital importance in the drive to reduce emissions in European energy and transport systems. The challenge and the opportunity for the EU refining sector will be to adapt so that refineries of the future will serve as hubs for the production and distribution of sustainable hydrocarbons. These will be used in a low-emission economy as liquid fuels, chemical feedstocks and for other purposes. This transition will serve the needs of society, both in Europe and the rest of the world.

FIGURE 5: EU REFINING SYSTEM: EVOLUTION TOWARDS A LOW-EMISSION ECONOMY



1.2. Liquid fuels for transportation

A. NO SILVER BULLET

While renewable electricity – hydro, solar and wind – will play a major role in Europe's energy system, for the foreseeable future full electrification is not likely to occur for all modes of transport.

Petroleum liquid fuels offer an unequalled combination of qualities:

- High energy density.
- Easy and safe handling.
- Extensive, resilient, already existing infrastructure for production, distribution and storage.
- Low cost compared to the alternatives.

As such, petroleum liquid fuels continue to be attractive for use in all transport sectors.

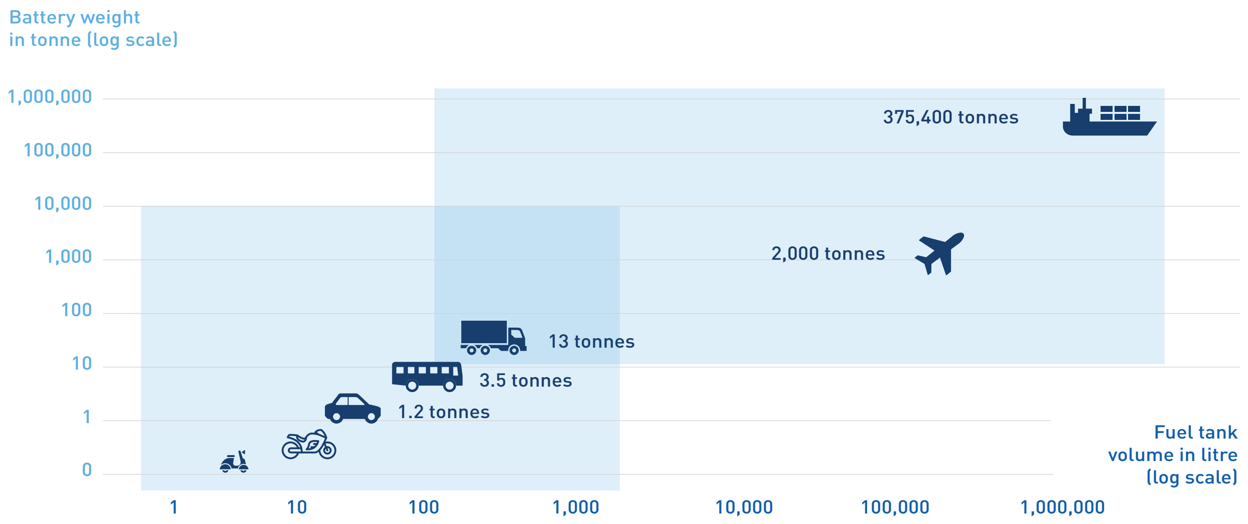
However, the development of alternative transport systems to reduce both GHG emissions and air pollutants such as particulates (PMs), sulphur dioxide (SO_2) and nitrogen oxides (NO_x) is underway and is particularly promising for passenger cars.

For marine, aviation and heavy-duty road transport, the energy density of liquid fuels represents a fundamental advantage that will be difficult to overcome even with future battery technology. For these modes of transport, the key requirement is to store the maximum amount of energy on-board in the smallest possible volume and weight.

Figure 6 shows the battery weight that would be required if electrical power trains were adopted for different transport modes.

It can be seen that battery technology will need to achieve at least a 10 fold reduction in weight in order to become a viable substitute for liquid fuels beyond passenger cars and light commercial transport. No breakthrough of this magnitude in battery technology is foreseen in time to impact the composition of the transport fleet by 2050.

FIGURE 6: LIMITED ELECTRIFICATION BEYOND THE BUS AND LIGHT TRUCK SEGMENT



Therefore, it is unlikely that a single option – a silver bullet – will deliver low-emission mobility across all transport segments. Instead, many technologies will be needed, and it will be essential to develop effective industrial cooperation in Europe, supported by the right R&D frameworks. This will be the most effective way to deliver sustainable, low-emission fuels for use in next-generation efficient engines – such as low GHG intensity oil-based fuels, biofuels, synfuels and Power-to-Liquid (PTL). Technological advances applied to a number of alternative fuel and vehicle options will be required to meet the growing demand for the transport of people and goods. The result will be a reduction in emissions.

The refining industry is working on new sources of liquid hydrocarbons, but in many cases the development and deployment phases will take time. In the interim, it is important to consider how to reduce emissions from the production of petroleum-derived hydrocarbon fuels and chemical feedstocks.

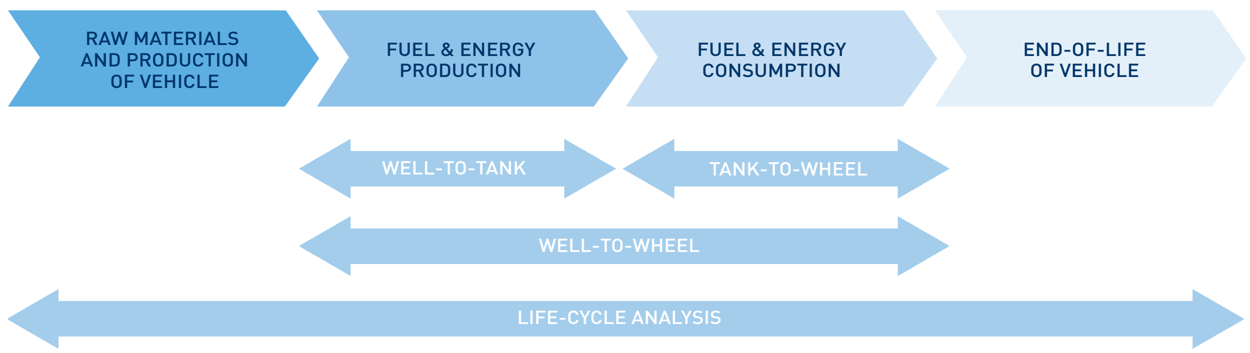
A HOLISTIC APPROACH TO GHG REDUCTION IN TRANSPORT

For policy purposes, a proper comparison of different options for the reduction of GHG emissions in transport needs to adopt a holistic approach. It should consider emissions from or associated with vehicles, fuels, infrastructure and consumers.

CO_2 emissions must be accounted for at every stage. First, there is the production of primary energy, such as crude oil, coal, gas, bio-feedstock and renewable energy.

This then needs to be transported. It is then converted into fuel or energy through processes such as refining, power generation and the manufacture of biofuels. The finished fuels and energy are then formulated and distributed. Finally, they are used in vehicles. These steps constitute the Well-to-Wheel (WTW) approach, which can be split into the Well-to-Tank (WTT) and Tank-to-Wheel (TTW) phases. If the CO_2 emissions from the manufacturing and eventual disposal of vehicles are included, the approach is called life-cycle analysis (LCA). The above can be summarised in the following scheme:

GHG EMISSIONS ASSESSMENT OPTIONS



As the impact of GHG emissions on climate change is independent of the specific point of emission, a non-comprehensive approach may lead to wrong – and counter-productive – conclusions. For example, if the analysis of CO_2 emissions from different vehicle technologies is limited to the TTW phase, a battery-electric vehicle (BEV) will be considered "zero emission". However, if it uses electricity generated from coal, a WTW analysis will show that the BEV actually results in substantial CO_2 emissions.

The transition towards low-carbon mobility in all means of transport can be achieved by optimising energy consumption and minimising CO_2 emissions at each step in the WTW chain:

1. Production of the primary energy source. In the case of petroleum, initiatives such as the Global Gas Flaring Reduction Partnership, led by the World Bank Group, are reducing the CO_2 emissions associated with crude oil production.

2. Optimisation the refining and distribution of fuel for carbon efficiency.

3. Final combustion point. The design of engines and vehicles plays a major role, as do low-emission fuels.

Any improvement achieved in the WTT phase – that is, in steps 1 and 2 of the WTW chain – will also reduce the impact of products generated in the refining of petroleum. The benefits will, therefore, apply across all transport sectors. Importantly, the improvements could boost the performance of the existing and future transport fleet. Moreover, when improved refinery products are used other than for transport – such as in the chemical industry, for domestic use and in any other application where an oil product is burnt – they will also contribute to a reduction in overall CO_2 emissions.

In contrast, to reduce emissions during the TTW phase, solutions specific to each transport sector – or to segments within a sector, such as coastal shipping rather than trans-ocean shipping – are required. For passenger vehicles, hybrid drivetrains and fully battery-powered vehicles are already an option. However, there are currently no emerging technologies that will allow full substitution of hydrocarbons by 2050 in either heavy-duty road transport or the marine and aviation industries.

The WTW approach for fossil fuels breaks down the CO_2 emissions associated with mobility into several stages. As an example, for the passenger vehicle segment, the CO_2 emissions associated with diesel and gasoline are as follows:

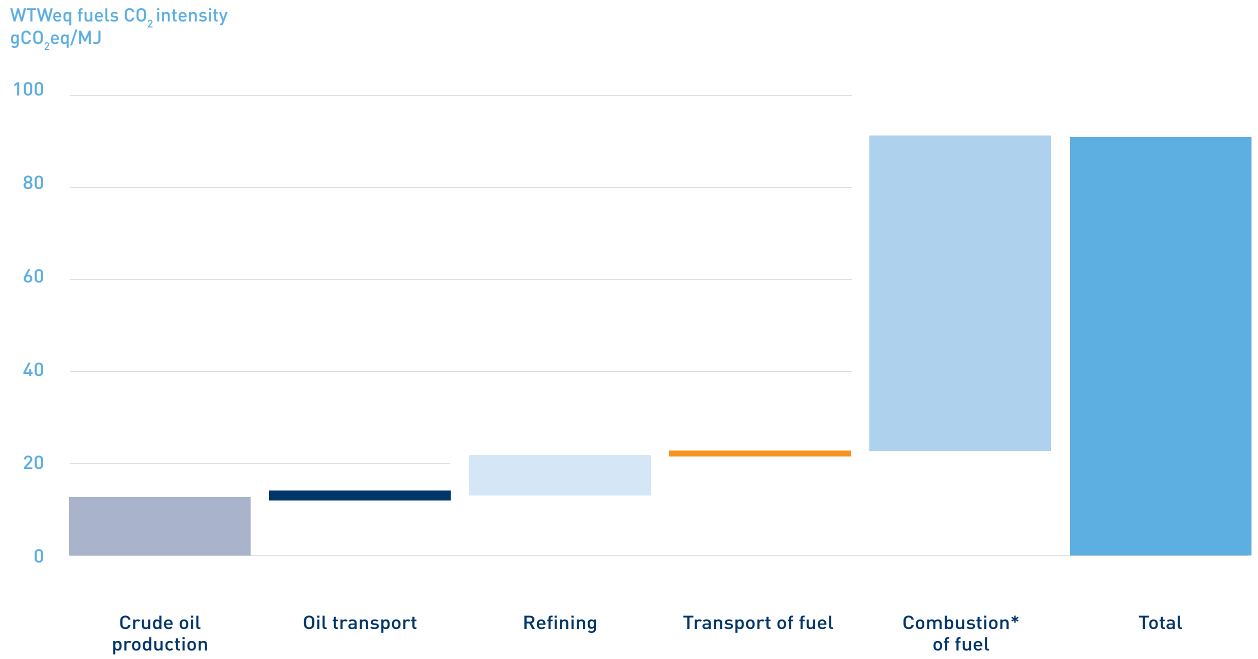
1. ≈ 12% of the CO_2 emissions are during the production and transport of crude oil (upstream emissions).

2. ≈ 7% of the CO_2 emissions come from refineries during the processing of crude oil into petroleum products and from the transport of the fuel to petrol stations.

3. ≈ 80% of the CO_2 emissions come from the combustion of the fuels in the engine (this is a theoretical value that does not consider any energy efficiencies specific to particular engines or vehicles).

As most of the CO_2 emissions come from fuel combustion, it is critical to understand the potential to reduce carbon emissions at this stage, and the ability of the drivetrain and the fuel to reduce emissions. In this respect, different transport sectors face different challenges, which will require different solutions.

FIGURE 7: CO_2 EMISSIONS FROM PRODUCTION AND USE OF FUELS - SIMPLIFIED WELL-TO-WHEEL APPROACH



*"Combustion" considers only emissions associated with the theoretical combustion of fuel.

Source: Concawe based on jec v4 and own data (average values).

B. OPPORTUNITIES FOR DIFFERENT SECTORS TO REDUCE THEIR CARBON EMISSIONS

When taking a deeper dive into different transport sectors, a broad range of opportunities to contribute to future low-carbon mobility can be identified at each WTW stage:

MARINE

- The marine sector is projecting global growth in traffic, leading to an increase in demand for mainly hydrocarbon-based marine fuels by 2050.

- The International Maritime Organization (IMO[3]) is considering setting an overall target to reduce total annual GHG emissions by at least 50% by 2050 compared to 2008. It also proposes designing ships to be at least 40% more energy-efficient by 2030 compared to 2008, pursuing efforts towards 70% by 2050, compared to 2008.

- Within Europe:
  1. CO_2 emissions from maritime transport in EU waters are to be cut by at least 40% by 2050 compared to 2005 and, if feasible, by 50%, according to the European Commission's 2011 White Paper on Transport.

  2. In addition to the above IMO initiative, the EU has since January 2018 required the monitoring, reporting and verification of CO_2 emissions from large ships using EU ports.

- To reduce global emissions:
  1. Reductions in CO_2 emissions can be achieved through the design of new ships with better hydrodynamics, along with more efficient engine and propulsion technologies.

  2. Optimisation of the logistics chain in marine transport, using smart management of ship voyages, can also significantly contribute, for example by minimising port congestion.

  3. New formulations of marine diesel can substitute conventional petroleum-based fuel oils and diesel with sustainable biofuels and e-fuels (such as synthetic methanol) as these become available.

  4. LNG has significant potential as a marine fuel, but it requires the development of relevant infrastructures in the EU and elsewhere.

  5. Other concepts, such as on-board CO_2 capture, may become technically feasible for large ships powered by diesel, LNG or alternative liquid-synthetic fuels.

  6. In contrast, other alternative fuels, such as hydrogen and nuclear, are not likely to play an important role in replacing liquid hydrocarbon marine fuels before 2050.

  7. Similarly, alternative energy sources such as on-ship wind turbines and hybrid electric-combustion systems may act as supplements but are unlikely to make combustion engines redundant in this timeframe.

- At the same time, EU refiners will have to increase CO_2 emissions by as much as 8 million tonnes per annum (an increase of 4%) to provide fuels that meet the IMO global 0.5% sulphur specification[4].

AVIATION

- The aviation sector is also projecting significant global growth in traffic, with a resulting increase in demand for aviation fuels by 2050.

- To manage CO_2 emissions, the International Air Transport Association (IATA[5]) has committed to the following:
  1. An annual improvement in average fuel efficiency of 1.5% between 2009 and 2020.

  2. A cap on net aviation CO_2 emissions from 2020 (carbon-neutral growth).

  3. A reduction in net aviation CO_2 emissions of 50% by 2050, relative to their 2005 level.

- Within Europe, the European Flightpath 2050 project aims for a 75% reduction in CO_2 emissions per passenger-kilometre by 2050. Significant quantities of low-carbon liquid fuels will be required to meet this objective, potentially including low-carbon kerosene and bio-jet or PTL fuels.

- IATA considers that the following innovations will contribute to reductions in CO_2 emissions from aviation:
  1. Improved technology, including sustainable low-carbon fuels.

  2. More efficient aircraft operations, such as ground handling.

  3. Infrastructure improvements, including modernised air traffic management systems.

  4. A single, global market-based measure to fill the remaining emissions gap (offsetting).

- There are currently no emerging technologies that will allow full substitution of hydrocarbons in aviation by 2050.

HEAVY DUTY ROAD TRANSPORT

- The EU GHG target for 2050 will require an annual reduction of at least 3% in the CO_2 emissions associated with heavy-duty road transport[6]. This is equivalent to a reduction of around 55% in the energy demand from heavy-duty vehicles over the period 2012-2050.

- In order to achieve such ambitious goals, both the European Road Transport Advisory Council (ERTRAC[7]) and a group of industry associations lead by the European Automobile Manufacturers' Association (ACEA[8]) have explored different measures that could contribute. The ACEA-led study highlights the importance of following an integrated approach including different opportunities and stakeholders.

[3] https://www.iea.org/media/news/2017/ISWGGHG2214.pdf
[4] LP modelling result, mean scenario, Concawe "2020 Marine Fuels Supply study".
[5] http://www.iata.org/policy/environment/Pages/climate-change.aspx
[6] www.avl.com/documents/10138/1131828/141119_PDiM_Electromobility+for+Commercial+Vehicles+%E2%80%93%20Challenges+%26+Opportunities_Svenningstorp.pdf/4f631607-dd8a-4616-a935-480d8e37ba9c
[7] ERTRAC roadmap, June 2016), heavy duty truck roadmap (2012) http://www.ertrac.org/uploads/documentsearch/id42/2016-06-09_Future%20ICE_Powertrain_Technologies_final.pdf and http://www.ertrac.org/uploads/documentsearch/id4/heavy-duty-truck-1_0_66.pdf
[8] ACEA (Integrated approach report, 2017), http://reducingco2together.eu/assets/pdf/trucks.pdf

These could encompass vehicles, trailers and tyres; more efficient engines, fuels and alternative fuels; and operations including infrastructure and logistics. They have the potential to cut CO_2 emissions from road transport by 20% by 2020 compared to 2014, showing the great potential of joint CO_2 reduction efforts. Among the initial measures identified in the study are the following:

1. CO_2 emissions could potentially be reduced by 6% through savings related to vehicles, including the optimisation of engines, trailers and tyres.

2. There is potential for a reduction of 2.5% in CO_2 emissions from the use of alternative fuels, including biofuels, synthetic fuels and natural gas.

3. A reduction of 13% could come from operational changes, including better infrastructure and fleet renewal.

- In the long-term, alternative fuels such as synthetic fuels and hydrogen may have the potential to result in much greater reductions in CO_2, subject to the development of the relevant technologies (see Annex 2D, Liquid fuels in the passenger car segment).

PASSENGER CARS AND LIGHT-DUTY COMMERCIAL VEHICLES

- According to many analysts, the stock of passenger cars is expected to increase, both worldwide and in Europe. Different initiatives could be implemented to reduce their associated CO_2 emissions over the long-term:

1. As fuel combustion represents 80% of total WTW CO_2 emissions, vehicle-related opportunities have the greatest potential for reducing carbon emissions from these vehicles.

2. New R&D programmes have the potential to improve the design of the ICE. Other vehicle-related measures to reduce fuel consumption include weight reduction, the thermal management of powertrains and vehicle systems, and the recovery of waste heat. These improvements could also be leveraged in heavy-duty vehicles.

LIQUID FUELS IN THE PASSENGER CAR SEGMENT: A LONG-TERM VIEW

The ICE will still play a key role in 2050, even if there is a significant share of EVs in sales of new passenger cars. That is the conclusion that can be drawn by combining the 2016 EU Reference scenario with the different technologies (such as powertrains) envisaged by stakeholders such as ERTRAC. The conclusion is illustrated in the new baseline defined by Emisia for its fleet modelling tool (see Annex 2D, Liquid fuels in the passenger car segment).

3. EVs in different forms will play a major role as the electricity mix becomes increasingly low-carbon. Options for the motorist now include different combinations of electric motors with optimised ICEs (hybrid vehicles), plug-in hybrid electric vehicles (PHEV) and pure BEV.

4. Hydrogen produced from renewable or low-carbon electricity and consumed in fuel cell hydrogen cars (FCHV) offers a viable alternative contribution to the partial electrification of the passenger car segment.

- However, even in the most optimistic scenarios for penetration of alternative powertrain technologies, liquid fuels will continue to be required for many passenger cars and light-duty commercial vehicles. The integration of different technologies has the potential to produce low-carbon liquid fuels in the long-term in the following ways:

1. Optimising processes and improving the CO_2 efficiency of both upstream production and refining sites through different measures.

2. Leveraging the full potential of sustainable and low-carbon bio and synthetic fuels, including PTL technologies (see Annex 3J, Power-to-Liquids: SUNFIRE technology).

3. The future evolution of ICEs, coupled with changes in the quality of liquid fuels, with properties designed to optimize the efficient use of energy (e.g. higher octane levels in gasolines, (see Annex 3B, High octane gasoline) will contribute to lower emission vehicles. Other technologies, currently at the very early stages of development, could be envisaged to enable the on-board capture of CO_2 emitted at the tailpipe and later, its storage and conversion (see Annex 3L, On-board CO_2 capture). This would be the final step in the GHG mitigation chain.

URBAN AIR QUALITY

Air quality is another strong driver of change, as many European cities search for ways to comply with ambient air quality standards. This makes it important for the vehicle fleet to move towards a mix of EVs and diesel vehicles (both passenger and commercial-duty) that are fitted with the latest after-treatment technology (Euro 6d or equivalent). These diesel vehicles must be fully compliant under real driving conditions.

This transition will mean that, as 2030 approaches, road transport will diminish as a factor in poor air quality in cities. In the short-term, other measures will be needed in many cities to remove older, more polluting vehicles and to control pollution sources other than transport (see Annex 2D, Liquid fuels in the passenger car segment).

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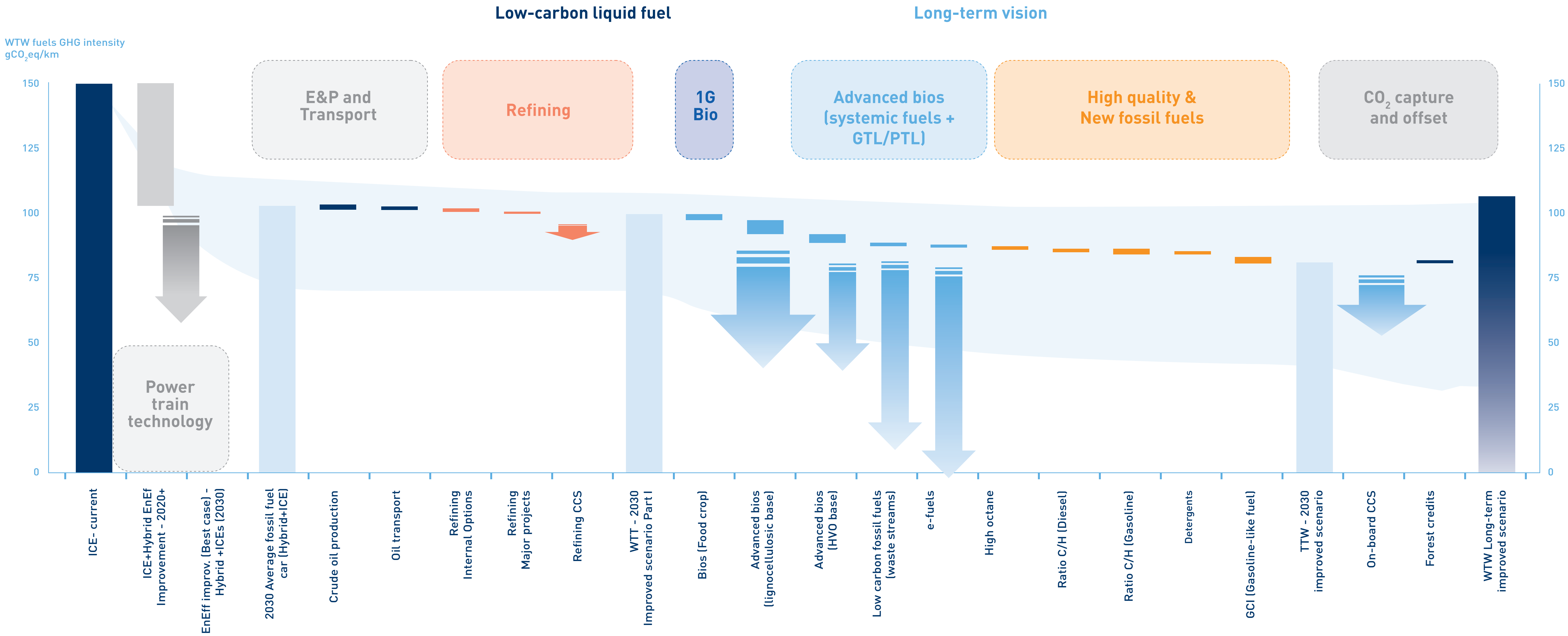
The following chart, taken from Concawe's Low Carbon Pathways[9], identifies key technologies and their potential for reducing the WTW GHG intensity of passenger cars:

[9] The Low Carbon Pathways Project. A holistic framework to explore the role of liquid fuels in future EU low-emission mobility (2050).

FIGURE 8: CONCAWE'S LOW CARBON PATHWAYS (PASSENGER CARS. AVERAGE C-SEGMENT)

Note: 2030 Mean Scenario (Bar chart). Sensitivity cases represented by the grey area (Boundaries of the Min / Max uptake). Arrows highlight the potential of different technologies in the long-term (2050).



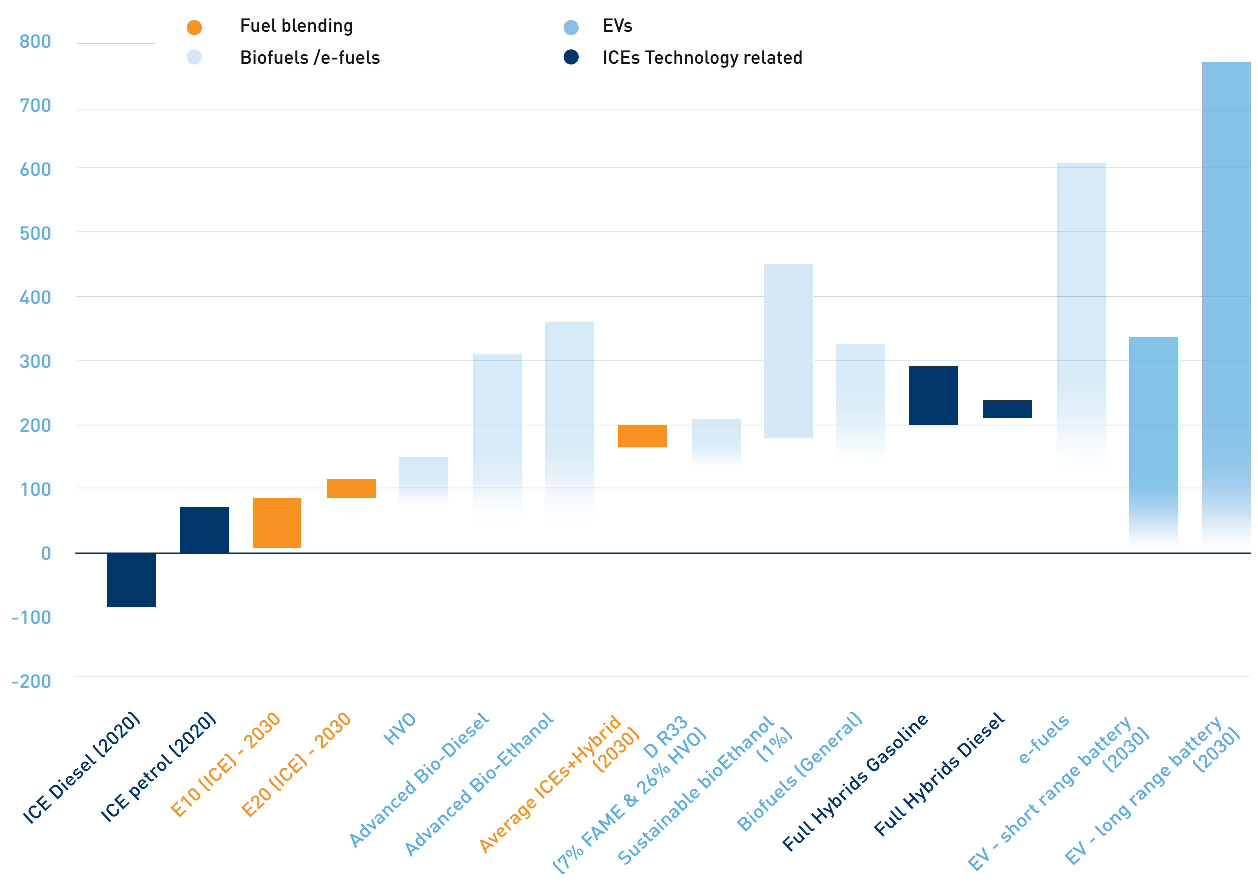
Source: Concawe, Low Carbon Pathways, April 2018.

Cost of different low-carbon fuels and powertrain technologies

In its preliminary assessment, Concawe chose the abatement cost per tonne of CO_2 as the cost metric because of its potential to compare different options for carbon emissions abatement on the same basis. However, the methodology is extremely sensitive to the aggressiveness of the assumptions made as well as to other factors. These include future fuel and electricity prices, in particular their evolution towards 2050; the defined boundaries of the analysis; and other financial parameters that will heavily affect the final outcome. Therefore, this approach should not be used alone when deciding investments.

Figure 9 compares different power sources for a C-class vehicle. The vehicle-related costs will vary according to the segment considered.

FIGURE 9: CO_2 ABATEMENT COSTS(€/T CO_2) OF DIFFERENT LOW-CARBON FUELS AND POWERTRAIN TECHNOLOGIES FOR A C-CLASS VEHICLE- A LOOK INTO 2030



Source: Concawe, Low Carbon Pathways, April 2018.

Economic comparison – a summary

- In the short to medium-term, low-carbon alternatives to petroleum-based liquid fuels such as biofuels and e-fuels will be more expensive to produce than the petroleum-based equivalents.
- However, the affordability of these alternative fuels will improve, as the ICE becomes more efficient and other developments are brought to market such as increasing hybridisation.
- Low-carbon fuels can use the existing supply infrastructure for petroleum-based fuels. Overall, low-carbon fuels can be cost-competitive compared with the full costs of electrification of the light-duty fleet.
- For aviation and marine transport, low-carbon fuels (gas and liquid) may be the only practical and affordable solution.
- Concawe is developing economic analyses for alternative fuels under different scenarios in the different transport sectors.

ROLE OF CONSUMERS IN THE TECHNOLOGY CHOICE: THE CASE OF LIGHT-DUTY TRANSPORT

Consumer choice is a decisive factor in determining the success of a technology. Consumer choice is influenced by desirability, economic considerations and ease of use. Whilst the costs of EVs are declining, EVs are still expensive and currently rely on subsidies to support purchases. Ease-of-use characteristics include driving range, recharging time and the availability of re-charging points.

Whilst range anxiety has so far had an influence on consumers' choices, newer models with next-generation batteries allowing greater mileage are now appearing on the market.

Recharging time is also important for consumers. A standard charger can take several hours and is more suitable for overnight charging at home or other long-term parking situations.

So, fast chargers must be installed in sufficient number to satisfy demand from people who need to recharge their battery during a trip.

The location and availability of recharging stations will increase in importance as more EVs enter the market. Intelligent, automated management of EVs will optimise the frequency and location of recharging during a trip and minimise peak loads, so helping to avoid disruptions in the electricity supply.

A mix of vehicle technologies will be needed to satisfy a variety of consumer needs and societal ambitions now and in the future. The following principles need to be kept in mind:

- The choice of a technology cannot be imposed on the consumer.
- Different vehicle technologies have advantages and disadvantages for specific uses.
- The scientific understanding, economics and assessment of externalities will evolve over time.

In general, it is unwise for regulators to pick winners in advance while neglecting the importance of consumer choice. This would likely to lead to the development of technologies that, once subsidies and other supports are removed, do not gain widespread acceptance in a free market.

C. CONCLUSIONS

- Climate change requires urgent and decisive action in all sectors of the economy.
- The ICE will continue to play an important role across different transport sectors for decades to come.
- Liquid hydrocarbons will remain an important part of the future mobility system, even as alternative energy sources increase.
- The development and deployment of low-emission hydrocarbon liquid fuels offer a significant opportunity to effectively meet market demand while also contributing to address the risks posed by climate change.
- Low-carbon liquid fuels can reduce the emissions of all transport segments in the shortest time, using existing vehicle fleets and existing infrastructure for the production, distribution and storage of fuels. The existing distribution network for marine, aviation and road transport fuels can easily adapt to future low-emission liquid and gas fuels.

EMISSION SOURCES IN A REFINERY

An oil refinery is made of different complex processes that are interconnected to produce a full range of highly valuable petroleum products. Each plant is unique, but they are all energy- and CO_2-intensive. The typical range is from 100 to 200 kg of CO_2 per tonne of crude oil (see Annex 2C, Emission sources in a refinery for a simplified flow diagram of a typical complex refinery and for a chart of its main CO_2 emission sources).

- At the same time, the network of service stations throughout Europe will continue to evolve. Fuel retail stations are likely to become multi-energy stations, expanding their offerings of fuels and energy and providing a wide range of new services to drivers (see Figure 10).

Collaboration across industries and sectors will be key to bringing innovative technologies for low-carbon liquid fuels and other products to market. Therefore, establishing an EU industrial symbiosis across the chemical and fuels production sectors, as well as the transport sector, will be essential to accelerate the market readiness of low-carbon technologies.

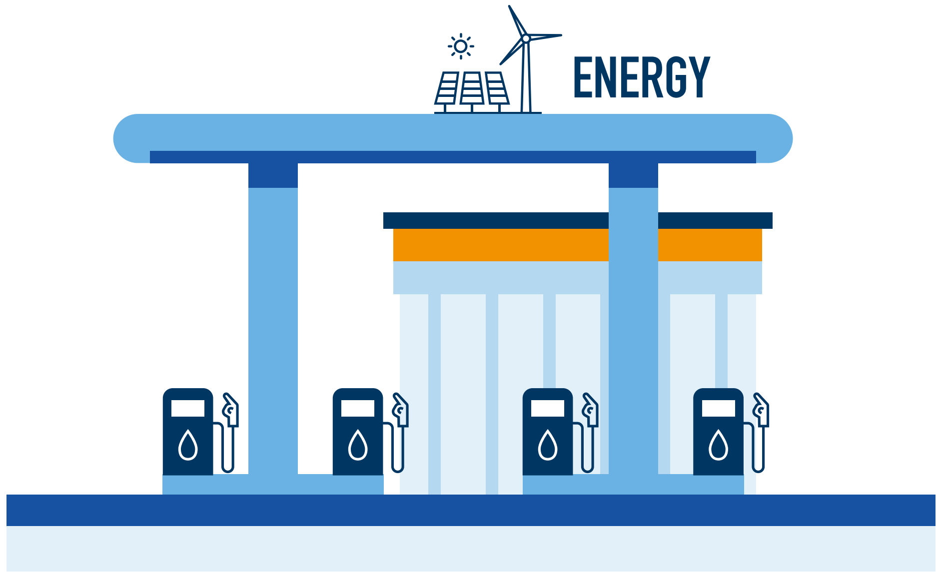
Further reductions in CO_2 emissions from upstream and refining operations will also contribute to the effective reduction of carbon emissions before viable zero emission substitutes have been developed and are ready to deploy. This applies both to fuels and non-fuel petroleum products, including petrochemical feedstock, bitumen, asphalt, lubricants, waxes, solvents and heating oil. Refinery products that are used in the industrial value chain – notably the petrochemical feedstock – will help reduce emissions in other industries and end-user products.

Therefore, to support the EU low-emission strategy the EU refining industry needs to evolve to substantially reduce the CO_2 emissions associated with its operations and the use of its products. At the same time, it will continue to provide outstanding value to the EU economy and citizens through the many products society will need in coming decades.

1.3. Petrochemical feedstock and other non-fuel products

Petrochemicals form the basis of countless products used in everyday life, including construction materials (especially thermal insulation), automotive parts, packaging, furniture, consumer electronics, clothes, footwear, tyres, paints, cosmetics and pharmaceuticals. Therefore, any potential replacement of refinery products as petrochemical feedstock concerns a broad range of segments and involves different kinds and levels of innovative technology.

FIGURE 10: EVOLUTION OF SERVICE STATIONS



ADDITIONAL PRODUCTS FOR MOBILITY

- Alternative liquid fuels
- Power-to-Liquid fuels
- CNG
- LNG
- H_2
- Electricity
- ...

ADDITIONAL SERVICES

- AdBlue©
- Collection of on-board CO_2 captured
- Hub for car-sharing
- Delivery point for online retailers
- ...

REFINERY AND STEAM CRACKER SITES IN EUROPE

- The majority of petrochemical feedstock (naphtha) originates in the refining industry.
- Out of the 58 steam cracker petrochemical units located in the EU, 41 are integrated with refineries located, on average, less than two kilometres away.
- The symbiosis of the refining and chemical industries enhances the international competitiveness of these clusters (see Annex 2B, Refinery/steam cracker sites in Europe).

The New Policies Scenario in the IEA's WEO 2017 shows that even in the most aggressive scenario for addressing climate change, global oil demand to produce petrochemical feedstock would still increase from 11 mb/d today to 16 mb/d in 2040.

This is also reflected in the DECHEMA-CEFIC study[10] on low-carbon feedstock. Under current conditions, the production costs of ammonia, methanol, olefins and aromatics from biomass would be between two and five times as high as from petrochemical feedstock.

Therefore, while biomass has potential as a bio-based feedstock, substantial progress in R&D will be needed to make it an economically viable option. In the short- to medium-term it will be more effective to focus efforts on reducing the GHG intensity of the petrochemical feedstock produced in refineries and to apply the principles of the circular economy to increase the feedstock from waste and re-used products.

[10] Report Low-carbon energy and feedstock for the chemical industry: www.cefic.org/Documents/RESOURCES/Reports-and-Brochure/DECHEMA-Report-Low-carbon-energy-and-feedstock-for-the-chemical-industry.pdf

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Petrochemical feedstock represents perhaps the best example of integrated value creation from two pillars of the EU industrial value chain. Further integration of refining and petrochemicals may unlock additional synergies and reduce GHG emissions through energy savings, lower transportation costs and increased operational flexibility. For example, intermediates can be exchanged to meet fluctuations of demand, and a hydrogen supply can be used as a backup for a refinery. Moreover, refineries of the future may produce low-carbon or renewable hydrocarbon feedstock for petrochemicals.

BIO-FEEDSTOCKS FOR PETROCHEMICALS

In recent years, there have been efforts to use non-oil-based feedstocks such as biomass to produce petrochemical products.

The success of bio-based chemicals will be largely determined by the cost competitiveness of the production process and the future availability of biomass feedstocks. There is currently a considerable cost gap where bio-based Power-to-Olefins could also play a role in the future, as envisaged by CEFIC and DECHEMA in a recent study. But it is hard to see these technologies happening without technological advances or breakthroughs. As a result, a limited penetration of bio-based feedstock for petrochemicals is envisaged by the IEA in its outlook (WEO 2017), even in its Sustainable Development Scenario.

In addition to petrochemical feedstocks, many other petroleum products are key elements in the industrial value chain and difficult to replace. We should not underestimate the importance for businesses and citizens of products such as bitumen, asphalt, lubricants, waxes and solvents. As for petrochemical feedstocks, the replacement of these petroleum-derived products with products derived from biomass or other alternatives is not technically or economically viable, at least in the medium-term. Moreover, as these products are not burnt during use, they represent an effective way to "store" CO_2 and prevent its release to the atmosphere.

Heating oil should also be mentioned among the key petroleum products, as it currently provides heat to some 20 million homes in the EU, mostly in rural and residential areas. It plays an especially important role in areas that are challenging to connect to a gas or electricity network.

The quality of fuels used for heating is being improved, reducing their carbon emissions, and more efficient boilers are also being produced. Moreover, the integration with renewable energy sources in hybrid heating systems and the progressive utilisation of low-carbon liquid fuels offer an opportunity to further reduce CO_2 emissions.

1.4. Energy storage

Energy storage will play an increasingly important role during the energy transition. The intermittency of electricity generation from solar and wind sources requires the availability of a vast, responsive and flexible capacity to store energy at times when its supply exceeds the demand. It can then be released for consumption when needed. Energy storage is needed to respond to fluctuations in demand and supply of electricity in a timely manner – whether to balance the grid over seconds and minutes or to deal with seasonal variations over the course of weeks and months.

While pumped hydro storage (storing water in a reservoir at a certain height) currently provides by far the most energy storage in the world, including in the EU[11], many other technologies are available for energy storage. The pace of innovation in technologies for stationary batteries is progressing fast, with impressive results in terms of increased storage capacity and reduced unit cost. However, the efficiency and sheer size of storage achievable through molecules greatly exceeds the storage performance of electrons. The Figure 11 provides an overview of the various pathways of energy storage.

Here are some examples:

- The total EU storage of crude oil and oil products (about 120 million tonnes) in compliance with the Compulsory Stock Obligation regulation (requiring storage equivalent to 90 days of consumption) corresponds to about 1500 TWh of energy (1.5×10^9 kWh), according to Concawe's calculations.
- The total EU gas storage capacity is about 1200 TWh (1.2×10^9 kWh)[12].
- In the hypothetical case that 200 million electric cars, each with a fully loaded 100 kWh battery, were connected to the grid, there would be 20 TWh (2×10^7 kWh)[13] of energy stored and available for release.

It can be concluded that the currently available and foreseeable technology solutions for the storage of energy in electric batteries will be limited to instantaneous or very short-term balancing of the grid. Molecules have a significantly higher capacity.

Hydrocarbons of fossil origin are not, however, the only practical way to store energy. Hydrogen produced from electrolysis of water using renewable energy, or "Power-to-Hydrogen", is a mature technology that allows a flexible storage of energy. Moreover, hydrogen has multiple uses, such as fuel for transport and heating purposes and as a component of synthetic fuels (PTL, synthetic gas and ammonia).

The refining industry is well placed to offer competitive solutions for energy storage.

- It has deep experience in the production, storage and use of hydrogen, in addition to owning and operating the relevant equipment and technical facilities.
- It has vast storage capacity for liquid products.
- Thanks to its integration in industrial clusters, such as petrochemicals, it can fulfil the role of an energy hub, by transforming excess renewable energy into liquids and releasing them when needed.

Though several technologies are available, further progress is needed in terms of cost competitiveness and technological development in order to achieve large-scale deployment. Investments are needed and should be encouraged by an enabling regulatory framework.

In conclusion, it is important that storage technologies are included in the EU strategic energy technology plan.

[11] EASE – European Association for Storage of Energy - Roundtable on Sectorial Integration Supported by Energy Storage and Hydrogen, European Commission, Brussels, 01 March 2018.
[12] EnergyNet - ELECTRICITY AND GAS NETWORKS' PERSPECTIVE High-level Roundtable on Energy storage and sectoral integration – 01 March 2018.
[13] ibidem.

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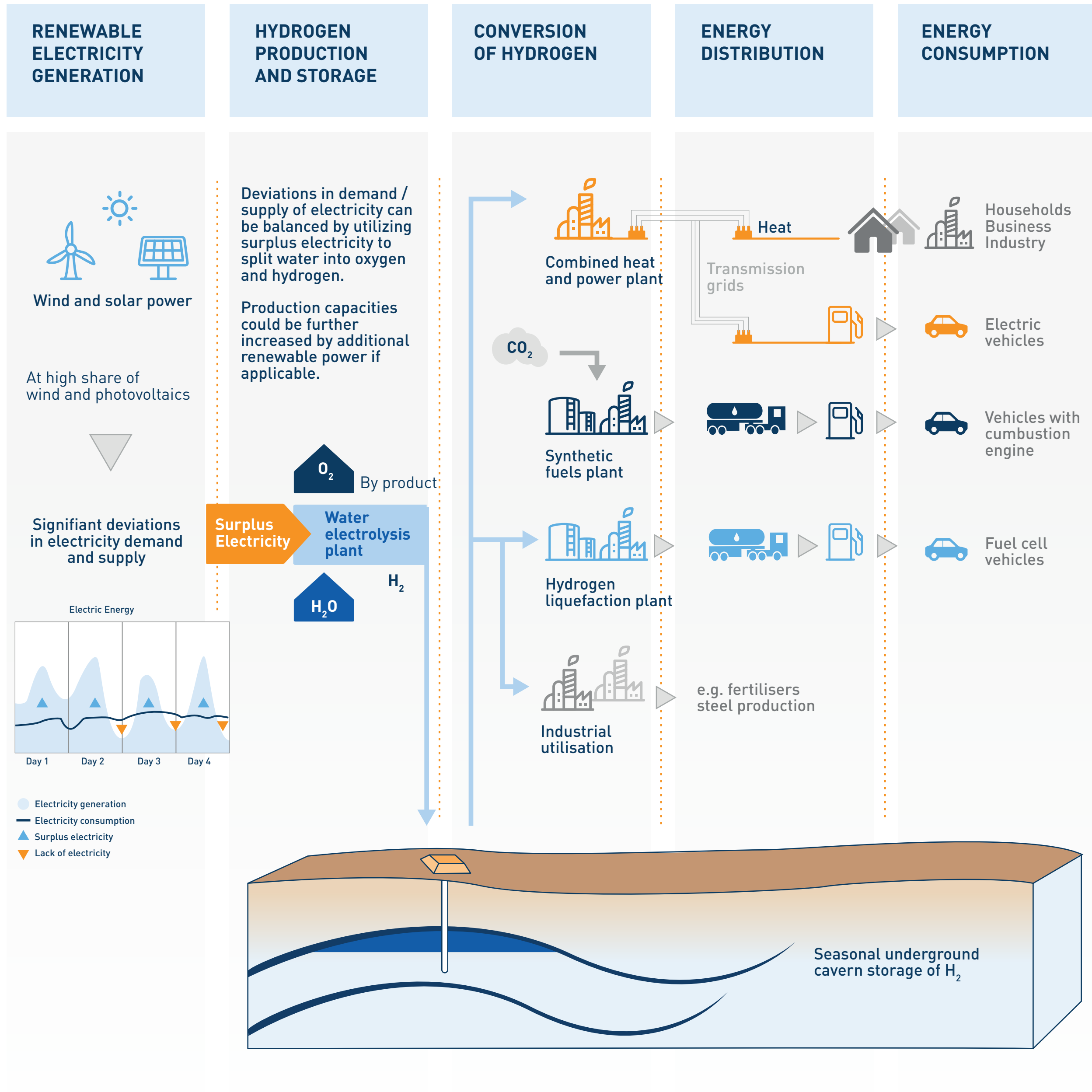
FIGURE 11: RENEWABLE ENERGY UTILISATION SCHEME



Source: ERTRAC, High-Level Round Table, Sectorial Integration supported by Energy Storage and Hydrogen, 01 March 2018.

2.

A VISION FOR MANUFACTURING: REFINERY 2050

The European petroleum refining industry is an important resource for the EU in the energy transition. For over 100 years, it has proved its ingenuity, technological leadership and entrepreneurial culture. The industry is facing an extremely challenging future, and action to mitigate climate change is required. The refining industry has started to evolve so that it can contribute to this goal. At the same time, it must continue to meet the needs of consumers and of the EU industrial value chain.

The refinery of the future will increasingly use new feedstocks, such as renewables, waste and captured CO_2, in a very efficient manufacturing facility. It will maximise the use of renewable electricity on-site and will be integrated into a cluster of cross-sectoral industries with the potential to boost and exploit industrial symbiosis in Europe. Through the flexibility and resilience of its infrastructures, the refining industry will process a variety of feedstocks and deliver a range of products. For instance, new low-emission hydrocarbon fuels will serve as building blocks for chemicals, lubricants, waxes and bitumen, which are needed to ensure the competitiveness of the EU economy.

At the same time, the network of service stations spread throughout Europe will continue its evolution. In the future, they may discharge and collect CO_2 captured on board vehicles, and they may host hubs for car sharing.

The evolution in refineries will be based on the combination of a wide range of options technically available with the potential to reduce the CO_2 intensity of refinery products. The preferred strategy will to a large extent depend on each individual site. Different refineries are planning or have already started this evolution in different ways. Many ongoing R&D projects illustrate how the industry could evolve whilst mitigating climate change.

The challenge cannot be addressed by a single industry or sector. Therefore, stronger cross-sectoral R&D programmes must be incentivised in Europe to support the effective development and deployment of both sustainable low-emission fuels and related vehicle technologies.

Technologies such as renewable ("green") hydrogen and carbon capture and storage (CCS), for example, have been widely identified as key enablers of a worldwide low-emissions economy. Europe has an opportunity to embrace cross-sectoral innovation to put both its processing and manufacturing industries in positions of technological leadership.

A future EU technology strategy will be key to defining the basis for the future of low-emission technologies, and it should not exclude any technology that could potentially emerge.

2.1. The role of the future EU refining system

The EU refining industry today is an example of European industrial excellence, providing an essential contribution to the EU value chain (see Annex 2A, The refining industry: An example of a positive evolution in the past and a key asset for the EU in the present). It has repeatedly demonstrated its capability to innovate and evolve, and to adapt to the needs of the economy and citizens and to environmental legislation. Today, extensive R&D efforts and investments, plus the deployment of low-carbon technologies at commercial scale, show what the refining industry can and – under the right circumstances – will do to contribute to the low-carbon economy in the long-term.

The refining industry will progressively embrace an evolutionary process by adopting new technologies and new low- and zero-carbon feedstocks. It will also play an important role during the transition to a low-emission economy.

During the transition period, refineries and the downstream oil industry will:

- Ensure that new low-carbon fuels and fuel components are compatible with conventional products.

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- Produce, blend and supply new and conventional fuels and energy to final consumers, leveraging the industry's logistics system, distribution network and widespread service stations.

Where a limited (e.g. in heavy-duty transport) or a high (e.g. for passenger vehicles) substitution by alternative powertrains is technically feasible, refineries will help to manage the transition. This will avoid disruption to the smooth functioning of road transport, a sector of key importance for the EU's economy and citizens.

In the future, refineries could play a crucial role as supply aggregators in the deployment of low-carbon fuels, by balancing fossil fuel production to fit localised imbalances between low-carbon supply and overall demand. They could also act as fuel quality normalisers, by ensuring that liquid fuels remain fungible throughout the network.

In this context, the EU refining system will be able to evolve and continue satisfying end-market demand in the future by delivering low-carbon products and fuels.

2.2. Potential pathways towards the transition of the EU refining system

Refineries will find ways to reduce CO_2 emissions through a combination of operational measures and targeted investments, and by taking advantage of external opportunities. The combination of options practically available will vary from site to site and will depend on factors such as existing configuration, location and proximity to other industries. A number of developments are likely to contribute to reducing GHG emissions both from refineries and their products. These can be categorised into three groups.

GROUP 1: Measures to further reduce the GHG intensity of the production cycle in refineries

The EU refining industry is continuously exploring ways to substantially reduce its own CO_2 intensity. These include:

- Investments and operational measures to maximise energy efficiency.
- Reduction in the burning of liquid fuel.
- Reduction of routine flaring in refineries.
- Use of low-grade heat resulting from refinery operations to produce electricity for internal and external use. Some developmental areas include the extension of heat-pump technology to achieve higher temperatures and alternatives to electric power.
- Closer integration with other industries such as petrochemicals, which are often located within the same industrial hub. This also provides further options for energy efficiency measures – e.g. shared utilities, which result in greater economy of scale and better optimisation of heat, steam and power.

The implementation of an energy management system (EMS) ensures that refineries are both designed and run following the most energy-efficient standards. An EMS combines equipment such as energy measurement and control systems with strategic planning, organisation and employee culture. An effective EMS both improves the day-to-day management of energy and identifies equipment upgrades and capital projects that improve future energy performance. The systems rely heavily on digital technologies such as advanced process control, process simulation, equipment performance monitoring, predictive analytics, refinery optimisation and scheduling and maintenance management.

GROUP 2: External contributions to reduce the GHG intensity of refining

As the transition of the EU economy progresses, refineries will be able to further reduce GHG emissions in new areas. The following new projects and major investments can be envisaged:

- The progressive decarbonisation of electricity from the grid will create new opportunities for the EU refining system to reduce its carbon emissions through the use of low-carbon electricity, either generated within the refinery or imported. Some potential projects are:
  1. The progressive replacement of steam-driven rotating machines and fired heaters with electric ones.
  2. The production of renewable ("green") hydrogen with electrolysers using imported or self-generated renewable electricity.
- Further integration of the refining system with local communities can be envisaged. For example, the export of low-grade heat to reduce energy consumption and the associated CO_2 emissions (district heating).
- CCS and CCU (Carbon Capture and Use): Applied to refinery flue gases, these have been identified as leading technologies to mitigate climate change. Refineries, in clusters with other industries, can play a major role in demonstrating and deploying these technologies across Europe.

GROUP 3: Opportunities to reduce feedstock and product-related emissions

Emissions resulting from the combustion of sustainably produced and processed biomass are recognised as carbon neutral – i.e. virtually zero. When new biomass is grown to replace it, it takes up the same amount of CO_2 from the atmosphere. This offers new potential pathways for the refining system to be integrated into the bio-component value chain and to blend a wide range of low-emission components.

Further modifications to the quality of the final fuel combined with advanced vehicle technologies could offer other potential routes to reduce the WTW GHG intensity of final products:

- **Processing low-carbon feedstocks with a higher bio-content level**

  Advanced biofuels are already being developed, and more opportunities exist with the processing or co-processing of new types of waste materials and biomass-based products. Some of these process routes have the advantage of using known refinery-like conversion technologies for upgrading renewable oils. This gives refineries the potential to process low-carbon feedstocks either in dedicated process units or in combination with fossil feedstocks. The end-products would be high-quality, renewable hydrocarbons, fully fungible with conventional diesel and gasoline and suitable for use in engines without blending limits.

  Processing biomass pyrolysis oil from waste, FT-wax (Fischer-Tropsch), syncrude and algae oil are some of the potential routes through which refineries might add value and offer alternative energy solutions. They can:

  a. Repurpose existing equipment rather than building new.

  b. Standardise products for use in mainstream fuel markets.

  There is also an opportunity to process waste of various origins, including plastic, in the feedstock diet of refineries of the future. This would be consistent with the EU Circular Economy strategy.

- **Low-carbon blendstocks, such as biofuels or e-fuels added via product blending**

  There will be a continued need for refineries to play an aggregating and normalising role to compensate for a variable slate of low-carbon blendstocks and ensure a consistent quality for mainstream products (see Annex 3A, Characteristics of alternative fuels). The main challenges for future low-carbon blendstocks are to ensure sustainability and increase volume to significantly penetrate the final market.

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- **Reduction of carbon emissions from road transportation through the quality of fuels**

  This can be achieved by improving the quality of existing liquid fuels in combination with advanced vehicle technologies that take advantage of these improvements. As an example, gasoline with a higher octane number combined with an engine designed for a higher compression ratio results in lower CO_2 emissions per kilometre. From the fuels perspective, these could be implemented relatively quickly. Because of the volumes involved, the impact could be significant.

- **Reducing carbon emissions by processing waste to produce fuels and feedstock**

  The processing or co-processing of new types of waste materials such as plastic waste and residues represents an opportunity to develop another category of advanced biofuels. The refining industry can contribute its know-how and expertise to the development of alternative options for plastic waste to landfill and incineration. However, further technology development is required to adapt waste processing streams to produce feedstock that can be used in a refinery to make a final product of sufficient quality.

To ensure the European refining industry's leadership in technologies enabling the use of end-of-life (EOL) plastics to make fuel, it is essential to do the following:

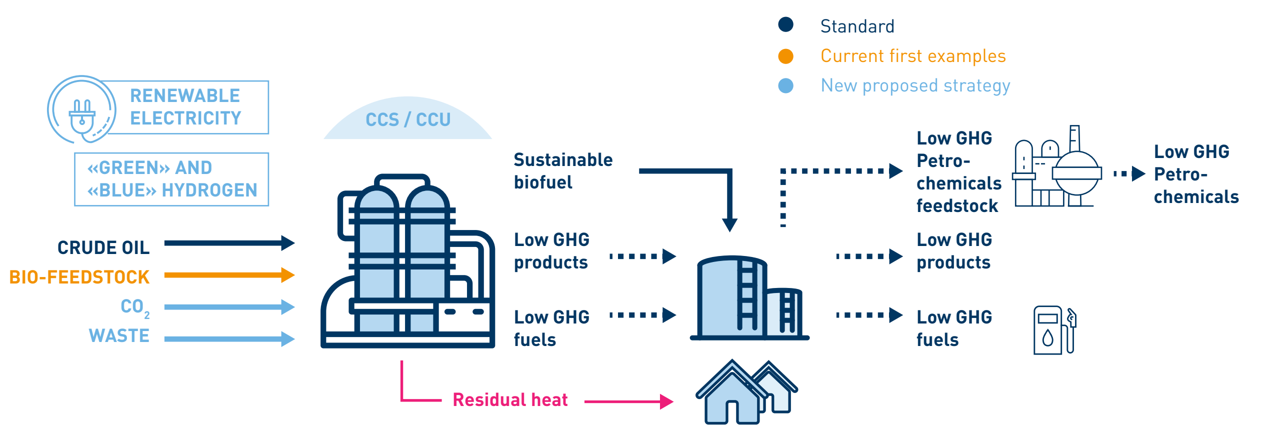
- Provide an appropriate framework to promote:
  1. Investment in the development and scaling of the new technologies to reduce operating costs, capital expenditure and scale-up risks and to make the most of economies of scale and other advantages.
  2. Incentives for the use of waste and residues in refining processes: A regulatory framework can provide synergies between the waste and refining industries.
- Ensure coherence and stability over time between resources and energy policies to allow investment in technologies related to low emissions in Europe.

Policy and regulation should take into account products made of waste. Under the current regulatory framework, not all fuels made from EOL waste streams are recognised as low-emission fuels (see Annex 3E, Waste-to-Fuel).

The opportunities involve several industries. Further investment in R&D and the deployment of effective inter-sectoral collaborative models will be crucial to release the full potential of these opportunities during the transition to a low-emission EU economy.

Figure 12 provides a conceptual overview of the refinery of the future.

FIGURE 12: THE REFINERY AS AN ENERGY HUB WITHIN AN INDUSTRIAL CLUSTER



The EU refining system will be an essential part of this transition and it is possible to envisage a continuation of the evolution of the refineries - and their associated distribution system - taking place in three different steps.

1. Early-stage (low-emission operation):

Product mix is oil-based with some low-carbon content in order to meet renewable energy or GHG regulations. refineries are optimised to meet evolving demand for fuels and products taking advantage of the emissions' reduction of the grid.

2. Evolution (progressive introduction of low-emission components):

Progressive transformation of the refinery co-processing low-carbon feedstock or blending higher ratios of new low-emission products.

3. Future-stage (hub for production and distribution of low-emission products and raw materials):

The refinery of the future will be a very efficient manufacturing centre, potentially integrated in a cluster of industries processing and exchanging a variety of feedstocks and semi-finished products. Within these clusters, CCS is foreseen to play a major role to caputre and storage remaining CO_2 emissions effectively.

Product mix will be based on low-emission fuel and products with fossil content components playing a role in countering varaitions and imbalances in supply-demand balance while ensuring consistent product quality.

2.3. The evolution of the EU refining system has already started

Refineries have already started to evolve along different paths. Oil and gas companies are currently investing in R&D and deployment projects that illustrate how the industry could evolve in a way that mitigates climate change. A few early R&D examples and some cases of deployment show the industry's engagement and capabilities at different stages of the value chain:

- Companies with EU refining operations are blending biofuels into road transport fuels according to EU regulations and international specifications. In many cases, they are also currently engaged in the production or co-processing of "drop-in" bio-components for blending beyond regulatory mandates. This will improve the quality and sustainability of the fuels (see Annex 3C, Hydrotreated vegetable oil).

- The next generation of advanced biofuels is already being developed, and some refining companies are already involved in R&D projects exploring different pathways:

  1. Lignocellulosic biomass (straw, forest residues) can be transformed into biofuel in different ways. For example, thermochemical conversion is being explored as a process to convert biomass first into syngas and then into a hydrocarbon mixture that can be used to produce second-generation biodiesel and bio-jet fuel (see Annex 3D, BioTfuel project: synthetic fuels via biomass thermochemical conversion).

  2. The Waste-to-Fuel technology is a promising area for accomplishing one of the objectives of the circular economy. The industry is engaging in relevant R&D activities to contribute effectively to this goal (see Annexes 3E, Waste-to-Fuel and 3F Waste-to-Fuel and feedstock).

  3. There are examples of very significant and promising R&D projects for the development of third-generation biofuels. These have superior sustainability credentials both in terms of reducing GHG emissions and their impact on land use and ecosystems (see Annex 3G, Algae, a biofuel of tomorrow processed in the refineries of today).

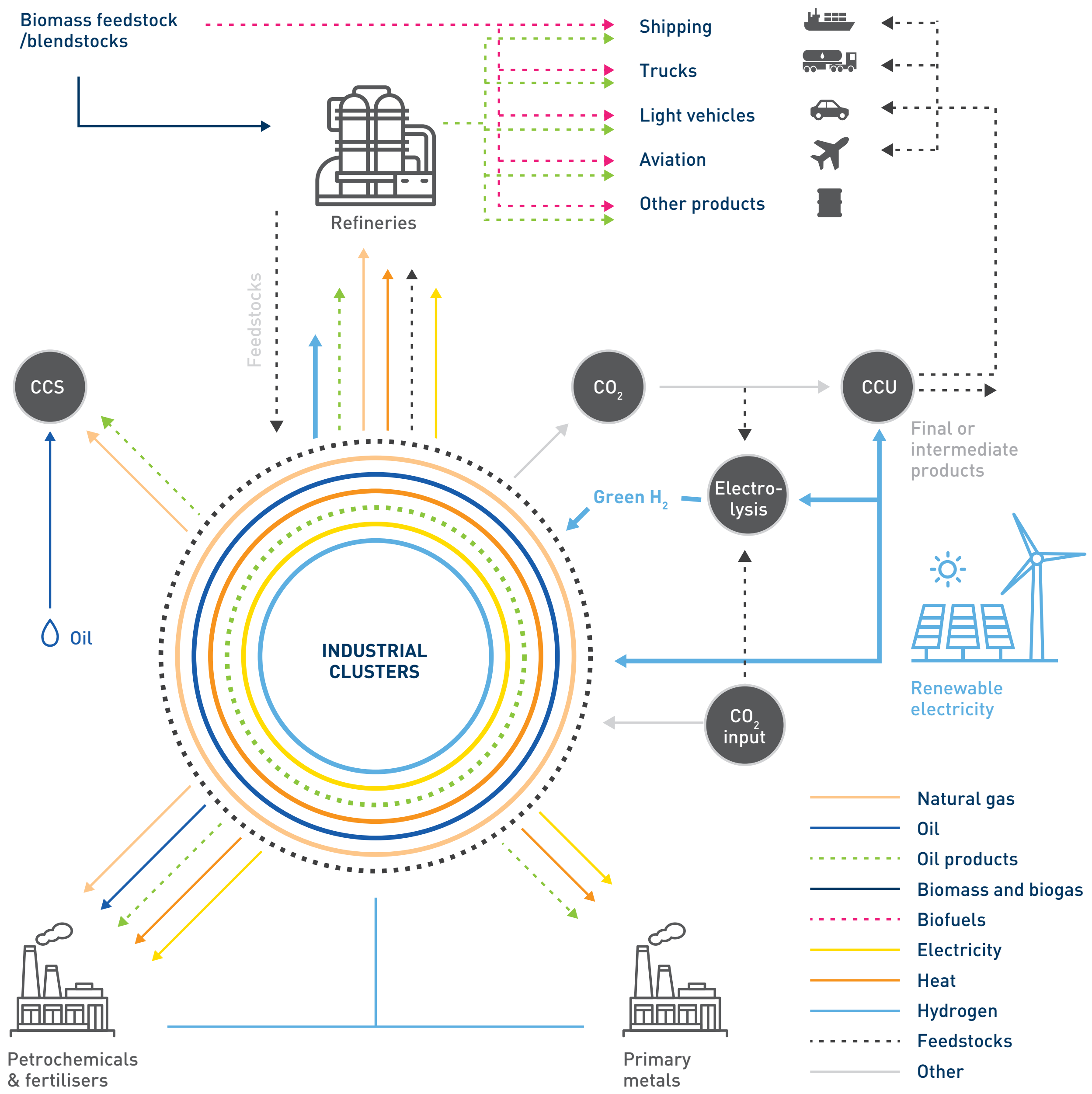
  4. Conventional refineries (whose feedstock is crude oil) can be transformed into "bio-refineries" for the production of a different range of biofuels and other products from biomasses. There are real examples of potential routes that could be followed (see Annex 4A, Bio-refineries).

- Several refineries are engaged in projects aimed at using or producing so-called "green hydrogen", i.e. hydrogen produced from renewable electricity (see Annex 3K, REFHYNE Project-10MW PEM Electrolyser). This provides the double advantage of lowering emissions from fuels and other refining products, while at the same time allowing the storage of excess renewable electricity generated when supply exceeds demand. As an example of the potential evolution of the industry, this technology also has the potential to strengthen the EU refining industry's leadership position in the deployment of future low-carbon solutions such as PTL and H_2 for mobility.

- The development of alternative fuels for production and for distribution is also an area of high interest for companies operating in the downstream petroleum industry. A project to produce methanol (see Annex 3H, Production of methanol) and the deployment of a hydrogen refuelling station in Germany are notable examples.

- Another important example of the contribution that refineries can provide to a low-carbon society is waste heat from refineries used for civil heating (so-called "district heating" (see Annex 4B, District heating project (MiRO) project).

FIGURE 13: THE REFINERY AS AN ENERGY HUB WITHIN AN INDUSTRIAL CLUSTER



- Many oil companies are also researching and planning the implementation of CCS systems, where CO_2 emitted from industrial activities (including refineries) is collected and stored in safe and permanent reservoirs (usually depleted oil or gas reservoirs) (see Annex 4C, Full-scale Carbon Capture & Storage value chain project).

- In product distribution, some service stations are making available a wide range of alternative fuels and energy to drivers. They are also using self-generated renewable energy to make the service stations themselves energy- and carbon-neutral.

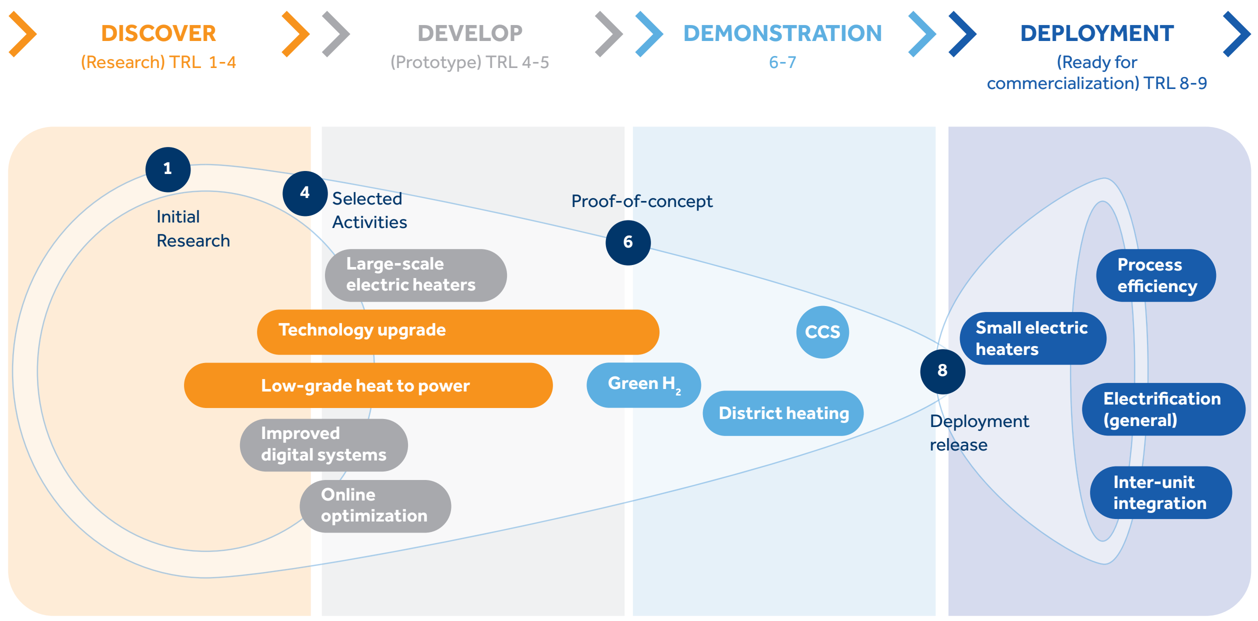
- Joint innovative business approaches in transport: The refinery and distribution industries are contributing jointly, together with other stakeholders, to several initiatives that could have an impact on consumers' lifestyles. An example is initiatives in urban car-sharing.

These low-emission technologies are at different stages of maturity (see figure below) and future R&D programmes will need to be incentivised in order to bring them to scale in the implementation phase. They will then help to make sustainable raw materials more available and increase their process efficiency, bringing costs down during both demonstration and deployment stages.

Future R&D programmes will explore how to boost cross-sectoral collaboration in an innovative way. Digitisation will enable the next production revolution, and future technology breakthroughs could also be envisaged to help mitigate climate change if the right innovation framework is put in place.

An EU technology strategy will be key to defining the bases of future low-emission technologies.

FIGURE 14: THE TRANSITION TO THE REFINEY 2050 HAS ALREADY STARTED: EXAMPLES OF R&D PROJECTS



TRL: Technology Readiness Level

Source: Concawe, Low Carbon Pathways, April 2018.

3.

QUANTITATIVE ASSESSMENT OF CARBON ABATEMENT POTENTIAL AND RELATED COSTS

3.1. GHG emissions from refineries

The CO_2 efficiency of European oil refineries has the potential to evolve in the future thanks to the combined deployment of new technologies. Other important factors include external market conditions, energy and CO_2 prices, and changes in product ratios. Provided a good regulatory framework is in place and effective commercial viability of the opportunities is identified, there is potential to achieve significant reductions in the CO_2 emissions associated with oil refining, first by 2030 and then by 2050.

A preliminary assessment conducted by Concawe[14] explores this potential. The first part of the assessment is purely focused on the technologies and their potential up to 2050, in a scenario where demand is constant from 2030 to 2050.

The preliminary results show that, when all options are used, the total CO_2 emissions intensity of EU refineries can be reduced by 20% to 30% by 2030 compared with the 2030 Reference Scenario. (The Reference Scenario is defined assuming similar complexity in the refinery sites, no additional technologies and - as already mentioned - no changes in the total demand ratio of refining products).

Concerning 2050, if we consider technologies related to energy efficiency, the use of low-carbon energy sources and the capture and storage of CO_2, EU refining emissions could be reduced by up to 70% compared with the 2030 Reference Scenario.

The capex required to implement the above-mentioned scenario to 2030 and 2050 is estimated at a minimum of €50,000 million for the whole EU refinery system (this figure is subject to revision after Concawe's work). This estimated cost refers only to the generic cost of the different technologies and opportunities identified and excludes investment outside the refining site as well as the relevant operating costs. Also, the actual cost of implementation will be determined by conditions specific to each individual asset.

The preliminary results of the detailed analysis (Interim report) include the following:

- Energy efficiency improvements of up to 15% by 2030 and 25% by 2050 compared with the 2030 Reference Scenario may be achieved. This is equivalent to an average annual improvement of about 0.7% for the period to 2050, slightly above the average for the past 25 years and in line with more recent data.

- The progressive availability of low-carbon electricity in the average EU mix could open up a number of routes for large savings in emissions by substituting fossil-generated electricity. These routes could additionally reduce EU refinery emissions by up to 25% by 2050, bringing the total electricity consumption of the sector close to 180 TWh/y. That would represent as much as 5% of the electricity currently generated in Europe. However, this would be conditional on the effective large-scale deployment of renewable electricity in Europe at an affordable price for industrial users. Recovery of low-grade heat can make a small contribution either through the internal production of electricity or by exporting heat, e.g. to district heating schemes.

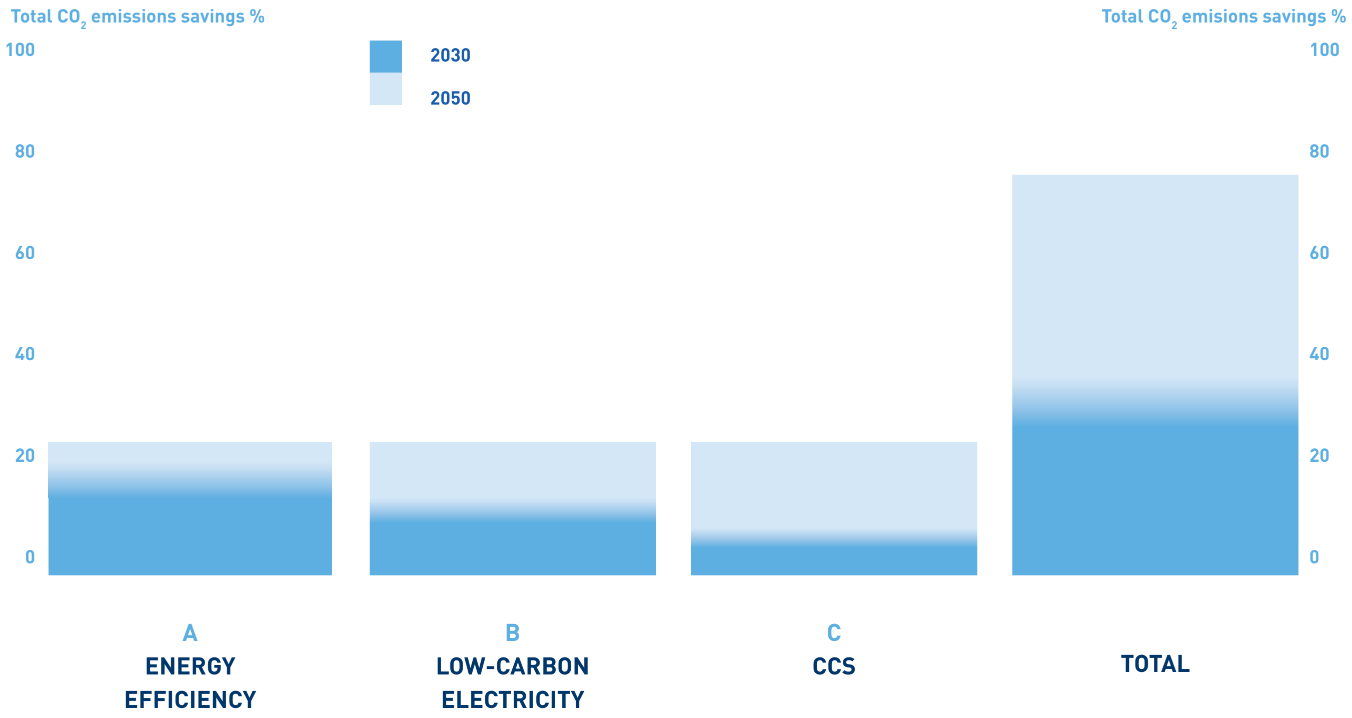
- The successful implementation of CO_2 capture (and storage or usage) appears crucial to reducing EU refineries emissions in the longer term. Total 2050 emissions savings would jump from 50% with no CCS to 70% with the effective deployment of CCS projects throughout the industry. However, the degree of penetration of CCS and the associated timeframe remain uncertain, as it is not clear how many sites will be able to implement it and have access to permanent storage facilities.

[14] Concawe, Low Carbon Pathways CO_2 efficiency in the EU Refining System. 2030 / 2050 – Executive Summary (Interim report), April 2018.

In summary, the potential savings of CO_2 emissions compared to the 2030 reference scenario could be 20% to 30% by 2030, going up to 70% by 2050.

Figure 15 shows the total emissions savings, including emissions from the production of imported electricity and (renewable) hydrogen, for the main opportunities identified. Each column shows the cumulative potential for a specific category for the 2030 horizon, with increasing deployment towards the 2050 horizon.

FIGURE 15: POTENTIAL CO_2 EMISSIONS SAVINGS FOR THE EU REFINING SYSTEM



Source: Concawe, Low Carbon Pathways CO_2 efficiency in the EU Refining System. 2030 / 2050 – Executive Summary (Interim report), April 2018.
Note: 2030 horizon (solid colour) with a higher deployment for the 2050 Horizon (colour degradation reflecting the uncertainly associated to the longer-term timeframe considerated).

Under these assumptions, the identified technologies may have the potential to contribute to CO_2 emissions savings close to 80% in 2050 compared with 1990 levels.

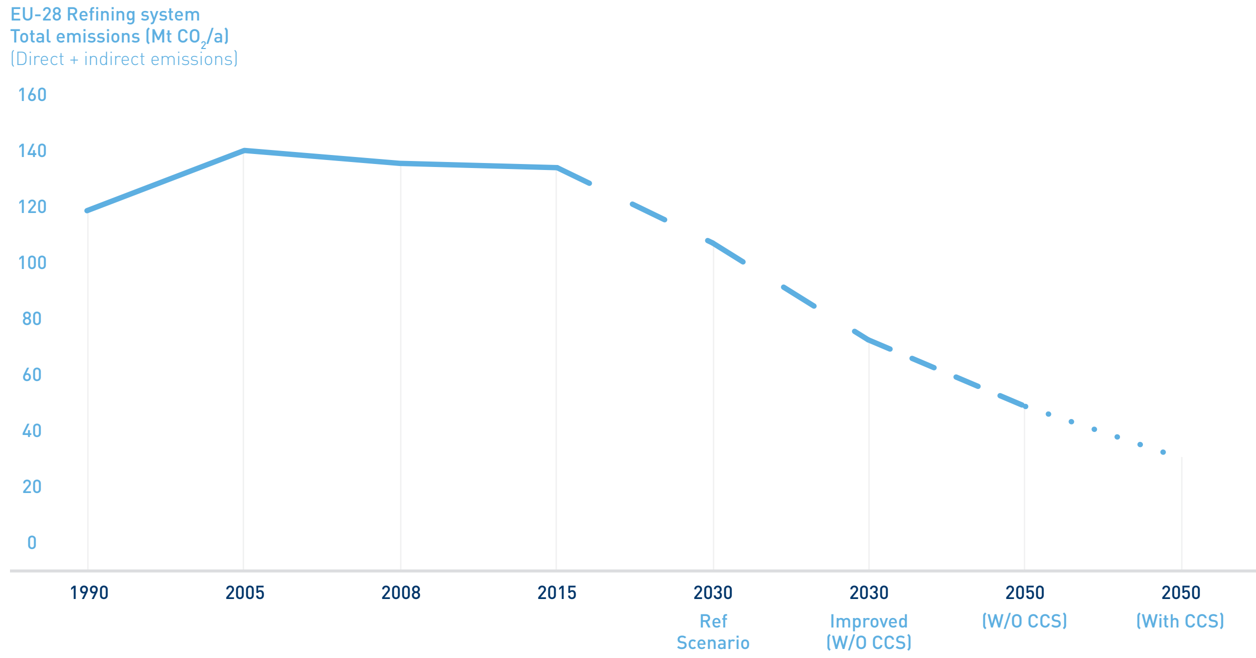
Work is currently ongoing to explore how total GHG emissions – both at site and end-use level – could be further reduced. This will depend on different demand scenarios, the effective deployment of low-carbon technologies and an increased uptake of bio and alternative feedstocks by refineries.

Improving the CO_2 efficiency of refineries at significant scale by 2030 or 2050 will require technological development. In a number of areas identified by Concawe, the refining industry and its technology providers can offer continuous improvements, as well as other projects. But cross-sectoral R&D projects might be required to accelerate the process.

Additional CO_2 savings (even negative emissions) could be achieved if we consider the potential for integrating non-petroleum-derived feedstocks into the refinery diet. However, the major benefit of these bio-feedstock technologies would come from the final use of products and fuels that contribute to a significant reduction in WTW CO_2 intensity.

While the combination of these technologies shows a potential pathway based on different assumptions, it is not intended to be a roadmap for the EU refining industry as a whole. Factors such as the CO_2 efficiency of existing facilities, coupled with local and structural constraints, will determine the potential of individual refineries to contribute to a mitigation of climate change.

FIGURE 16: EU-28 REFINING SYSTEM – TOTAL EMISSIONS



Source: Concawe, Low Carbon Pathways, April 2018.

Direct emissions: GHG released into the atmosphere from sources in an installation – i.e. emissions that occur inside the system boundaries of a refinery.

Indirect emissions: Emissions linked to the electricity consumed by the sector. To determine the emissions related to the production of electricity consumed, electricity consumption needs to be converted into emissions by using an electricity emission factor. This represents the emissions intensity of the electricity generation (this refers to emissions that occur outside the refinery, upstream).

3.2. Widespread adoption of low-carbon fuels in light-duty road transport (passenger cars and vans) – scenarios

The aim of this section is to answer the question: "What level of carbon abatement can potentially be achieved in light-duty road transport through the use of low-carbon liquid fuels? And at what cost?".

The results presented have been elaborated by Concawe, based on several third-party studies but mainly on a study performed by Ricardo for Concawe[15].

The methodology adopted in the Ricardo study to assess the GHG emissions in transport was to look at the life-cycle emissions – i.e. the CO_2 emitted during the manufacturing and disposal of the vehicle; the production of fuels or energy; and the use of fuel or energy in the vehicle. As we saw in previous sections, such a holistic approach is the most suitable to provide a conclusive analysis of the impact of various technologies on the global climate.

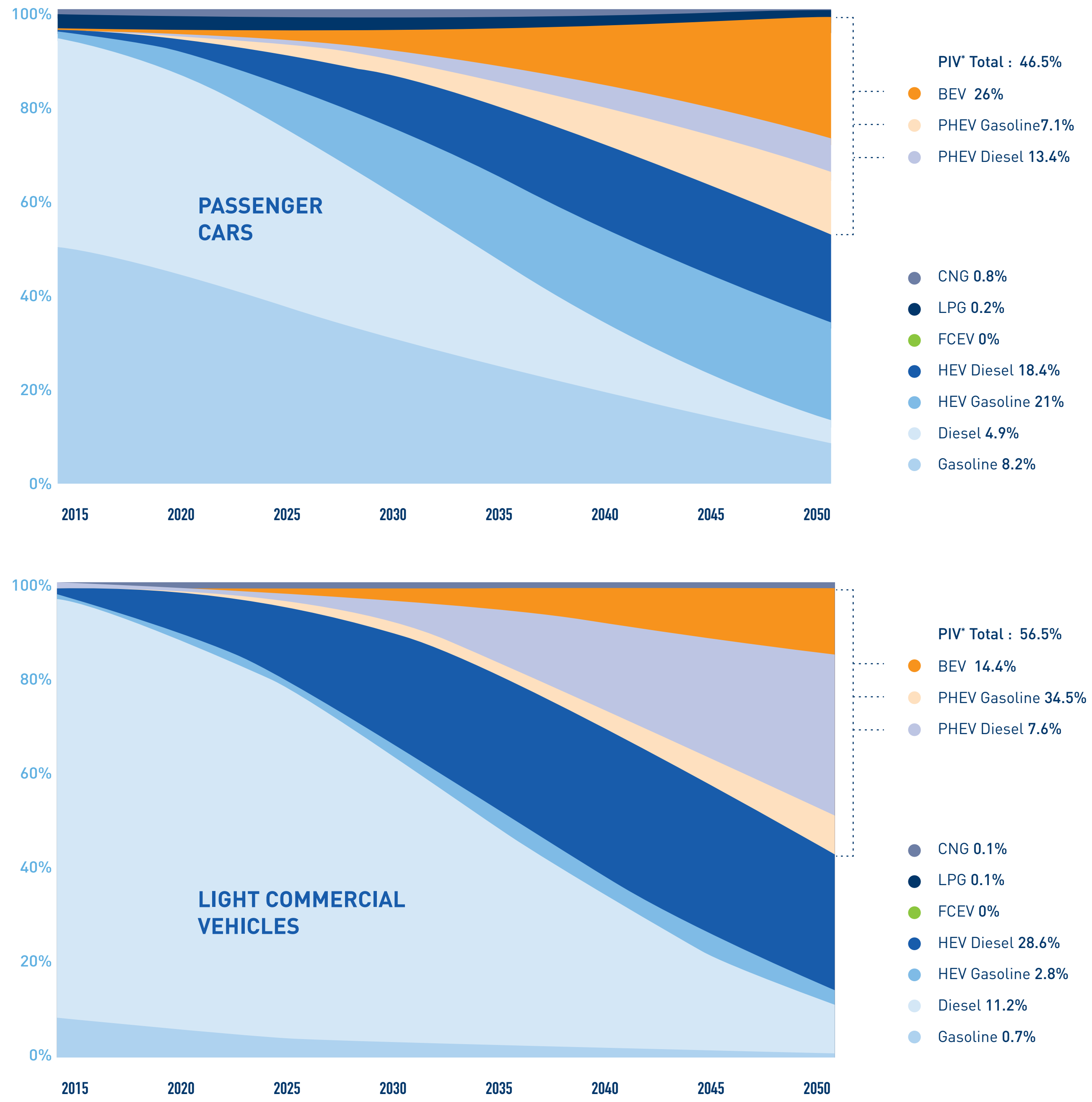
The study assumes an evolution of the car and van parks in the EU from 2015 until 2050 and in parallel a transition towards fuels and energy of a lower energy intensity.

In the scenario called Low-Carbon Fuels:

- New car sales see a progressive reduction of gasoline and diesel vehicles from more than 80% in 2015 to zero in 2050. At the same time, sales of hybrid electric cars increase very significantly, from about 5% in 2015 to almost 40% in 2050.
- Sales of plug-in cars – i.e. those partially or fully powered by an externally chargeable battery – grow the most. In 2050 these achieve more than 60% market share.
- However, the car parc - as a consequence of the turnover time of vehicles in use – is still more than 50% gasoline, diesel and hybrid in 2050.
- For light commercial vans, the trend is similar to that of cars, albeit with a quicker uptake of plug-ins.
- This scenario consists of a combination of conven-tional and electrically-powered vehicles.

[15] Ricardo, Impact Analysis of Mass EV adoption and Low Carbon Intensity Fuels Scenarios, July 2018.

FIGURE 17: VEHICLE PARC IN THE LOW-CARBON FUELS SCENARIO



PIV: Plug-in-Vehicle
HEV: Hybrid Electric Vehicle
Source: Ricardo, Impact Analysis of Mass EV adoption and Low Carbon Intensity Fuels Scenarios, July 2018.

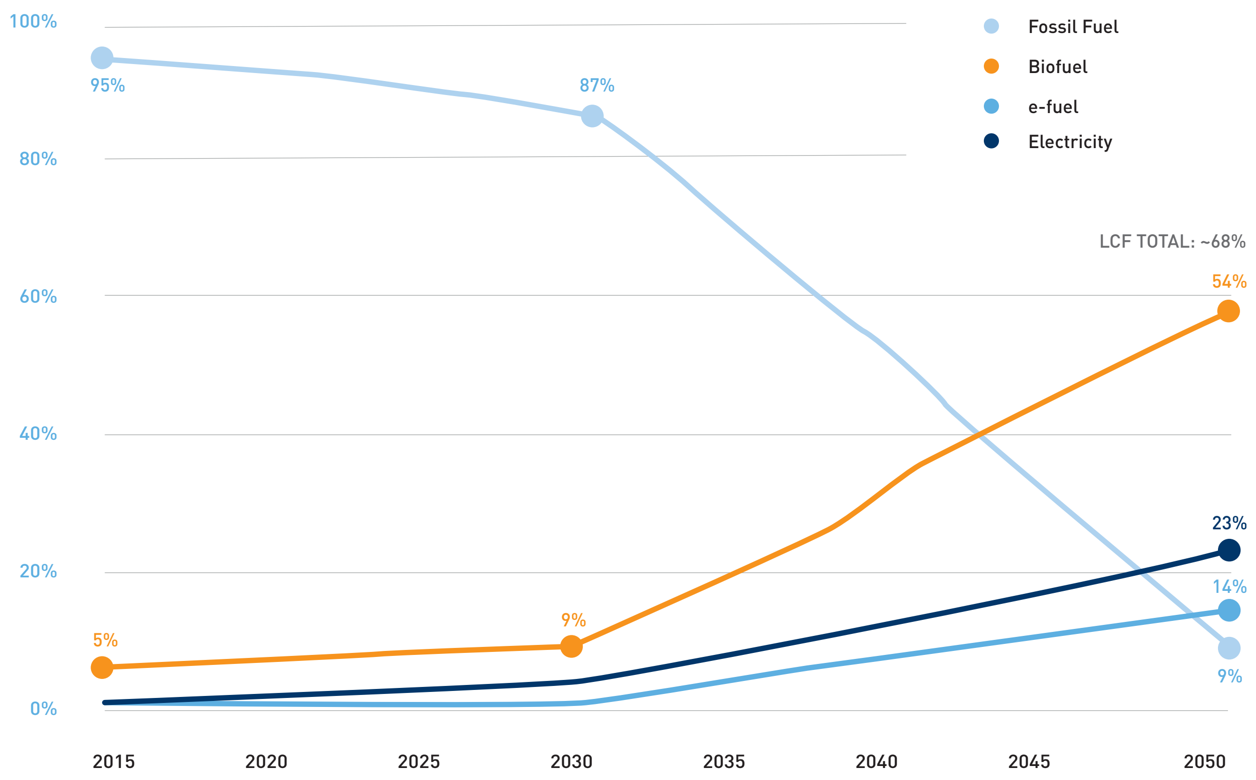
WHAT ENERGY IS USED TO FUEL THESE CARS AND VANS PARC?

The first important result is that **liquid fuels remain by far the most important form of energy** used in light duty road transport, as ICEs (full, hybrid and plug-in hybrid) are present in the vast majority of the vehicle parc. In fact, liquid fuels very slowly decline from 90% in 2015, to about 90% in 2030 and almost 80% in 2050.

What actually changes, however, is the **make-up of the low-carbon liquid fuels pool**: starting from 2030, fossil diesel and gasoline steeply decline and are replaced by **biofuels and e-fuels (renewable PTL)**, respectively accounting for more than 50% and more than 15% in 2050.

The share of **electricity** steadily increases during the period, growing from almost zero in 2015 to more than 20% in 2050.

FIGURE 18: FUEL SHARE BY ENERGY IN THE LOW-CARBON FUELS SCENARIO



Source: Ricardo, Impact Analysis of Mass EV adoption and Low Carbon Intensity Fuels Scenarios, July 2018.

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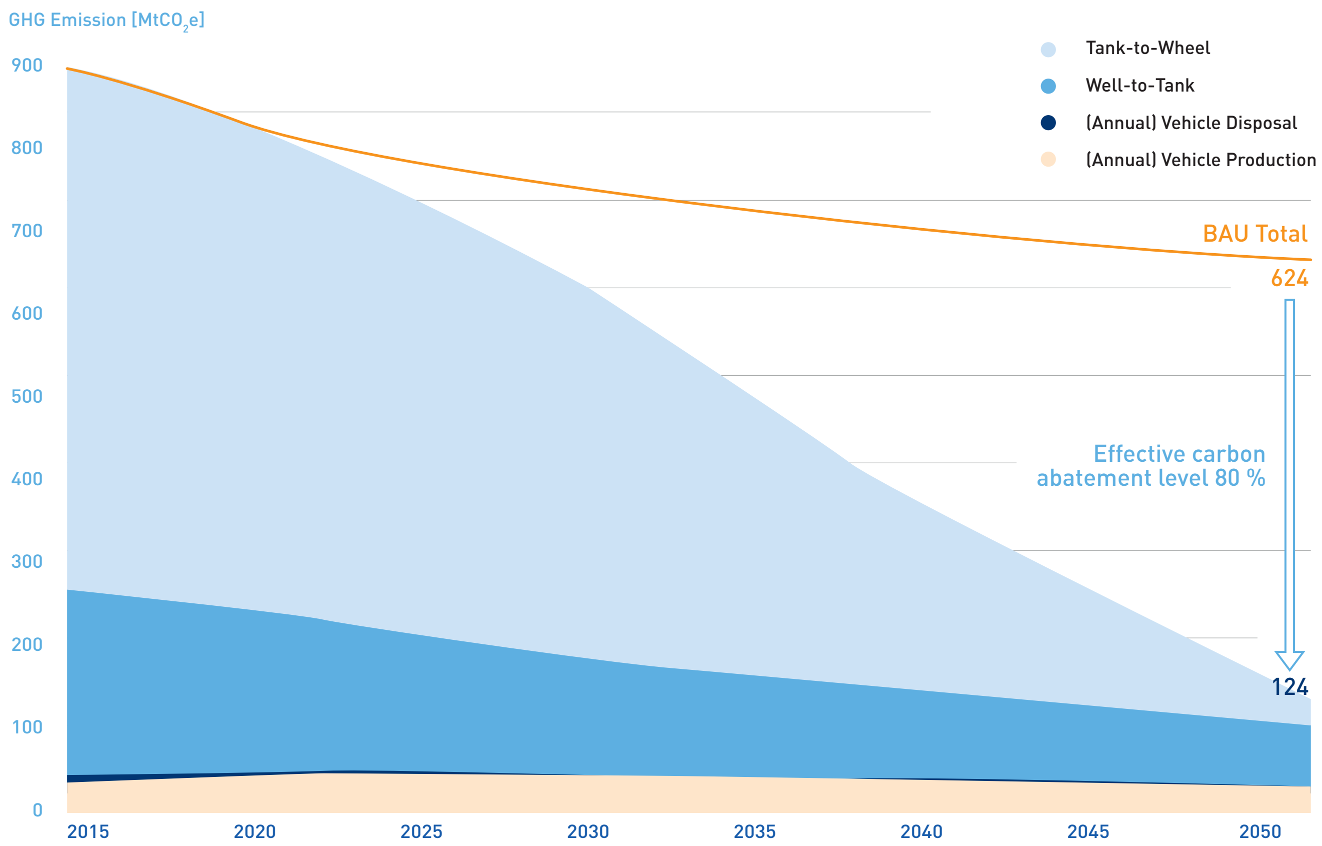
WHAT LEVEL OF CARBON ABATEMENT IS ACHIEVED UNDER THE LOW-CARBON FUELS SCENARIO?

As illustrated in the Figure 19, the life-cycle (i.e. WTW and vehicle-embedded) GHG emissions in EU light-duty road transport decline to less than 13% of the 2015 level by 2050.

Another result is also very significant. The 2050 TTW GHG savings from light-duty road transport are about 90% compared to the 1990 level. This compares to the EU objective of 60% TTW GHG savings from all transport.

FIGURE 19: LIFE-CYCLE GHG EMISSIONS IN EU LIGHT DUTY ROAD TRANSPORT



Source: Ricardo Energy & Environment SULTAN modelling and analysis.

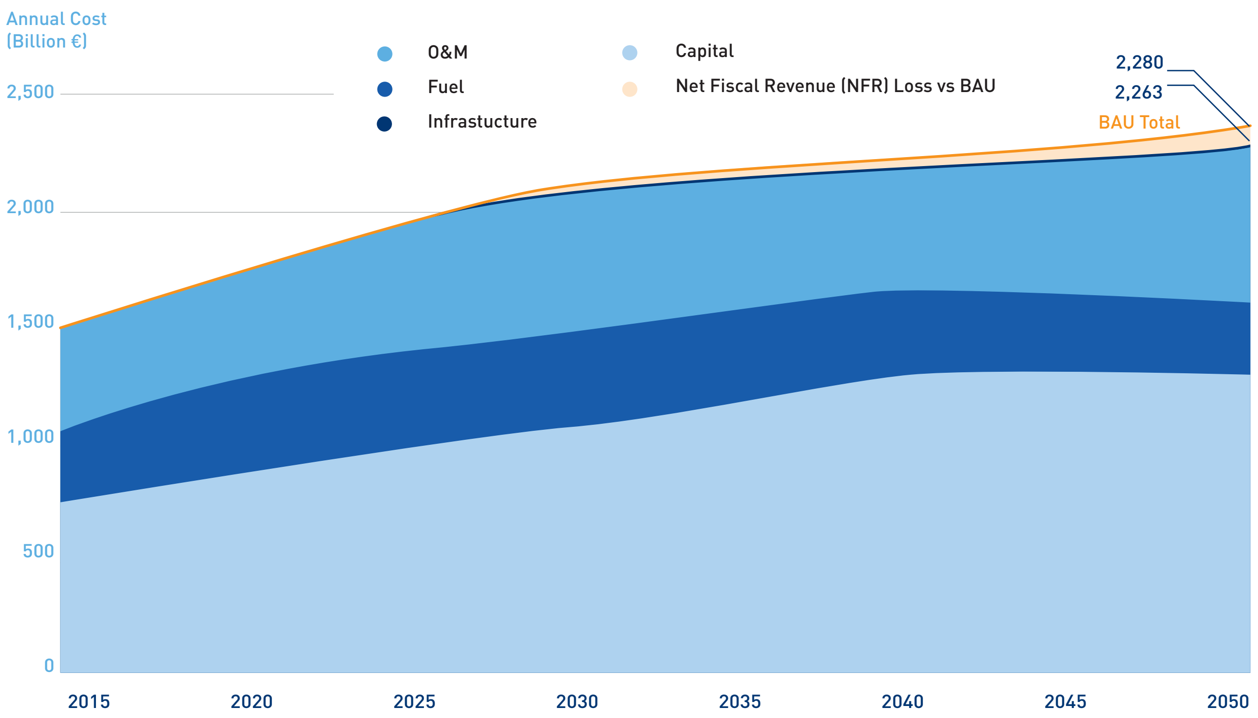
THE NEXT IMPORTANT QUESTION IS ABOUT THE COST ASSOCIATED WITH THE LOW-CARBON FUELS SCENARIO

From the point of view of the end-user (see Figure 20), the total parc annual cost is even lower than in the business-as-usual scenario[16]. The trend in the following chart shows that the cost is essentially the same until 2030, then progressively diverges to reach 2,263 billion €/y in 2050 for the Low-Carbon Liquid Fuels Scenario and 2,280 billion €/y for business as usual.

The cost of reducing emissions (in euros per tonne of CO_2 cut) in the Low-Carbon Liquid Fuels Scenario is therefore negative. That is, the cumulative reduction in GHG emissions in the Low-Carbon Liquid Fuels Scenario is about 4,500 Mt CO_2 compared with business as usual, at a lower cumulative cost for the end user.

[16] The Business as Usual or BAU scenario represents the default position if no changes are made to policy or legislation from those are in place or pending implementation today.

FIGURE 20: COST ASSOCIATED TO GHG REDUCTIONS IN THE LOW-CARBON FUELS SCENARIO



Source: Ricardo Energy & Environment SULTAN modelling and analysis.

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The Ricardo study also compares the results of the Low-Carbon Liquid Fuels Scenario to the high EVs scenario, which assumes light-duty vehicle registrations will consist 100% of BEV by 2040 and the vehicle parc will be about 90% BEVs in 2050.

The most significant results of this comparison are the following:

- The total parc life-cycle GHG emissions decline in approximately the same way in both scenarios, with an edge in favour of the Low-Carbon Liquid Fuels Scenario: 124 Mt CO_2 emitted in 2050 vs. 135, and about 270 Mt CO_2 cumulatively lower in the period 2015 – 2050.
- The annual cost to end-user for the total park is slightly higher for the high electric vehicles scenario until 2035 but then becomes lower than the low-carbon liquid fuels scenario (70 billion €/y in 2050, or 3% lower). However, taking away the impact of the net fiscal revenue loss (up to 66 billion €/y lower for the high electric vehicles scenario), the two scenarios have approximately the same end-user cost.
- The role played by externalities in the comparison is also important. Externalities are defined by Ricardo as the societal cost associated with emissions of GHG, nitrogen oxides (NO_x), sulphur oxides (SO_x) and particulate matter (PM). In 2050 the cost of externalities in the Business-As-Usual Scenario is almost 130 billion €/y, and they are very significantly reduced both in the Low-Carbon Liquid Fuels Scenario (less than 30 billion €/y) and the high EVs scenario (slightly above 20 billion €/y).
- Another important consideration is societal cost, which is defined as the end-user cost minus fiscal revenues plus externalities. Until about 2040, the cost of externalities is higher in the high EVs scenario than in the Low-Carbon Liquid Fuels Scenario. In the last 10 years of the period analysed, however, the opposite occurs and the societal cost in 2050 in the high EVs scenario is 33 billion €/y, or 3% lower than in the Low-Carbon Liquid Fuels Scenario.

Vision 2050

3.3. Conclusions

The main conclusion that can be drawn from the results of the Ricardo study is very clear. It may shake some of the commonly held views about the future emissions reduction potential of the light-duty transport sector.

The use of low-carbon liquid fuels (e.g. sustainable biofuels, e-fuels and PTL), in combination with the partial electrification of the vehicle park and further improvement in the energy efficiency of the ICE vehicle, is as effective and efficient in the reduction of life-cycle GHG emissions from light-duty road transport as full electrification of the vehicle park.

The following points are particularly striking:

a. Both scenarios cut 2050 life-cycle GHG emissions to less than 13% of the 2015 value.

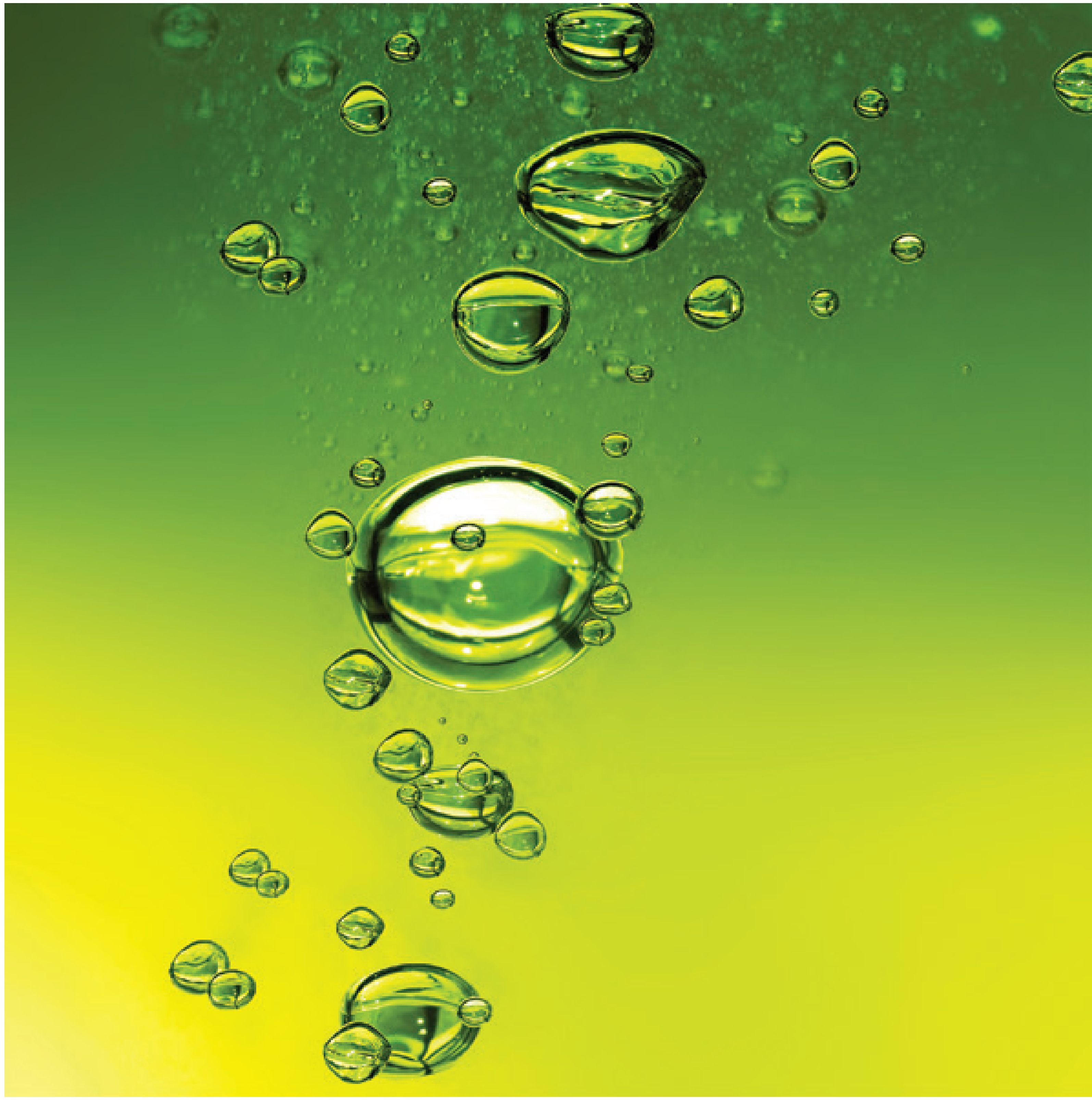
b. Low-Carbon Liquid Fuels Scenario achieves marginally higher life-cycle emissions reduction than the high EVs scenario. In terms of TTW, the Low-Carbon Liquid Fuels Scenario reduces the emissions of light-duty road transport by 90% in 2050 from the 1990 level.

c. In terms of both cost to end user and societal cost (including externalities), the two scenarios are practically equivalent.

Some other results of the Ricardo study deserve to be mentioned among the main conclusions. In particular:

- The cost of charging infrastructure in the high EVs scenario is very significant (€630 billion cumulative up to 2050) and contributes to making the two examined scenarios very similar in terms of both end-user and societal cost.
- There are potential risks in the high EVs scenario. One is the issue of the security of supply of key resources for battery manufacturing. Another is the increased battery production rates required to effect a complete transition to BEV by 2040.
- The substantial (up to 66 billion €/y) reductions in net fiscal revenues in the high EVs scenario would certainly require changes in the generation of tax revenues.
- Due to the rapid rate of progress in technologies and their costs, there are other significant uncertainties:

1. The future evolution and costs of battery technology, as well those of ICEs.
2. The infrastructure requirements to support a wholesale shift to battery EVs.
3. the carbon efficiency and costs of low-carbon liquid fuels.
4. The evolution of the carbon footprint and of the cost of EU electricity.
5. The availability of advanced biofuels and e-fuels.
6. Consumer purchase preferences (see text box p23).
7. The impact of autonomous driving and shared car ownership which has not been considered.



4.

POLICY AND REGULATORY TRANSITION TO MAKE THE VISION A REALITY

4.1. An industrial opportunity for the EU and the role of policy

As described in the previous sections, the manufacture of low-carbon liquid fuels and products and the systems they are used in have huge potential to contribute to the EU goal of a low-GHG economy. This presents a great industrial opportunity for the EU to further enhance its global leadership in actions to address climate change.

It also leverages its technological know-how, flexible infrastructure and skilled workforce. Hence the EU can create a modern industrial value chain that reliably supplies products, while at the same time fulfilling its climate ambitions. The oil refining and distribution industry has the capability to deploy its vast R&D potential and financial resources to develop the low-carbon products and business models necessary for the energy transition. It can also bring them to market in close cooperation with the most industrial sectors involved.

At the same time, a suitable regulatory framework is needed to ensure that this industry can remain competitive against non-EU refineries. Policymakers at EU and national level have a crucial role in making this happen, by creating the right regulatory framework to encourage and enable investments and the development and implementation of innovative technologies.

It is essential to have an EU industrial policy that establishes the conditions for European refineries to evolve and innovate in order to ensure the technical development needed for the future industrial landscape.

4.2. Disruptive technologies and policy support

Many examples exist of the successful adoption of disruptive technologies. These include electricity replacing kerosene in home and street lighting and the ICE replacing the horse-pulled cart in transportation. Computers, mobile telephony, digital photography, robotics and the internet are other examples. They all share a common feature: their fast, exponential roll-out was due to their superiority in terms of consumer value; it was not the result of regulatory mandates or policy support for specifically selected technologies.

An objective-driven and market-based approach will generally allow new technologies to emerge at the lowest cost to society. But in some cases, time-limited direct support is justified to encourage the research, development and initial market penetration of novel technologies aimed at tackling issues of utmost importance.

Where time-limited direct support is provided, policymakers should create a level playing field so that all promising technologies with the potential to meet the policy objectives can develop and compete once they reach the market. Policymakers should avoid picking specific technologies for policy support based on arbitrary selection criteria. While this might help the pre-selected technologies to mature, it also inhibits the development of alternatives. It is unwise to deny diverse solutions the chance to compete and to place trust in selected new technologies that have not yet proven their superior value for consumers or for society as a whole.

4.3. Return on investments and public recognition for low-carbon technologies

It is a key requirement of the regulatory framework that it creates the conditions for the remuneration of investments in those new technologies that contribute to the achievement of EU policy objectives. At the same time, citizens and consumers should be informed in a fair, transparent and unbiased way about the benefits and drawbacks of all the competing technologies. To this end, policy and regulations should also ensure a level playing field in the way the public is informed. This will facilitate a comprehensive, holistic approach so that the consumer can make informed choices with a complete understanding of the consequences.

4.4. The principles of an investment-friendly policy framework

Policy frameworks have a significant impact on investors' decisions. Investors have to balance financial risks with the prospects of returns. In a global business environment, investment decisions in different regions are determined by demand trends, trade opportunities and other factors such as operating costs and tax regimes. Another extremely important factor influencing decisions to invest is the regulatory environment. This is especially true in capital intensive industries such as oil refining, which are characterised by long investment cycles. To attract investments, certain policy principles should be fulfilled:

- A policy framework has to provide long-term stability over the financial lifetime of a project being invested in, which may be 15 years or more.
- Technology neutrality should be fulfilled by:
  1. Ensuring that regulations allow fair competition between technologies and avoid any bias in the way the benefits from each competing technology are accounted for.
  2. Providing support for R&D and early market deployment within defined limits in time and amount. This will allow a wide range of promising no-regret technologies to make progress on their learning curves.
  3. Providing the public with accurate information about the benefits of each technology, in a transparent and unbiased fashion.
- Measures have to be consistent throughout the EU, if not globally, to safeguard the internal market.
- Alternative compliance mechanisms are needed to prevent disproportionate impacts on obligated parties.
- Policy objectives should balance environmental, social and economic goals.
- When policies and regulations put EU industries at a competitive disadvantage compared to non-EU competitors, appropriate protective measures should be enacted to prevent the relocation of industries out of the EU.

4.5. The current framework for energy and climate policy and its shortcomings

The current approach to energy and climate policy is sector-based, in several cases mandate-driven, not always technology-neutral and lacking in long-term predictability. As a result, the most cost-effective solutions are not always pursued, and promising new technologies are only invested in if policymakers judge them worth supporting.

The adoption of a sectoral approach consists of addressing a general issue by applying different regulations to different sectors of the economy. The reduction of GHG emissions is driven through the following regulations:

- In the power and industrial sectors, mainly through a cap-and-trade system (ETS).
- In vehicles, mainly through CO_2 emissions standards.
- For fuels, indirectly through the RED II and directly through the FQD Art.7a; and through other pieces of legislation, such as the Energy Efficiency Directive. In addition, the choice of fuel or technology is significantly influenced by taxation.

The vehicle and fuels regulations also have an impact on the effort-sharing agreement for non-ETS sectors.

The lack of a holistic approach makes each regulation easier to implement and enforce, especially as the obligated party is clearly identified. But it can lead to sub-optimal solutions to a general problem. In the example of GHG emissions, the cost of abating one tonne of CO_2 varies significantly between sectors. Expensive technologies can be encouraged in one sector to achieve a reduction in GHG emissions that other technologies applied in other sectors could bring about more economically.

Mandates on specific technologies, disregarding the technology neutrality principle, are implicit in the CO_2 emission standards for vehicles. While a target can, in theory, be met by diverse technologies, the adoption of a TTW methodology is biased in favour of technologies with low or zero CO_2 emissions in the phase of vehicle use. It ignores the GHG emissions associated with the production of fuels and other energy used in the vehicle and those emitted during the manufacturing and disposal of the vehicle. It also fails to take into account the origin of the CO_2, which might come from a renewable source, as in the case of biofuels. In fact, to meet the CO_2 emission standards vehicle manufacturers have a strong incentive to produce and sell so-called "low- and zero-emission vehicles", and to focus their investments on developing technologies relevant to these. The drawback is that investments to exploit the huge potential for further efficiency improvements in conventional vehicles are given low priority or neglected. Moreover, this regulation gives fuel manufacturers no incentive to invest in and develop low-carbon fuels, as their contribution to emissions reduction in transport does not count.

One important shortcoming of the current regulatory framework is the lack of reward for investments in innovative, low-carbon technologies for refineries and their products. In fact, the ETS incentives for carbon savings are insufficient to allow the remuneration of big investments in refineries. This has an impact, for instance, on projects to develop carbon capture and storage or use, which aim to cut the GHG emissions associated with the manufacture of oil products. In the case of low-carbon liquid fuels, only the RED II gives credit to substantial projects for PTL or advanced biofuels, and the predictability of the rules is uncertain. Given the design of the CO_2 standards, there will be no recognition of the benefits that vehicle manufacturers get from advances in fuels.

Another obstacle to address is regulatory certainty. If investments are made on the basis of a specific policy option, subsequent political changes that alter this policy can have huge impacts on those investments. When the biodiesel and renewable energy industries lost their regulatory support in several EU countries, their business cases collapsed, and they strongly reduced their output. Regulatory certainty can be improved by also avoiding overlaps between regulations and ensuring regulatory complementarity. For this purpose, the European Commission should periodically carry out an appropriate assessment of the impact of new pieces of legislation and of the overlap of existing regulations.

ANNEXES
A pathway for the Evolution of the Refining Industry and Liquid Fuels

ANNEX 1
EU Law imposing GHG emissions reduction on the transport sector

Specific pieces of EU law demand reductions in GHG from the transport sector. Two laws in particular have a significant impact on transport fuels: FQD and RED II. The ETS also plays a significant role in emissions abatement for European industry, including refining.

The FQD requires a 6% reduction in the GHG intensity of the fuels used in vehicles by 2020 compared to the EU-average level of life-cycle GHG emissions per unit of energy from fossil fuels in 2010 and regulates the sustainability of biofuels. It has already brought about large reductions in the sulphur content of fuels, leading to the deployment of vehicle technologies that reduce emissions of GHG and air pollutants and deliver substantial health and environmental benefits. The GHG intensity of fuels is calculated on a life-cycle basis, meaning that the emissions from the extraction, processing and distribution of fuels are included.

According to the RED II, all EU countries must ensure that at least 10% of their transport fuel comes from renewable sources by 2020. The text also sets out sustainability criteria for all biofuels produced or consumed in the EU. To be considered sustainable, biofuels must achieve GHG savings of at least 35% in comparison to fossil fuels. This requirement rose to 50% in 2017 and 60% in 2018 – but only for new production plants. All life-cycle emissions are taken into account when calculating the GHG savings. This includes emissions from cultivation, processing and transport.

In 2020, emissions from sectors covered by the system will be 21% lower than in 2005. In 2030, under the under the revised EU ETS Directive (2018/410), they would be 43% lower.

GHG emissions in the transport sector increased between 1990 and 2015, both in relative and absolute terms as shown in the figure below.

FIGURE 1: GREENHOUSE GAS EMISSIONS, ANALYSIS BY SOURCE SECTOR, EU-28, 1990 AND 2015
(Percentage of total)

	1990	2015	Share 1990	Share 2015
Fuel combustion and fugitive emissions from fuels (without transport)	3,554,774	2,454,082	62.2%	55.1%
Transport (including international aviation)	851,082	1,048,070	14.9%	23.6%
Industrial process and product use	516,886	373,937	9.0%	8.4%
Agriculture	548,270	436,784	9.6%	9.8%
Waste management	240,948	139,313	4.2%	3.1%
Total (without LULUCF, with int.aviation)	5,711,969	4,450,151	100%	100%

Source: EUROSTAT, GHG statistics tables and figures update, 2017.

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However, the European Environment Agency (EEA) data on GHG emissions show that between 2006 and 2015 total emissions from fuel combustion in road transport decreased in the EU-28 while the number of vehicles and kilometres travelled increased.

FIGURE 2: EU-28 TOTAL EMISSIONS FROM FUEL COMBUSTION IN TRANSPORT

	2006	2007	2008	2009	2010	2011	2012
European Union (28 countries)	919,687.43	930,594.17	907,134.33	883,165.35	878,080.31	868,655.49	842,471.48

	2013	2014	2015
European Union (28 countries)	838,238.55	848,351.01	862,088.61

Source: European Environment Agency.

UNIT: Thousand tonnes.
AIRPOL: GHG (CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent).
AIREMSECT: Fuel combustion in road transport.

FIGURE 3: AVERAGE CO_2 EMISSIONS PER KM FROM NEW PASSENGER CARS

Unit: g CO_2 per km

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EU-28								123.4	119.5	118.1
EU-27	158.7	153.6	145.7	140.3	135.7	132.2	126.7			

Source: European Environment Agency.

A clear increase in the number of vehicles per 1,000 inhabitants can be observed[1] and is complemented by small increases in lorries and road tractors. This implies a continued increase in the number of vehicles on the road and should, if all other things remain equal, translate into a significant increase in emissions.

Yet average CO_2 emissions per kilometre from new passenger cars, as shown by EEA and EC data[2], are steadily decreasing, proving that the efforts of the car and fuels industries have been successful.

[1] EUROSTAT publication Energy, transport and environment indicators (2016).
[2] EUROSTAT EEA GHG emissions statistics, EUROSTAT average GHG emissions per km in passenger cars, EUROSTAT EEA GHG emissions in road and interior aviation.

ANNEX 2
About EU Refining

A. The refining industry: an example of a positive evolution in the past and a key asset for the EU in the present

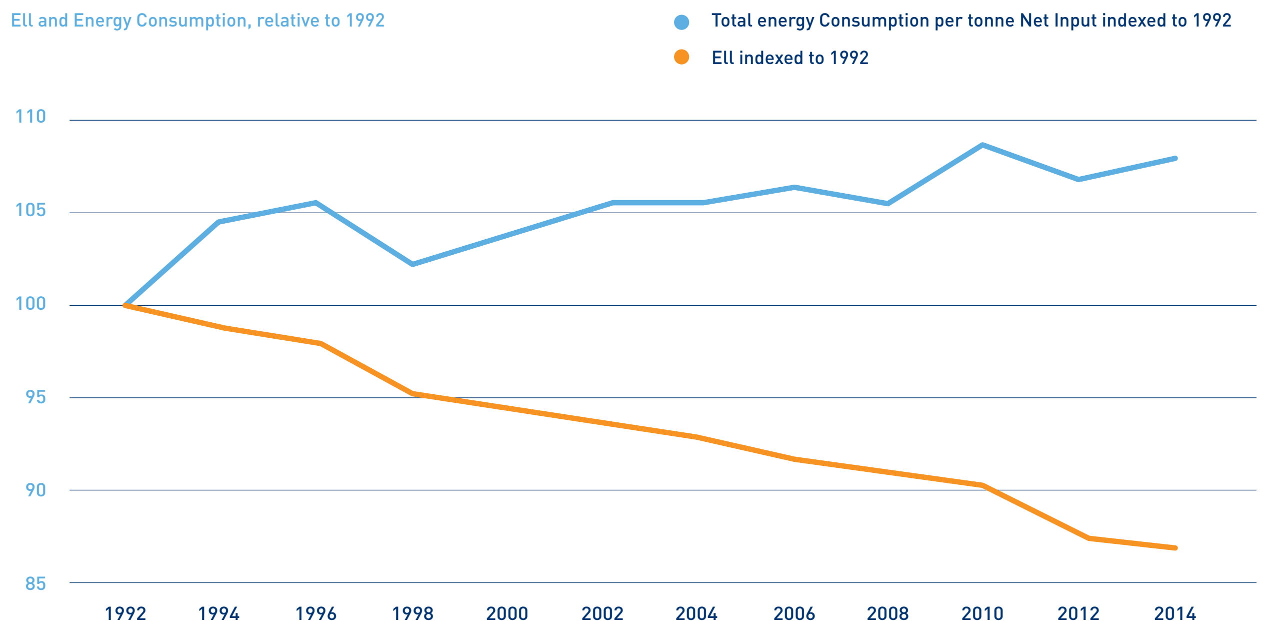
Over the last century, the refining industry has proved that it can evolve and improve, and contribute to better air quality and the mitigation of climate change.

a) Quality improvement:
Over time the final applications of petroleum products have become more sophisticated, requiring more stringent specifications related to safety, performance and pollutant emissions. This has led to an increase in the overall sulphur removal from crude oil in EU refineries from about 35% in 1992 to over 60% in 2010 (Concawe Report 3/13).

b) Energy efficiency improvement:
Individual EU refineries have been gradually using more energy because of shifting market demand and increased refinery complexity (and some increase in throughput) to support tighter product specifications (most notably lower sulphur content).

Refinery operations have, however, become more efficient. Their efficiency has risen by 13% over the last 22 years (see Figure 4). By 2010 this represented an annual average saving over the 1992 efficiency level of some 60 ktoe (2.5 PJ) per refinery, or over 4 Mtoe (167 PJ) for EU refineries as a whole. This annual saving is roughly equivalent to the total average annual energy consumption of four large EU refineries.

FIGURE 4: EU REFINERIES' ENERGY CONSUMPTION AND EFFICIENCY TRENDS RELATIVE TO 1992



Source: Solomon Associates, reported in Concawe Report 3/13.

Vision 2050 / **Annexes**

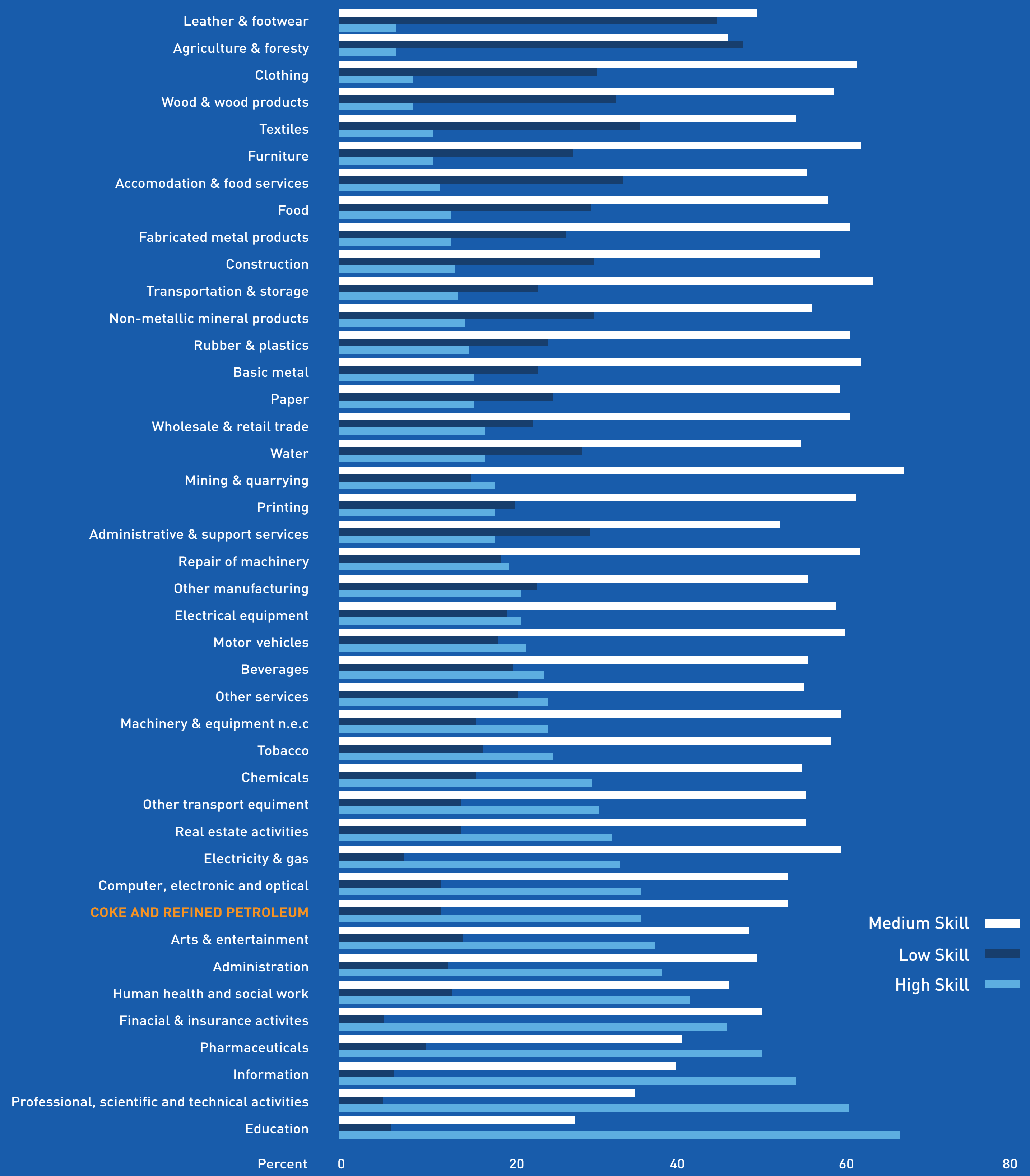
The EU Refining Fitness Check, conducted by the Commission, concluded that the EU refining sector accounts for a visible share of the EU manufacturing gross value added, contributes to EU jobs and and produces a substantial turnover:

- According to data found by the Commission, the EU oil refining sector directly contributed around 1.2% to manufacturing gross value added.
- The sector directly employs around 119,000 people and spends around €6.3 billion in wages and salaries annually. Wages accounted for 43.4% of the total value added; the remaining 56.7% included capital consumption and other taxes on production net of subsidies and profits.
- The EU refining industry has a total annual turnover of around €686 billion, or around €5.8 million per employee.
- The 80 petroleum refineries represent 17.33% of the world's total refining capacity.

Refined petroleum products are an important element of extra-EU trade: They account for the majority of EU energy exports. In 2013, Europe exported 96.6 million tonnes, or approximately 2 million barrels, of refined products daily, resulting in net imports of 89.4 million tonnes (BP Statistical Review of the World Energy 2014).

While intangible and therefore difficult to measure quantitatively, there could also be important positive externalities associated with the oil refining industry, such as knowledge spillovers from research and innovation. Figure 5 & 6 in pages 66 & 67 show the levels of product and process innovation taking place in different industry sectors across the EU. An immediate observation is that the sector "Manufacture of coke and refined petroleum products" is one of the most active industries in product and process innovation.

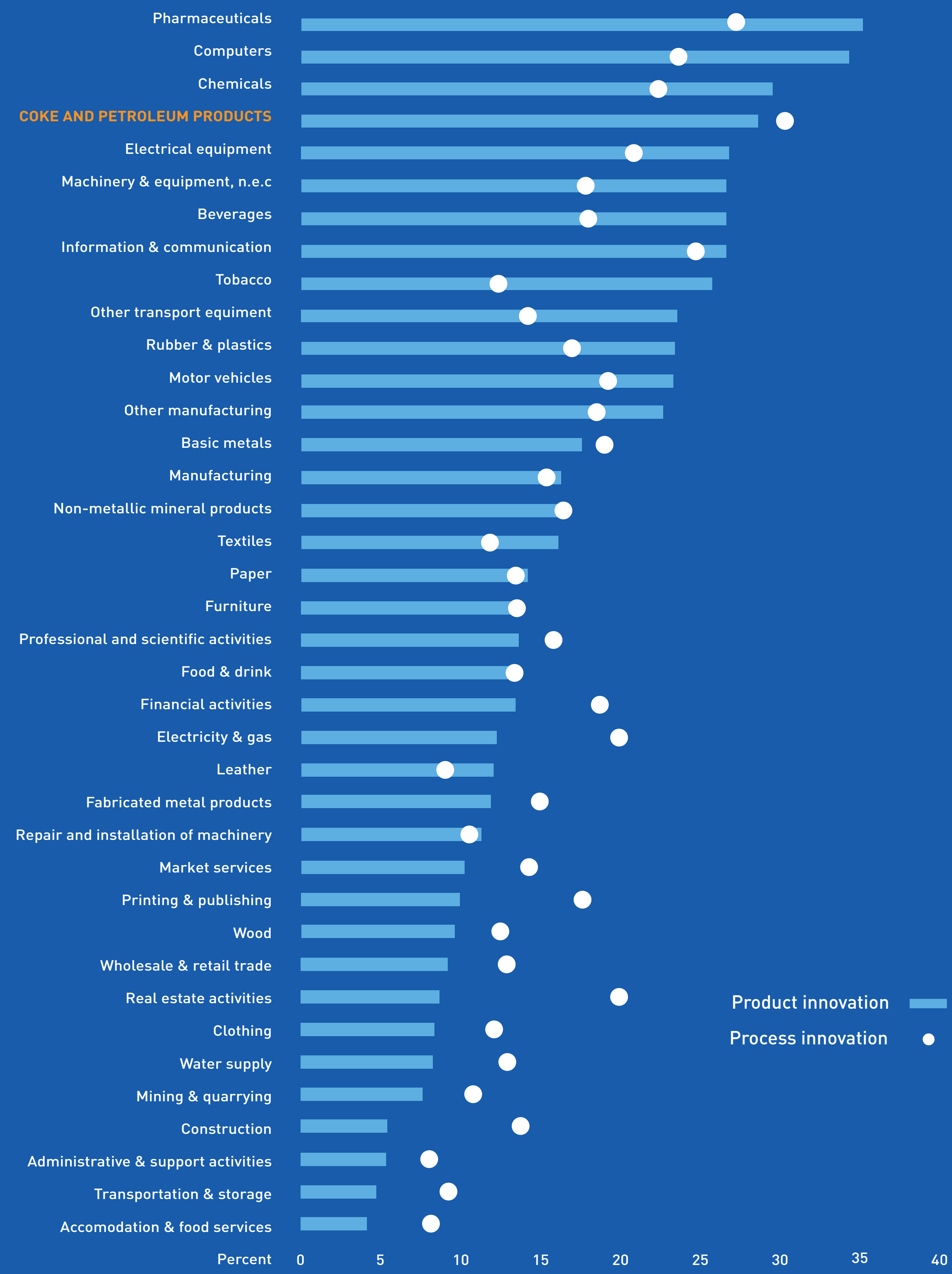
FIGURE 5: SHARE OF THE COMMUNITY INNOVATION SURVEY RESPONDENT COMPANIES REPORTING PRODUCT AND PROCESS INNOVATION ACTIVITIES



Source: European Commission, Sector highlighted by IPTS, 2013.

FIGURE 6: SKILL AND KNOWLEDGE INTENSITIES

(% of total employment)



Source: European Commission, Sector highlighted by IPTS, 2013.

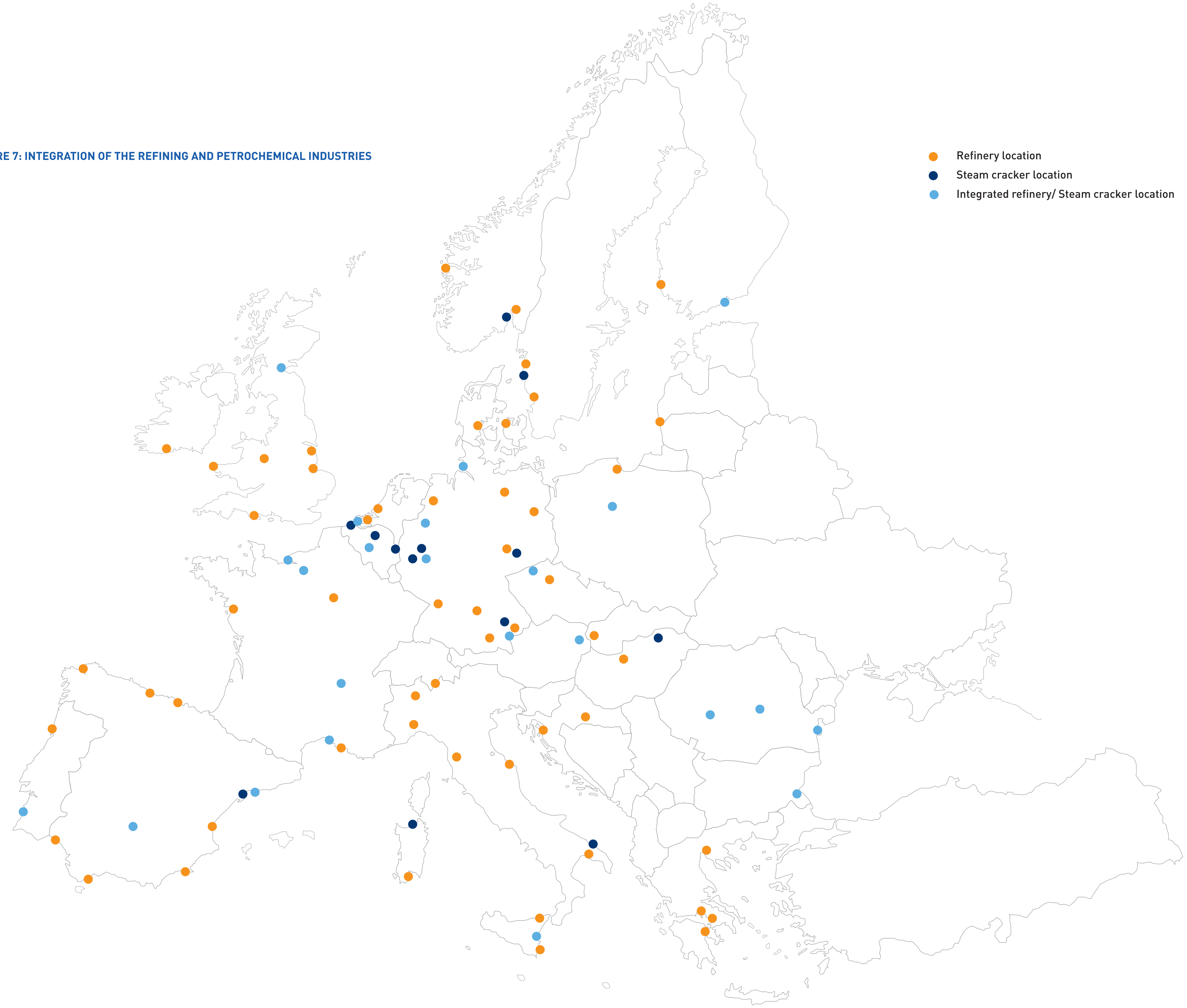
B. Refinery/steam cracker sites in Europe

Hydrocarbons are the main feedstock for the chemical industry for everyday products such as plastics, clothing and pharmaceuticals.

- 40 million tonnes of ethylene-based chemicals are produced in the EU every year[3]. The majority of the petrochemical feedstock (naphtha) is supplied by the refining industry.
- Many chemical and refining sites are integrated. Indeed, out of the 58 steam crackers (petrochemical units) located in the EU, 41 are integrated with refineries located, on average, less than two kilometres away. This proximity facilitates an efficient shared used of infrastructure, exchange of feedstock and by-products between the plants, as well as energy-efficient operations. Moreover, the integration of these industrial sites creates synergies, such as product pipeline interconnectivity, shared ports and common utility services.
- The symbiosis of the industries – refining and chemical – enhances the international competitiveness of the clusters.

[3] https://ec.europa.eu/energy/sites/ener/files/documents/20131127_2nd_meeting_cefic_competitivenes.pdf

FIGURE 7: INTEGRATION OF THE REFINING AND PETROCHEMICAL INDUSTRIES



C. Emission sources in a refinery

An oil refinery is made up of different complex interconnected processes, which produce a range of highly valuable petroleum products. While each plant is unique, they are all energy-intensive (typical range of 100 to 200 kg CO_2/tonne crude oil).

The example below[4], of a typical complex refinery, shows more than 10 emission sources, of which five represent 75% of the total CO_2 emitted. The CO_2 concentration fluctuates between 5% and 20% of volume.

[4] https://www.sintef.no/recap, "Understanding the cost of retrofitting CO_2 capture to an integrated oil refinery", published in June 2017.

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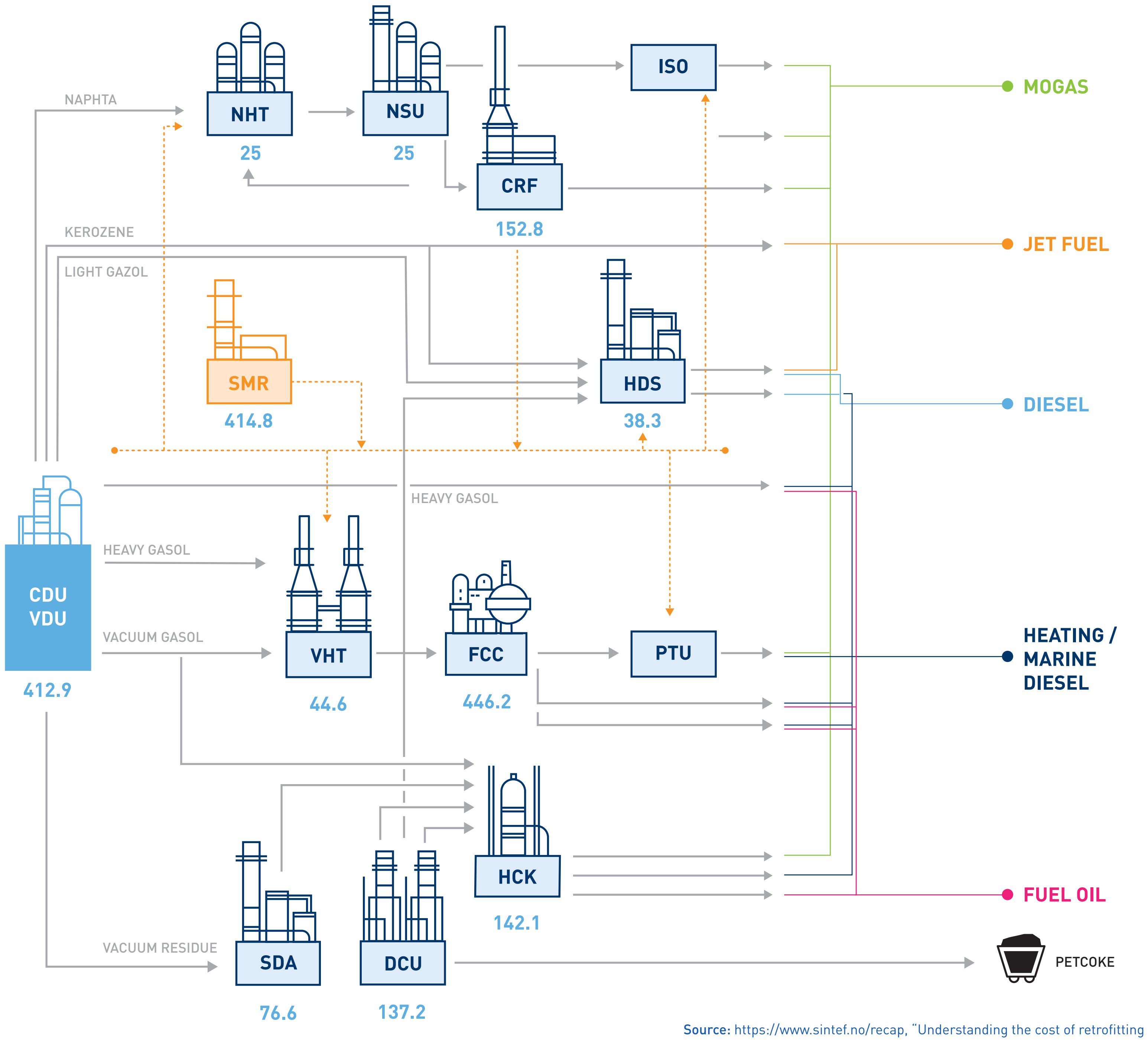
FIGURE 8: SIMPLIFIED FLOW DIAGRAM FOR A "TYPICAL COMPLEX REFINERY" AND MAIN EMISSION SOURCES

Emissions are in Kt/y



CHP	Combined heat and power plant
CDU	Crude distillation unit
CRF	Catalytic reformer
DCU	Delayed coker unit
FCC	Fluid catalytic cracker
FGD	Flue gas desulphurisation unit
HCK	Hydro cracker
HDS	Diesel hydro-desulphurisation unit
KHT	Kerosene hydrotreater
NHT	Naphtha hydrotreater
NSU	Naphtha splitter unit
POW	Power/CHP plant
SDA	Solvent deasphalting unit
SMR	Steam methane reformer
SRU	Sulphur recovery unit
VBU	Visbreaker unit
VDU	Vacuum distillation unit
VHT	Vacuum gasoil hydrotreater

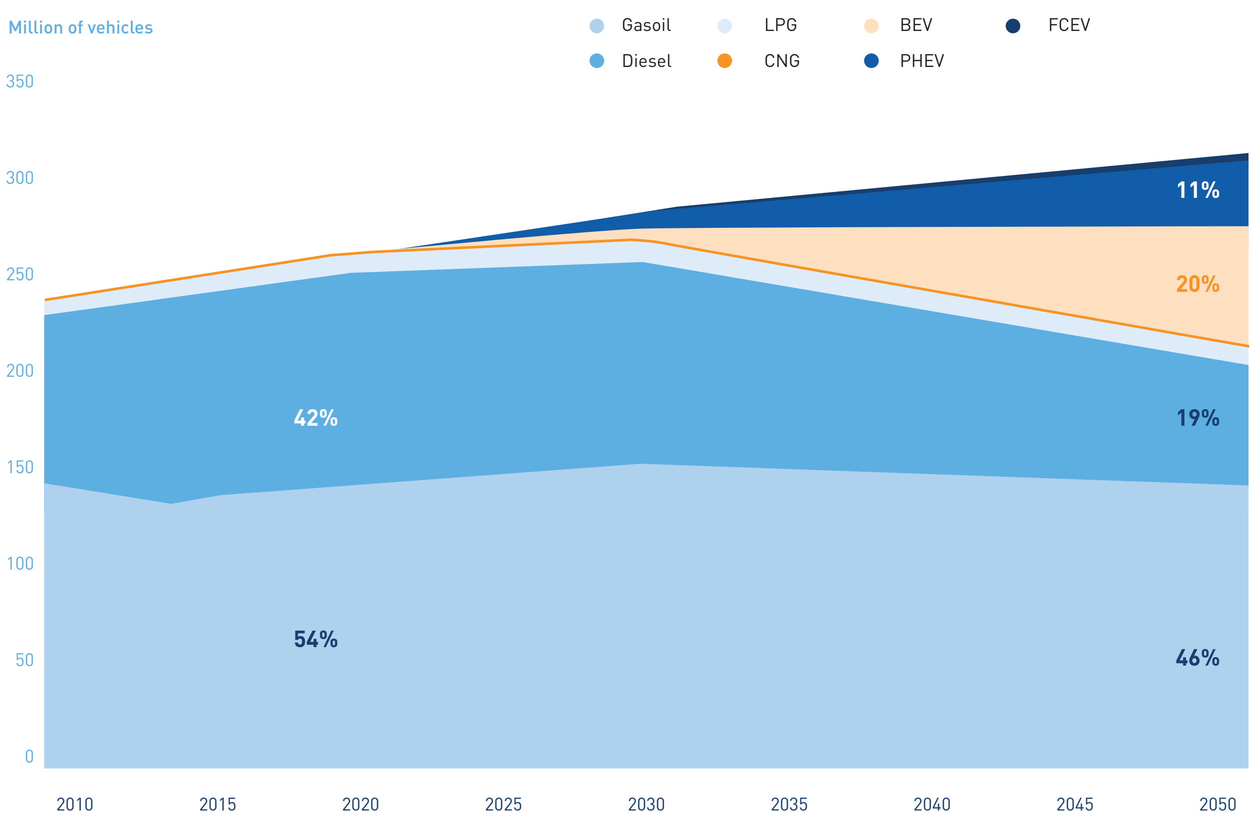
Source: https://www.sintef.no/recap, "Understanding the cost of retrofitting CO_2 capture to an integrated oil refinery", published in June 2017.

D. Liquid fuels in the passenger car segment: long-term view

The prevalence of the ICE in the existing car fleet, together with its high share in new vehicles, means that liquid hydrocarbons will be needed for passenger vehicles until 2050. In the coming decades, improvements in the efficiency of the internal combustion engine, leading to lower fuel consumption and lower CO_2 emissions, will be an important contribution to the EU GHG emission reduction objectives for transport.

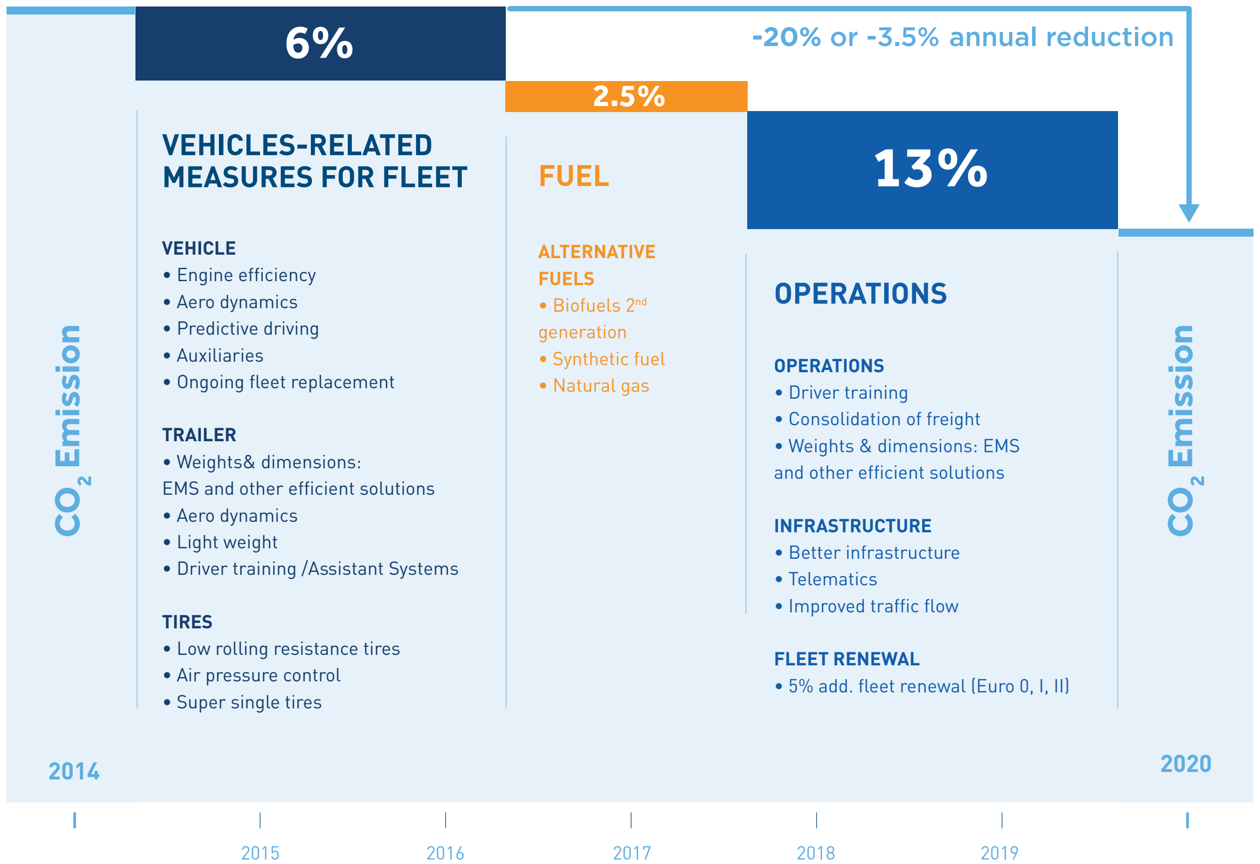
Some analysts and fleet modelling experts have developed new baselines for the potential composition of the passenger car segment in the long-term, which consider a progressive penetration of alternative powertrains. Specifically, Emisia, a spin-off company of the Aristotle University of Thessaloniki, has recently updated its SIBYL baseline, which is based on COPERT, a software tool used worldwide to calculate air pollutant and greenhouse gas emissions from road transport. SIBYL maps the potential evolution of the fleet based on data and scenarios published by the EU Commission and other institutions and stakeholders, such as the European Road Transport Research Advisory Council (ERTRAC). This model foresees a continued requirement for liquid fuels, as ICEs will remain the main drivetrain technology beyond 2030 when gasoline and diesel will represent around 60% of the total passenger car segment, and even up to 2050.

FIGURE 9: VEHICLE STOCK PROJECTION



Source: Emisia, Updated baseline included in SIBYL (a vehicle stock projection tool with internal energy consumption, emission and cost estimation capabilities).

VEHICLE-RELATED MEASURES FOR FLEET - EXAMPLE FOR HEAVY-DUTY



Source: ACEA TML Reports, July 2014.

URBAN AIR QUALITY

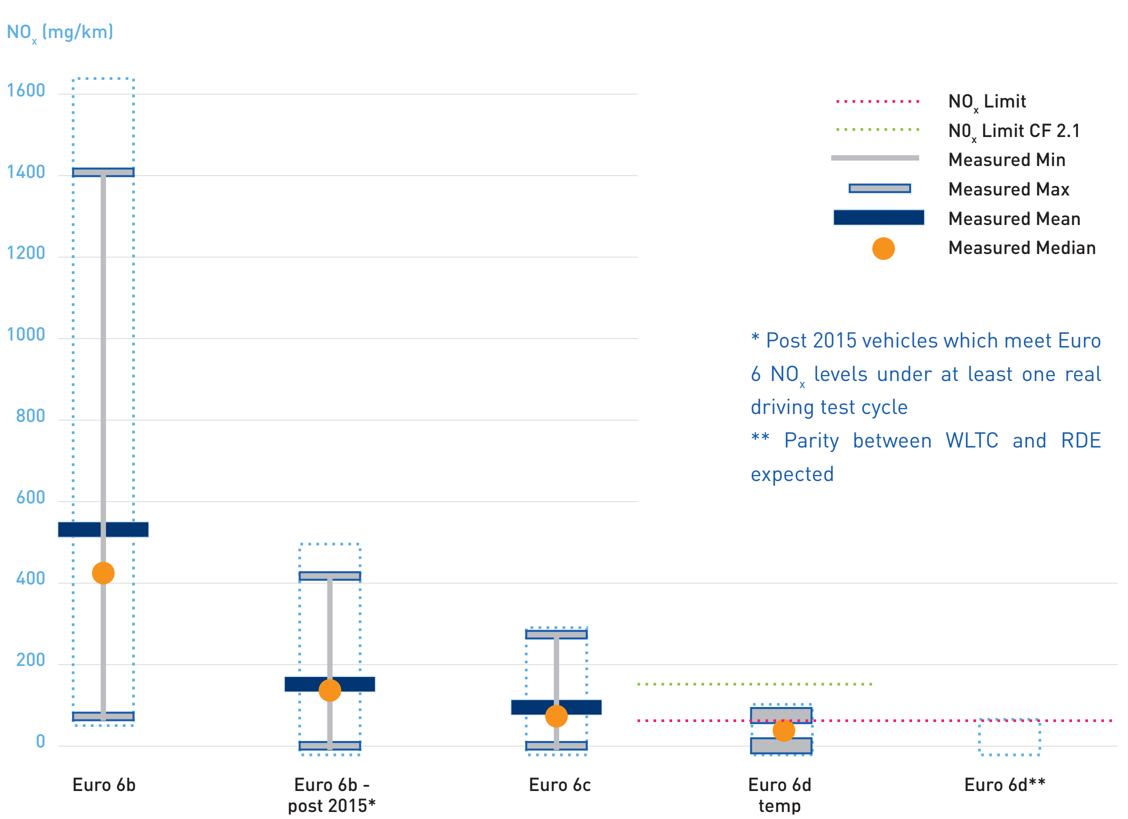
Under real driving conditions (RDE) diesel cars with the latest technology are compliant with EU emission limits for NO_x and PM.

A study conducted by Ricardo showed that Euro 6d (temp) diesel cars tested under “RDE conditions” comply with the EU emission limits for NO_x and PM*.

1. Evidence indicates that vehicle-averaged real-world NO_x emissions from diesel are substantially reduced by successive levels of Euro 6 legislation, from Euro 6b to Euro 6d.
2. Evidence suggests that the technical solutions applied to Euro 6d will achieve regulated Conformity Factors under real-world driving and “moderate RDE” condition.
3. Specific and careful configuration and calibration of the emissions control systems are required for real-world diesel NO_x control.

* https://www.concawe.eu/wpcontent/uploads/2018/04/RD18-000697-2-CONCAWE_Expectations_for_Actual_Euro_6_Vehicle_Emissions.pdf.

MEASURED NO_x EMISSIONS FROM EURO 6 DIESEL PASSENGER CARS UNDER REAL WORLD TEST CONDITIONS



Source: Ricardo, Expectations for Actual Euro 6 Vehicle Emissions, April 2018.

Diesel cars that comply under RDE deliver significant improvements to air quality in cities.

A study conducted by AERIS modelled the impact of the emission levels under RDE for Euro 6d temp and Euro 6d on urban quality in European cities**.

1. Based on Ricardo’s estimates for Euro 6d emission levels under RDE conditions, compliance with current emissions limits under air quality regulations will be largely achieved by 2025/2030:

   a) For NO_2, in 2020 approximatively 4% of monitoring stations are assessed to be non-compliant, falling to 2% by 2025.
   b) By 2030, 1% of the stations remain non-compliant.

2. Diesel PM exhaust is a diminishingly small contributor to urban air quality:

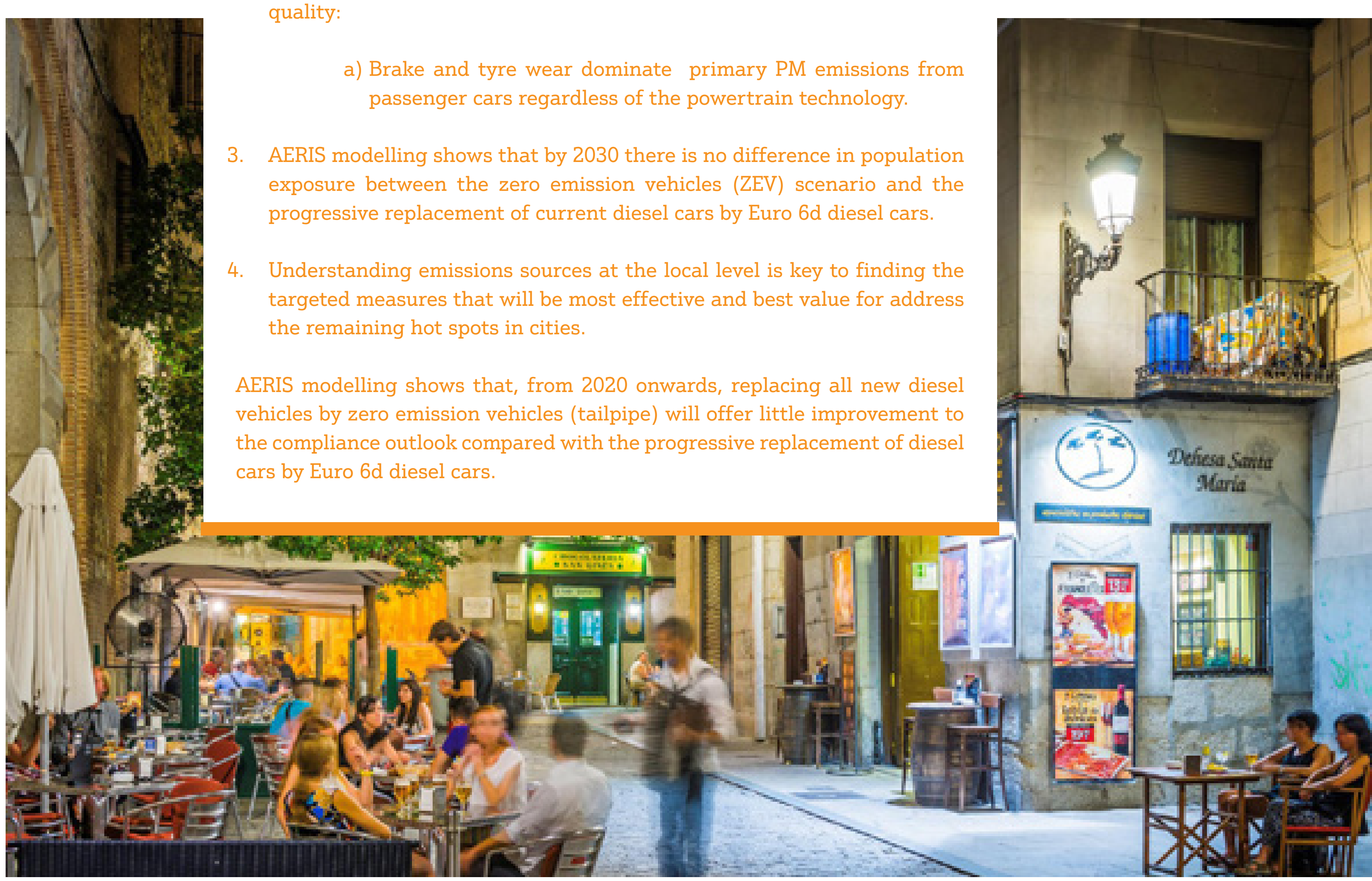
   a) Brake and tyre wear dominate primary PM emissions from passenger cars regardless of the powertrain technology.

3. AERIS modelling shows that by 2030 there is no difference in population exposure between the zero emission vehicles (ZEV) scenario and the progressive replacement of current diesel cars by Euro 6d diesel cars.

4. Understanding emissions sources at the local level is key to finding the targeted measures that will be most effective and best value for address the remaining hot spots in cities.

AERIS modelling shows that, from 2020 onwards, replacing all new diesel vehicles by zero emission vehicles (tailpipe) will offer little improvement to the compliance outlook compared with the progressive replacement of diesel cars by Euro 6d diesel cars.

** https://www.concawe.eu/wp-content/uploads/2018/04/Rpt_18_8.pdf



ANNEX 3
Low-carbon fuels and low-carbon on-board technologies

A. Characteristics of alternative fuels

Alternative liquid fuels can be obtained from natural gas and renewable or biological sources. They can be used to develop sustainable, low-carbon mobility. The benefits of using these fuels also include energy conservation and the overall environmental impact. Some of these compounds are already included in oil refinery blending activities (such as ETBE, ETOH and HVO) and are currently available at service stations (e.g. E10 gasoline, E85 gasoline and B7 diesel fuel). Other products are in the research phase, development or small-scale early production. They include both biofuels, waste raw materials and renewable power based sources.

B. High octane gasoline

Collaboration between oil companies and car manufacturers (OEMs) concluded that increasing the octane level of gasoline is a key way to improve an engine's efficiency. Downsized engines can be designed with a higher compression ratio and improved engine breathing to increase the overall efficiency. But these modifications may lead to detonations or combustion knocks due to the high temperature. So, these effects must be counterbalanced by a higher fuel quality (research octane number, or RON). Modern vehicles have sophisticated engine management systems that can detect engine knocks and will configure the engine to run without knocking, by changing the time at which the spark fires to simulate a lower compression. With a lower octane fuel, the engine will switch to a configuration under which it can be used without any combustion knocks, but this will lead to a loss in power and an increase in emissions.

Studies of the production in Europe of gasoline with a high-oxygenate blend ratio have shown that a RON of at least 102 is initially feasible for a small percentage (10%) of the gasoline pool within existing EN228 specifications. The CO_2 intensity of this new fuel may be close to existing 95 RON gasoline but will depend on the oxygenate. Collaboration between petrol companies and car manufacturers should be encouraged to achieve progress in this promising opportunity to improve engine efficiency.

Independent study[5] shows that a rise of five points of RON reduces the consumption of vehicles equipped with high-compression-ratio engines by between 3.0% and 4.4%.

C. Hydrotreated vegetable oil

Hydrotreated vegetable oil (HVO) is a type of biofuel available in the market since 2007 and is widely accepted because it has physical and chemical properties very similar to fossil-derived fuels. It is obtained by hydrotreating various kinds of lipids: vegetable oils, used or residual oils and animal fats. Different processes, all based on petroleum refining know-how, have been developed by oil companies and technology providers (Axens-IFP, Honeywell- UOP, Neste, Haldor Topsoe, Eni). Most of them can also handle other types of bio-feedstock, such as lignin derivatives (e.g. tall oil). Whatever type of feedstock is used, the final product is a paraffinic hydrocarbon mixture, free of aromatics and oxygen, with high fuel quality properties. HVO can be considered a premium "drop-in fuel" in the sense that, due to its essentially paraffinic and iso-paraffinic nature, it can replace diesel without any modification to the refuelling

[5] Environ. Sci. Technol. 48, 12, 6561-6568.

system or the vehicle and without causing any operational problems[6]. Negative interactions with the engine components (such as filters, injectors and engine oils) are also avoided. As another advantage, the cold flow properties of HVO can also be adjusted to meet local requirements (including fuels to be used in Arctic weather conditions and jet specifications) by modifying the severity of the process or through additional catalytic processing.

HVO as an automotive fuel (blended or pure) can contribute to a reduction in tailpipe emissions and is an alternative way to boost the reduction of GHG emissions from transport, according to the European Alternative Fuels Infrastructure Directive. Indeed, the incorporation of HVO – beyond oxygenated biofuel components – contributes to an increase of renewable fuels in transport.

Depending on the feedstock, HVO can deliver up to 90% lower GHG emissions compared to petroleum-based diesel. In addition, scientific studies and field trials have shown that pure renewable diesel can reduce PM emissions by 33%, NO_x by 9% and CO_2 emissions by 24%.

HVO has a high cetane number[7] of 75-95, ensuring efficient and clean combustion and providing extra power compared to, for instance, traditional biodiesel (FAME).

Renewable diesel can be distributed in a blend with petroleum-based diesel within the technical limits set by the EN 590 diesel fuel standard. It can also be used pure as it meets EN 15940 for paraffinic diesel fuel. It is estimated by Neste that 4.5 million tonnes of HVO were produced worldwide in 2017.

HVO does not require investment in infrastructure for supply to the final customer because the existing infrastructure and logistics schemes are already suitable.

Most heavy-duty engine manufacturers and an increasing number of passenger car manufacturers have certified their vehicles for pure renewable diesel (RD100; the only additions are lubricating additives).

As an example, since January 2016 Eni has been distributing a premium product labelled Eni Diesel+ in Italian retail stations. This is formulated with 15% green diesel (HVO), which is more than double the maximum FAME content allowed by EN590 (blending wall, 7% v/v) and can significantly reduce CO_2 emissions.

Another early mover to HVO manufacturing and distribution is Neste. Since 2017 Neste is distributing a 100% HVO product in Finnish stations under the brand Neste MY Renewable Diesel.

[6] Nils-Olof Nylund, Kimmo Erkkilä, Matti Ahtiainen, Timo Murtonen, Pirjo Saikkonen, Arno Amberla & Hannu Aatola - Optimized usage of NExBTL renewable diesel fuel – VTT - ISBN 978-951-38-7795-8 (http://www.vtt.fi/publications/index.jsp).
[7] Cetane number: Measure of the ignition quality of diesel fuel; higher this number, the easier it is to start a standard (direct-injection) diesel engine. It denotes the percentage (by volume) of cetane chemical name Hexadecane) in a combustible mixture (containing cetane and 1-methylnapthalene) whose ignition characteristics match those of the diesel fuel being tested.

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D. BioTfuel project: synthetic fuels via biomass thermochemical conversion

The BioTfuel project uses a thermochemical process to convert lignocellulosic biomass, such as straw, forest residues and dedicated plants into biofuels.

The project connects different processes to produce high-quality biodiesel and biojet as illustrated in the Figure 10.

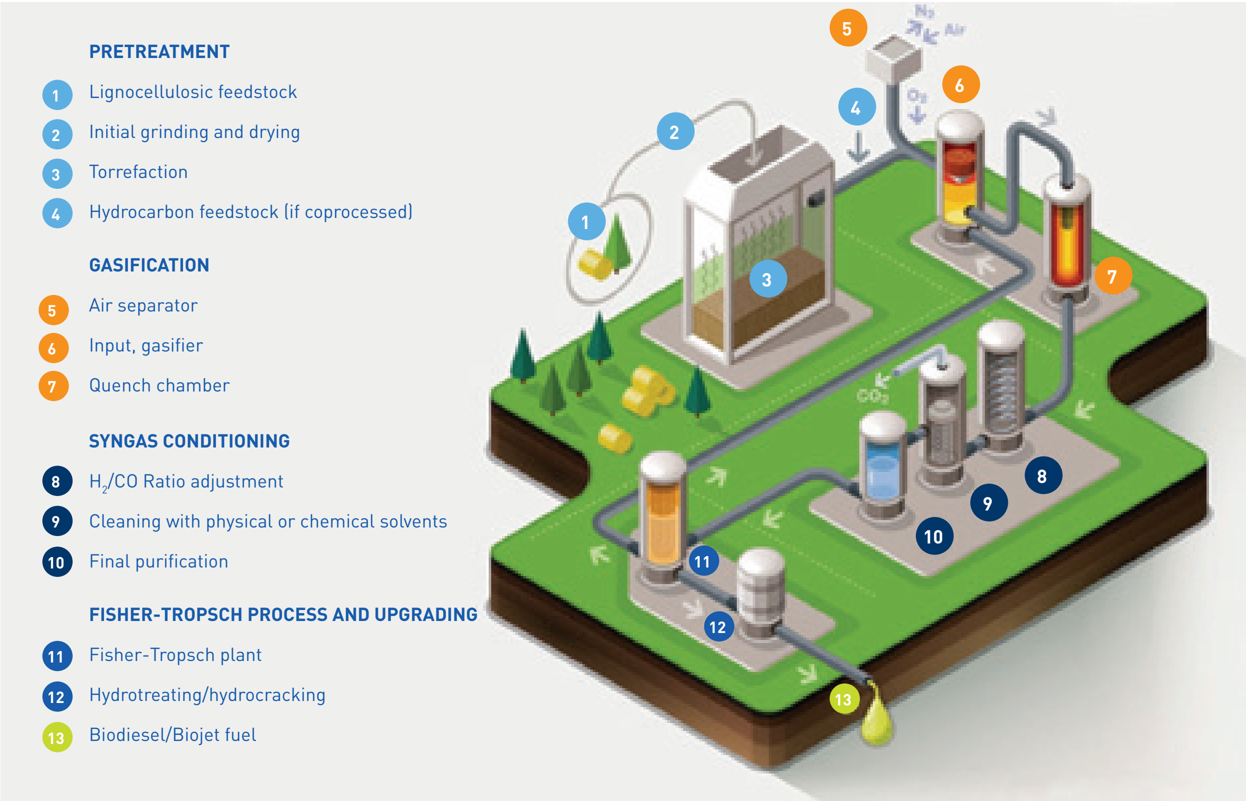
1. Pretreatment.
2. Gasification of cellulosic material that has previously undergone roasting in a dedicated plant.
3. Purification (syngas conditioning).
4. Fischer-Tropsch synthesis.

The gasification technology expands the type of biomass that can be used to produce biofuels to include lignocellulose (agricultural by-products, forest residues or specific biomass). The flexibility of the process means that it can handle a mixture of petroleum-based feedstock and biomass, which is subject to potential changes in availability.

The BioTfuel project produces sulphur-free and aromatic-free biofuels. These can be used as such or in mixture with other fuels, and they can fuel any car or truck engine or jet turbine.

After five years of R&D, the first production facility was inaugurated in December 2016 at the Flandres site in Dunkirk (France) and is now close to starting production.

FIGURE 10: BioTfuel, A PROJECT TO PRODUCE BIOFUELS VIA THERMOCHEMICAL CONVERSION



Source: https://www.total.com/en/energy-expertise/projects/bioenergies/biotfuel-converting-plant-wastes-into-fuel

Vision 2050 / **Annexes**

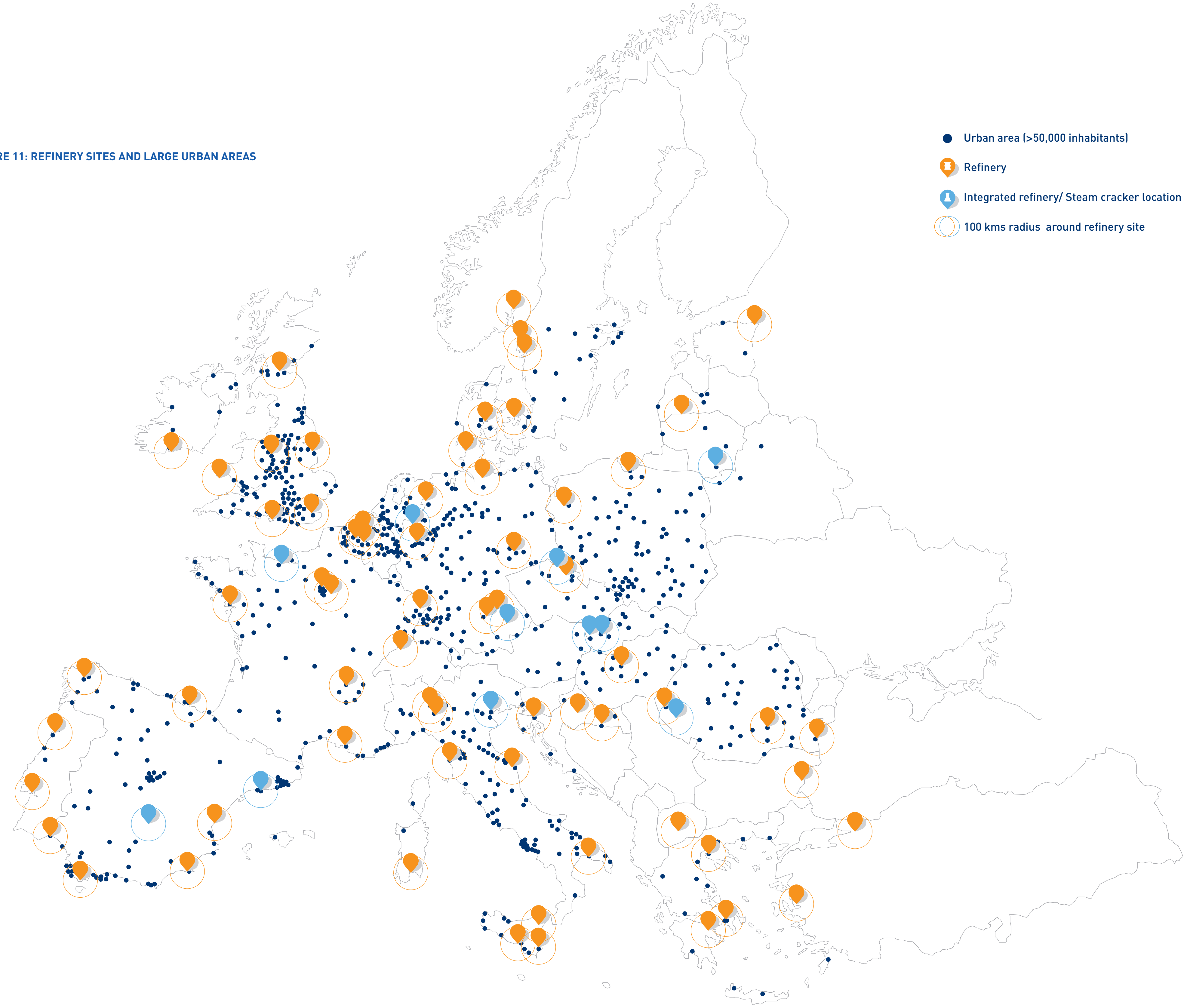
E. Waste-to-Fuel

Emissions associated with the use of petroleum-refined products can be reduced in many ways, but most of them will involve alternative feedstocks for oil products. Advanced biofuels are already being developed at scale, but more opportunities are arising from the processing or co-processing of new types of waste materials.

Waste management and treatment is an important issue in developed countries but even more so in developing ones. Europe has the opportunity to lead a sustainable framework in this field to turn a problem into an opportunity. The refining industry can contribute its know-how and expertise to the development of alternative options to the landfilling and incineration of plastic waste and residues. Further technology development will be required to adapt waste processing streams into feedstock that can be used in a refinery and to guarantee the quality of the final product.

The map in the Figure 11 shows that many refinery and integrated refinery & steam cracker sites (orange and light blue markers) are within a 100 km radius (orange and light blue circles) of cities (dark blue dots) with more than 50,000 inhabitants.

FIGURE 11: REFINERY SITES AND LARGE URBAN AREAS



Case: End-of life Plastic-to-Fuel
Project development: Thermal anaerobic Cracking Oil

- **CO_2 reduction achieved by**:
  › Replacing a share of the crude as feedstock in refineries.
  › Avoiding plastic incineration.
  › Swapping part of the long-distance crude supply with local transport of plastic waste and residues.

- **Circular economy:**
  Life-cycle improvement of petrochemical products.

- **Advantages**:
  › Low cost and local raw material.
  › Availability of plastic waste and residues: According to PlasticsEurope 30.8% of plastics are sent to landfill.

- **Technology**: Anaerobic thermal pyrolysis (TRL 7).

- **Modular technology**: Existing references with process capacity between 10-20 tonnes/day.

To ensure the European refining industry's leadership in technologies enabling the conversion of EOL plastics to fuel, the following conditions are essential.

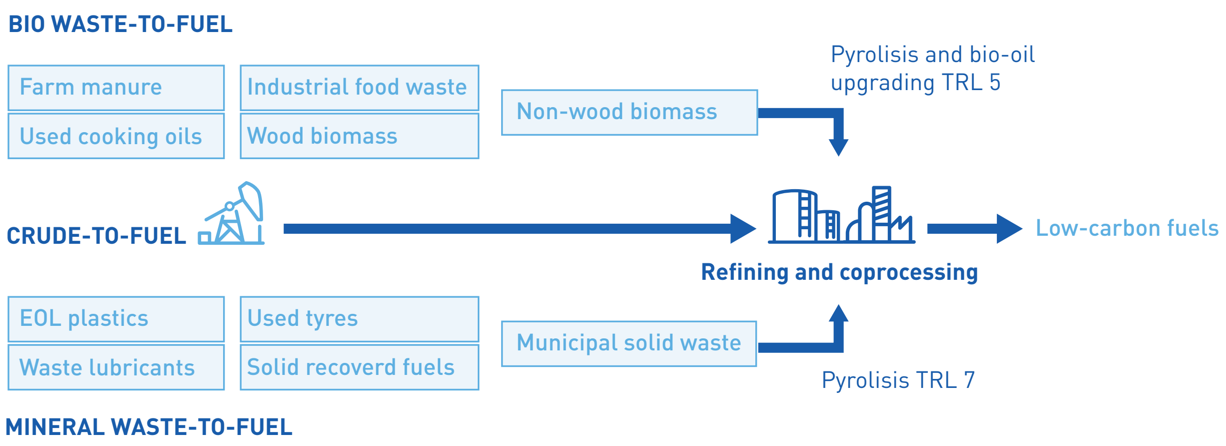
- An appropriate framework to promote:
  1. Investment in development and a scaling-up of technologies in order to reduce operating costs, capital expenditure and scale-up risks and to take advantage of economies of scale.

  2. Incentives for the use of waste and residues in refining processes: A regulatory framework can provide synergies between the waste and refining industries.

- Coherence and stability over time between resources and energy policies to promote investment in technologies related to low-emission in Europe.

  1. Policy and regulation should take into account products made of waste. Under the current regulatory framework not all fuels made from EOL waste streams are recognised as low-emission fuels.

FIGURE 12: INTEGRATION OF DIFFERENT KINDS OF WASTE INTO OIL REFINING PROCESSES



Source: PlasticsEurope.

F. Waste-to-Fuel and feedstock

Case: Municipal solid waste (MSW) to fuel and feedstock
Project development: Fulcrum

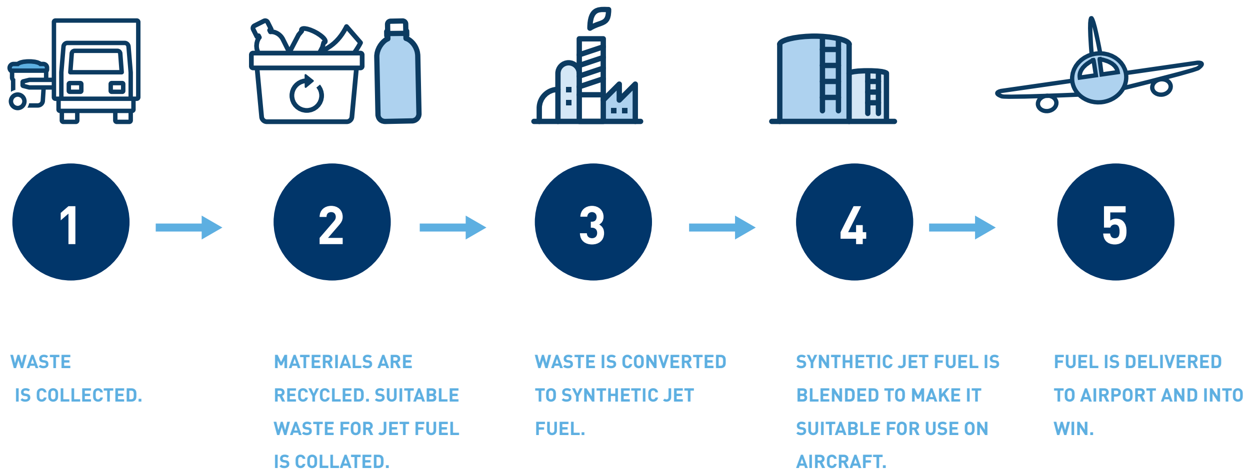
The continued rise in demand for liquid fuels represents a significant challenge for the car and oil industries to meet tough future EU GHG targets. Within BP it is recognised that the refining industry has to evolve to embrace new technologies, feedstocks and ways of working to provide lower-carbon mobility.

In one such move, BP has formed a strategic partnership with Fulcrum BioEnergy, a pioneer in the development and production of low-carbon jet fuel. Fulcrum has developed and demonstrated a reliable and efficient process for producing low-cost, sustainable biojet from MSW.

The company has secured long-term access to large volumes of MSW feedstock and is actively developing its plan. Initially, it will build Waste-to-Fuel plants in North America, where its first plant is currently under construction. Later, it could expand in other parts of the world.

The process uses gasification and Fischer-Tropsch technology to produce a synthetic crude oil substitute that can be converted into jet fuel using BP's refining and blending experience.

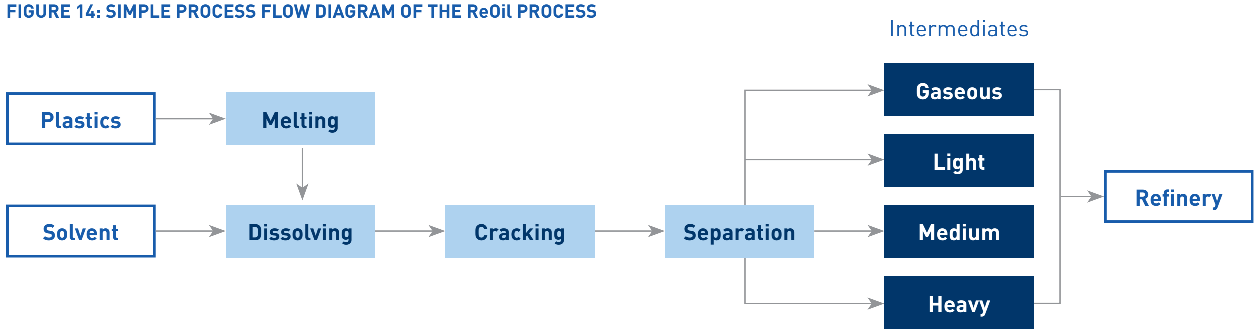
FIGURE 13: MUNICIPAL SOLID WASTE TO LOW-CARBON JET FUELS



Case: Plastic-to-Fuel & Feedstock[8]
Project development: ReOil by OMV

An innovative process developed by ReOil converts used plastics under moderate pressure and normal refinery operating temperatures into so-called R-crude. This R-crude can then be used in refineries to produce fuels or chemical feedstock. Figure 14 shows the basic process steps.

FIGURE 14: SIMPLE PROCESS FLOW DIAGRAM OF THE ReOil PROCESS



Compared to crude oil, the R-crude produced by the ReOil process contains high shares of valuable light and medium components. These components can be converted into chemical feedstock, transport fuels or both. Only a small share needs further treatment, e.g. by cracking. Alternatively, it could be used as an energy source for internal processes.

The majority of plastic waste is landfilled and incinerated. 60 % of plastic waste originates from packaging, of which only 40 % is recycled[9]. In some cases, it is possible to re-use the waste or recycle it to virgin quality (e.g. to make PET-bottles). But for poly-olefinic waste like foils, containers and cups, the recycling rate is around 10%[10] (it can make thick-walled polyethylene, polypropylene or polystyrene). See examples below.

[8] Another Waste-to-Fuel project being developed is ReOil by OMV.
[9] European Commission Plastics Strategy.
[10] Kranzinger et al. 'Outputorientierte Betrachtung Der Nass-Mechanischen Aufbereitung von Polyolefinreichen Abfällen Für Das Rohstoffliche Recycling'. Österreichische Wasser Abfallwirtschaft 69, no. 11 (1 December 2017): 460–69. doi:10.1007/s00506-017-0423-y.

Examples of plastic waste fractions suitable for the ReOil process

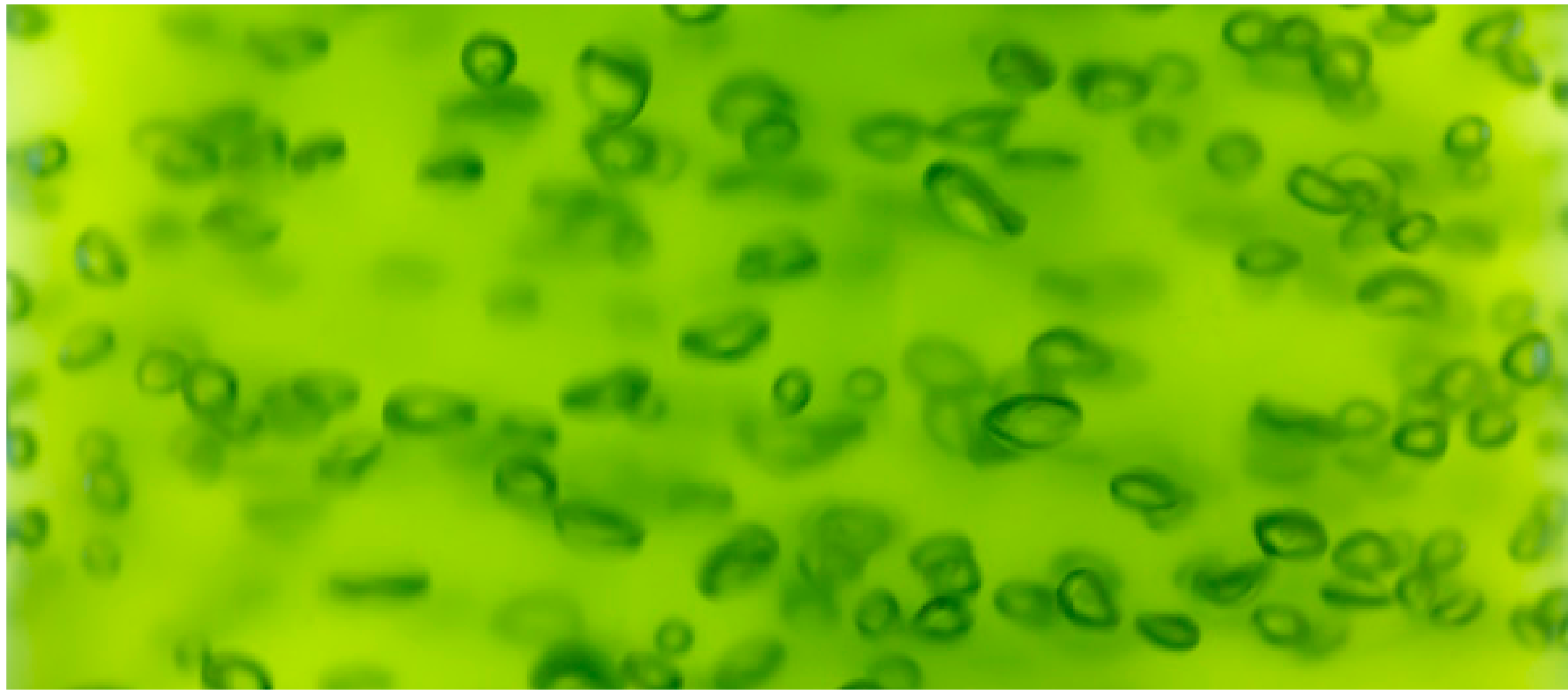
G. Algae, a biofuel of tomorrow processed in the refineries of today

Algae naturally consumes CO_2 and produce lipids that can be turned into a renewable, low-emission fuel for transportation. From production to combustion, algae production has some key advantages that make it worth pursuing further research:

- **Algae consume CO_2**: Production sites could also act as carbon capture projects.
- **Lower-emission fuel**: On a life-cycle basis, algae biofuels emit about half the quantity of GHG as petroleum-derived fuels.
- **High yield**: Each acre of algae yields more than 7,570 litres (2,000 gallons) of fuel.
- **Year-round harvest**: Algae can repeatedly be harvested throughout the year.
- **Don't use arable land**: Algae can be cultivated on land unsuitable for other purposes with water that can't be used for food production.
- **Water purifier**: Algae can be grown in waste water and industrial effluent and can purify polluted water while simultaneously producing energy-rich biofuels.
- **Engine-ready**: Algae-derived diesel can be pumped into existing diesel automobiles without making major changes to the car engines and fuel distribution infrastructure.

As the manufacturing processes for algae biofuels and conventional fuels are similar, algae biofuels could be processed in existing refineries to supplement supplies of conventional gasoline, diesel and other fuels.

The challenge is to achieve this in an economically sustainable way and at scale – moving the technology from the cell-culture dish to the fuel tank. ExxonMobil is actively researching biofuels made from algae. Together with Synthetic Genomics Inc, the Colorado School of Mines and the Michigan State University, it continues to make progress in identifying and enhancing algae strains capable of high-lipid production while maintaining desirable growth rates.



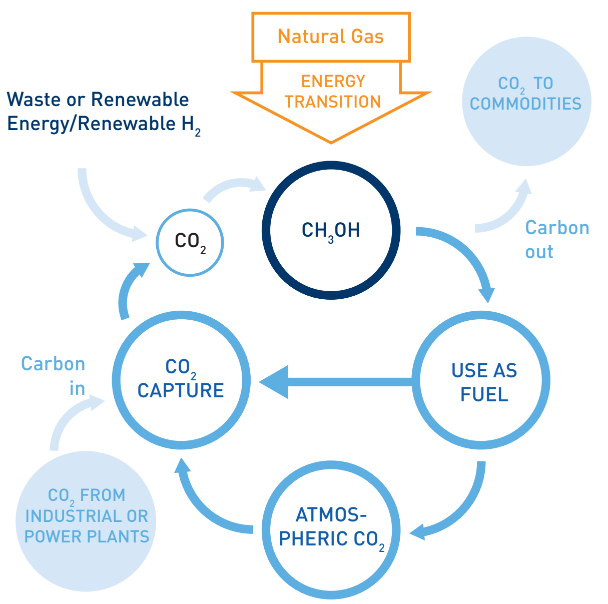
H. Production of methanol

The "methanol economy" vision endorsed by George Olah[11] in the last decade could be a possible way to manage the transition from fossil fuels to low-carbon fuels. Methanol might even be a way to create a circular economy with zero-carbon emissions in the long-term.

The transition to renewable sources requires time, but natural gas could immediately contribute to reducing GHG emissions either through direct use or if it is transformed into methanol.

Natural gas is abundant and widely used, and there are well-known and proven technologies available for its exploitation. Natural gas has a lower carbon intensity (in terms of the CO_2 emissions that result from burning it) than coal or oil. It can be transformed into methanol to produce an alternative fuel for blending with traditional fossil fuels, which would reduce the carbon footprint of the transportation sector.

FIGURE 15: THE METHANOL ECONOMY



Source: George A. Olah, Alain Goeppert, G. K. Surya Prakash - Beyond Oil and Gas: The Methanol Economy - John Wiley & Sons, 21.08.2006.

Methanol is a good energy carrier, easily transportable and can be used as a raw material for the production of fuels and chemicals. It has a high octane component and can be used for the production of alternative fuels by blending it with refinery streams in different ratios. It has been used as fuel in the Indianapolis Grand Prix (Formula Indy) and in other vehicle competitions. China currently uses up to 12 Mt of methanol/year as transportation fuel. Different methanol-gasoline blends (M15, M50 and M85) are used in Chinese provinces, and it has been used to drive more than 200 million miles in China. Israel has carried out a successful road trial using M15. Australia is currently testing gasoline-ethanol-methanol (GEM) fuel[12].

Today, methanol is produced mainly from natural gas. In the medium-term, it could be produced from agricultural waste products or other waste materials. A further step in the long-term could be the production of methanol from CO_2 captured from the emissions of industrial activities and vehicle exhausts. So, methanol can significantly contribute to the promotion of a circular economy by reducing the GHG intensity of the energy mix of transport fuels.

An example of the use of methanol as a component of automotive fuel is the development of an alternative fuel in Italy by Eni in collaboration with Fiat Chrysler Automobiles. The alternative fuel is made from methanol from natural gas (15 %v/v) and ethanol from renewable sources, which are then blended with oil refinery streams.

I. Enjoy car-sharing test

In addition to formulation studies, blending components and tests on vehicles and engines, a road test was carried out from December 2017 until mid-2018. Enjoy is a car-sharing initiative launched by Eni with the objective of developing products and services for sustainable mobility. The test featured five Enjoy car-sharing vehicles in the city area of Milan, which were fuelled with alternative M15 fuel. The vehicles were refuelled in standard Eni service stations at dedicated fuel pumps without any hardware modification.

[11] George A. Olah, Alain Goeppert, G. K. Surya Prakash - Beyond Oil and Gas: The Methanol Economy - John Wiley & Sons, 21.08.2006.
[12] http://methanolfuels.org/public-policy/asia-pacific-middle-east/

Use of this alternative fuel can reduce CO_2 emissions by up to 4% (2% in the combustion phase and a further 2.3% deriving from the fuel production cycle and the organic component).

The possible future replacement, currently being studied, of methanol by bio-methanol from renewable sources, could reduce CO_2 emissions by around 10%, a significant contribution.

J. Power-to-Liquids: SUNFIRE technology

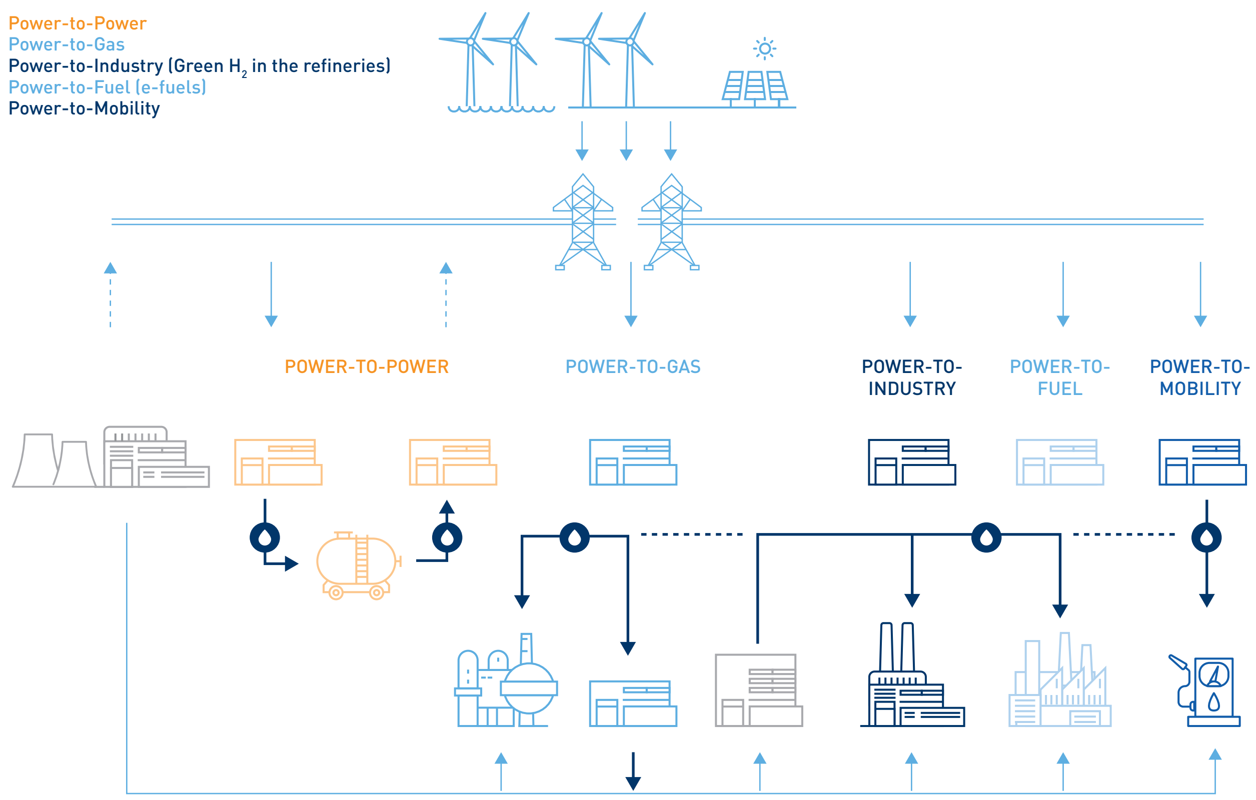
Renewable power can be used in different ways to contribute to the production of liquid fuels.

One is Power-to-Industry, in which renewables reduce the GHG intensity of industry by reducing CO_2 emissions from the electricity consumed, and green hydrogen is produced to desulphurise the crude base of diesel and gasoline. Renewables can also be used in Power-to-Fuels by producing synthetic fuels (e-fuels) such as syn-diesel through various processes.

Sunfire began the production of its low-carbon synthetic fuels – also called "wonder fuel" – in its pilot plant in Dresden. This plant is the world's first PTL production plant. According to the company, the PTL technology that synthesises Blue Crude (a synthetic crude oil) reaches system efficiencies of about 70%.

The centrepiece of the three-stage production process is a reversible electrolyser that generates hydrogen with an efficiency of approximately 90%. This green hydrogen (H_2) reacts with CO_2 (captured from the air or waste sources) to produce a mixture of hydrocarbon chains, similar to those found in conventional crude. This crude can then be processed

FIGURE 16: ROLE OF RENEWABLE POWER

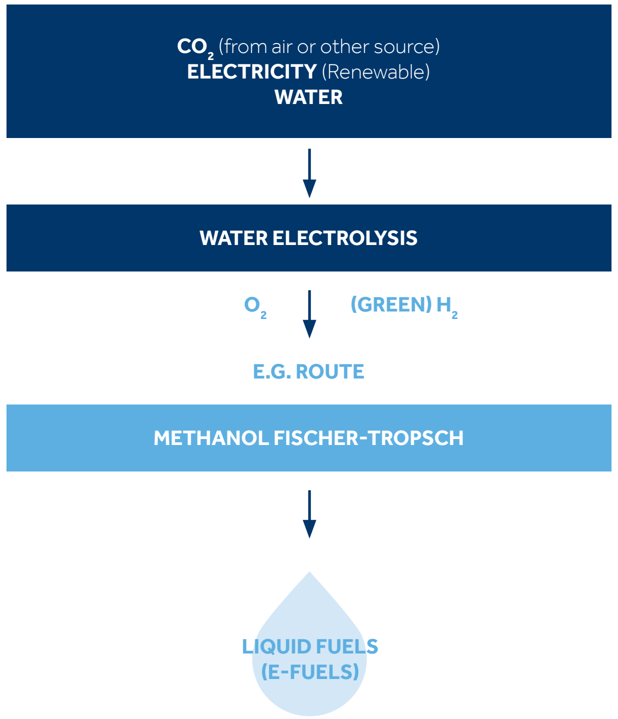


Source: European Fuels Markets & Refining Strategy Conference, Role of Renewable Power HYDROGENICS, London 2017.

in refineries (or in a refinery-like process) to produce, for example, a synthetic diesel with similar properties to conventional crude-based diesel. This synthetic diesel can be plugged into the existing fuel infrastructure. This new syn-diesel was publicly tested in an Audi A6 in Berlin in 2015.

The technology has proved its potential at pilot plant scale. But it faces big challenges in the form of scalability and access to green, cheap electricity.

FIGURE 17: THREE STAGE PRODUCTION PROCESS



Source: SUNFIRE

K. REFHYNE Project – 10 MW PEM Electrolyser

The electrolysis of water to generate hydrogen may be a key component of the interconnected energy systems of the future. For any of these "Power-to-X" concepts to become commercially viable, water electrolysis needs to make a number of technical and commercial advances, which will be tested in the REFHYNE project.

Shell, together with ITM Power and the consortium partners SINTEF, Thinkstep and Element Energy, is planning a project to install a large-scale electrolyser that will produce hydrogen at the Wesseling site in the Rheinland Refinery Complex. This is the largest unit of its kind in Germany and the world's largest PEM (polymer electrolyte membrane) electrolyser.

The REFHYNE project will be supported by the EU Fuel Cell Hydrogen Joint Undertaking. The European partner consortium has received funding of €10 million (approximately 50% of the project's total investment). It will improve the stability of the electricity grid, which has an increasing share of variable renewable energy inputs.

Electrolysis using low-cost renewable electricity could be a key technology for potential CO_2-free hydrogen production in the refinery. The electrolyser also has the potential to provide large quantities of renewable hydrogen for targeted large-scale applications either in industry or transport, provided that the input energy is "green" (renewable) power. The project was approved in late-2017 and is expected to start operations in 2020. The chosen electrolysis technology has the potential to be further scaled up to achieve unit cost reductions.

L. On-board CO_2 capture

Directly capturing CO_2 from vehicles in the transportation sector could significantly cut the overall carbon emissions from transport and could play a strategic role in the development of a sustainable low-carbon economy in the long-term. On-board carbon capture could be highly effective despite the complexity of the process. Indeed, the complexity of separating CO_2 from other gases decreases as the CO_2 concentration increases. This can be calculated by the minimum work required to separate CO_2 from a gas mixture in an isothermal and isobaric process. In terms of thermodynamics, the minimum work is equal to the difference in Gibbs free energy between the initial and final states. Typical mole fractions of CO_2 are 0.12 in coal flue gas, 0.0004 in atmospheric air and 0.135 in automobile exhaust. The reason the mole fraction of CO_2 is higher in automobile exhaust than in flue gas from a coal power plant is that automobiles tend to run at or near ideal Air-to-Fuel ratios for environmental and performance reasons. Power plants tend to operate with excess air[13].

The calculated minimum work to capture CO_2 is shown in the table below:

[13] Francisco Javier Sotomayor - Future of Carbon Capture: Materials and Strategies - A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Environmental Engineering) in the University of Michigan 2016 - Doctoral Committee: Associate Professor Christian M. Lastoskie, Chair; Associate Professor Terese M. Olson; Associate Professor Donald J. Siegel; Assistant Professor Ming Xu.

FIGURE 18: MINIMUM WORK TO CAPTURE CO_2 IN MCC, PCC, AND DAC AT 298 K

Percent of CO_2 Captured	Purify of Captured CO_2	MCC* (0.135 CO_2) kJ/kg	PCC** (0.12 CO_2) kJ/kg	DAC*** (0.0004 CO_2) kJ/kg
100	100	165	172	497
90	98	145	153	477
75	98	135	141	465
50	98	123	129	452

Source: Francisco Javier Sotomayor - Future of Carbon Capture: Materials and Strategies - A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Environmental Engineering) in the University of Michigan 2016 - Doctoral Committee: Associate Professor Christian M. Lastoskie, Chair; Associate Professor Terese M. Olson; Associate Professor Donald J. Siegel; Assistant Professor Ming Xu.

* MCC: Molecule Carbon Capture - ** PCC: Post Combustion Carbon Capture - *** DAC: Direct Air Capture

In general, on-board CO_2 capture in vehicles follows the more traditional CCS technologies. These have been developed mainly in the context of localised power generation emission points; capturing carbon on-board a vehicle amplifies the complexity because of the need to miniaturise the processes. on-board CO_2 capture could also be used in heavy-duty and maritime transport.

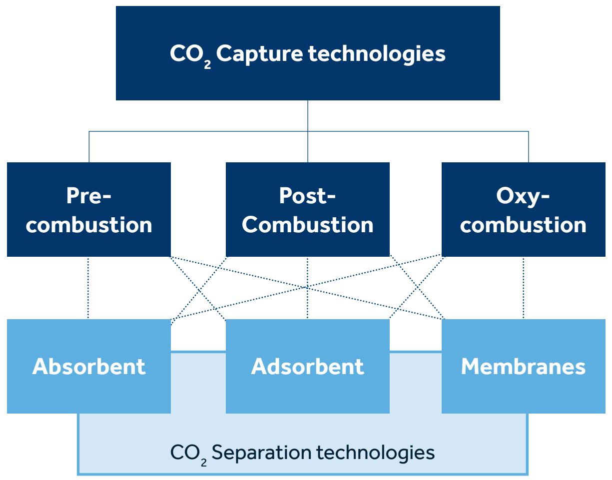
The capture and separation of CO_2 can follow the three different technologies[14] in figure 19.

The post-combustion technology is well-suited to the ICEs as currently used in the transport sector[15].

[14] Overview of CCS Activities in Saudi Arabia reported that On-board carbon capture storage system (SCCS) demonstration vehicles optained a 10% CO_2 capture in a pickup and a 25% CO_2 capture in a passenger vehicles.

[15] J.M, Sivak M. "Carbon capture in vehicles: a review of general support, available mechanisms, and consumer-acceptance issues", UMTRI, May 2012.

FIGURE 19: EXAMPLE OF ON-BOARD CAPTURE TECHNOLOGIES



Source: Al-Meshari A.A., Saudi Arabia's efforts in carbon management, 2014.

ANNEX 4
Other low-carbon technologies (refinery-related)

A. Bio-refineries

In the late 1980s, as a consequence of a progressive phasing out of lead in gasoline, refiners started blending oxygenated molecules to boost octane. In countries where incentives were provided to promote the development of bio-components, ethyl tert-butyl ether (ETBE) units were built within or next to refineries. More recently, to fulfil their biofuel obligation, some refiners have co-processed vegetable oil and cut the fossil component in order to make biofuels. This makes up the early stages of bio-refining.

Over the last 10 years, some 20 refineries have been closed down across Europe. Several of them have been reconfigured into bio-refineries. This was possible for the following reasons:

1. The techniques, experience and skills built up over years for refining crude oil (distillation, hydrotreating, cracking and isomerisation) can be used advantageously to upgrade bio-liquids into high-value biofuels.

2. Units that have been shut down can be reconfigured into biofuel units at a much lower cost than building biofuel units from scratch. Moreover, logistics infrastructure (pipelines, tanks, loading and unloading facilities) can be reused.

3. The regulatory environment gives sufficient value to biofuels to justify the investments.

4. An economically sustainable industrial activity can be maintained and jobs preserved. Moreover, there is a remarkable reduction in the overall environmental impact.

In some cases, the newly reconfigured bio-refinery can take advantage of existing synergies with conventional crude oil-based refining units, which may remain in use. Examples of potential integration include the (co)distillation of bio-crude, hydrogen production by reforming and the valorisation of bio-naphtha and bio-LPG for producing fuels or specialities.

The new types of biofuels produced have a similar hydrocarbon structure to conventional fuels. In some cases, such as HVO, they have excellent quality with lower CO_2 intensities. As mentioned in the HVO section, the quality of the final products is independent of the nature of the renewable feedstocks used. They can be blended as drop-in fuels with conventional oil-based fuels like LPG, diesel fuel, kerosene or gasoline.

One step beyond the evolution of a conventional refinery into a bio-refinery is the potential integration with renewable sources. As some of the conventional facilities (including oil tanks) would no longer be needed, some additional space within the facility could become available to install, for example, solar panels. The renewable electricity produced in this area could either feed the bio-refinery's needs or be sent to the grid. The example of La Mède bio-refinery in France offers an example of this potential integration. Other novel technologies that are space-intensive could also benefit from the additional land that may become available as a result of this transformation.

An example: Eni's Green Refinery

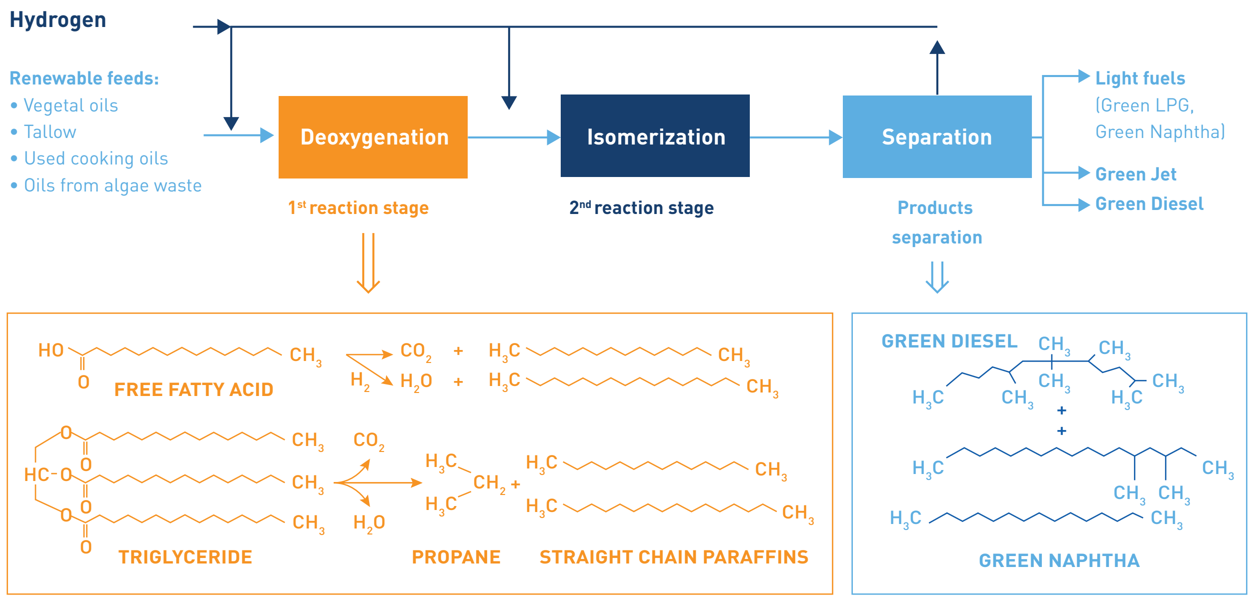
To address the structural crisis faced by the European refining industry, Eni invested in an innovative Green Refinery[16] project, which led to the transformation of its Venice Refinery into a bio-refinery able to produce a new generation of biofuels. The reconfiguration of the existing units in Venice significantly accelerated the completion of the project and considerably reduced the required investment, which was estimated at one-fifth of that needed for a new Ecofining™[17] grass root unit of the same capacity. Some of the equipment in the former plant was converted to be incorporated in the new process, and the operational set-up of the previous refinery was changed to create a new production route dedicated to biofuels.

[16] The patents protecting this innovative idea were filed in September 2012 by Eni.
[17] Honeywell UOP/Eni Ecofining™ Process for Green Diesel Production.

The Green Refinery process is based on Ecofining™ technology. The production scheme involves two successive reaction stages and a final separation stage. In the first stage, deoxygenation, hydrogen reacts with the renewable feed to completely remove the oxygen from the feedstock. This produces an intermediate product with a straight chain paraffinic structure. In the second stage, the isomerisation process gives the molecules a branched structure. Finally, the separation stage divides up the different products (green LPG, green diesel, green jet and green naphtha) on the basis of their distillation curves.

HVO is a high-quality biofuel, and its green diesel fraction can overcome all qualitative issues related to traditional biodiesel. HVO represents an alternative to fossil diesel fuel. It is immediately available with a lower CO_2 footprint (g CO_2/MJ) thanks to the organic feedstock and a more sustainable production cycle.

FIGURE 20: HYDROTREATED VEGETABLE OIL PRODUCTION PROCESS



Since 2014, the bio-refinery in Venice has processed around 360,000 tonnes of vegetable oil per year. This production level was scheduled to be increased by 2018 with the shift to operations of the Gela bio-refinery. It will have the capacity to process about 720,000 tonnes of vegetable oil a year and produce 530,000 tonnes a year of green diesel.

B. District heating MiRO project

The Mineraloelraffinerie Oberrhein GmbH (MiRO) refinery located on the Rhine in Karlsruhe, southwest Germany, and Stadtwerke Karlsruhe, the local utility company, have together developed a revolutionary environmental project that aims to supply Karlsruhe's district heating system with waste heat from the refinery. During the winter of 2017-18, it was expected that more than half of Karlsruhe's district heating would be supplied by MiRO.

This €24 million investment project will enhance the security of the area's heating supply while increasing the energy efficiency of the refinery by up to 5%. As waste heat from the refinery is used, there are no additional CO_2 emissions produced for heating purposes. So, the project stops more than 100,000 tonnes of CO_2 emissions each year, a strong environmental benefit.

Reliable heat supply from the refinery is a prerequisite for the planned expansion of the district heating network along existing pipeline routes. The network currently has around 180 km of pipeline, and new lines will be added in coming years. Similarly, more than 90% of Karlsruhe's heating water comes from combined heat and power generation in EnBW's Rheinhafen[18] steam power plant and processed waste heat from MiRO.

The Gunvor Refinery in Ingolstadt has developed a comparable project with the local utility company. The project uses industrial waste heat and saves 67,000 tonnes of CO_2 each year. It is the second heating supplier in Ingolstadt.

C. Full-scale Carbon Capture & Storage value chain project

The three companies signed a partnership agreement in October 2017 to bring to maturity the development of carbon storage on the Norwegian continental shelf (NCS).

The project is part of the Norwegian government's efforts to develop full-scale CCS. It will capture the CO_2 from three onshore industrial facilities in eastern Norway and transport it by ship to an onshore plant located on the west coast of Norway (CCB Kollsnes). At the receiving plant, the CO_2 will be pumped from the ship into onshore tanks. It will then be sent through pipelines east of the Troll field on the NCS and injected for permanent storage more than 2,000 metres below the seabed.

The first phase of this CCS project could reach a capacity of approximately 1.5 million tonnes a year. The project will be designed to accommodate additional CO_2 volumes and so stimulate other commercial carbon capture projects in Norway, Europe and around the world. The project, therefore, has the potential to be the first in the world that receives CO_2 from industrial sources in several countries.

The construction of the full-scale project, including the onshore terminal, is subject to a decision by the Norwegian parliament to approve investment in it. This decision is scheduled for 2019.

The objective of the project is to promote the development of CCS as a means of reaching the long-term climate targets of Norway and the EU. This industrial collaboration will form the basis of further partnerships for the construction and operational phases.

Technologies for CCS in geological formations are well known and established. There are currently 21 full-scale CCS projects worldwide that are either in development or operational. Statoil's CCS projects at Sleipner and Snøhvit are among these, and they have given Statoil more than 20 years of operational carbon storage experience.

[18] Energie Baden-Württenberg AG.

Vision 2050 / **Annexes**

Vision 2050 / **Annexes**

Facts :

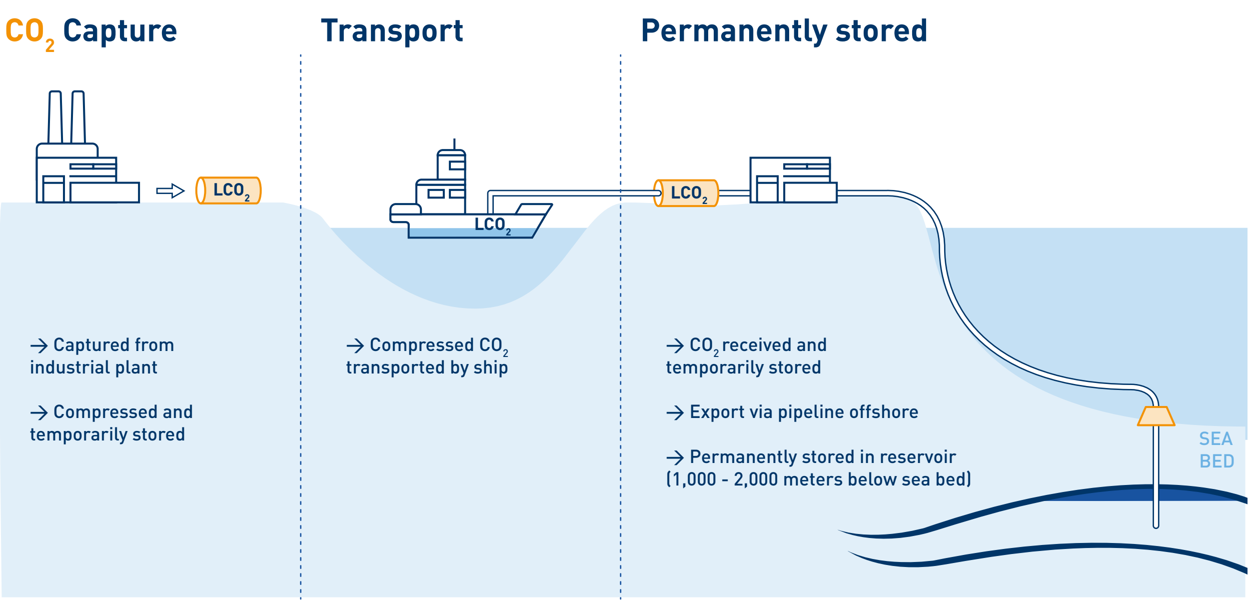
- Carbon capture and storage (CCS) is an important tool for reducing CO_2 emissions and for reaching the global climate goals set in the Paris Agreement.
- Gassnova SF has overall responsibility for realising the Norwegian government's ambition of a full-scale demonstration facility.
- CCS involves three main stages:

a) Capture
CO_2 is captured after being separated from other gases in an emission stream using a chemical process. The CO_2 stream is compressed to a liquid-like state and sent on for transport.

b) Transport
When the CO_2 gas has been compressed, it is transported either via pipelines or in tankers and shipped to a location suitable for permanent storage.

c) Storage
The CO_2 is injected into geological formations at depths of one kilometre or more in the subsurface of the earth. Geological formations that are suitable for CO_2 storage are composed of porous layers that allow the CO_2 to move and spread out within the formation, as well as one or more solid rocks that remain on top like a cap. These form a barrier that prevents the CO_2 from leaking out.

FIGURE 21: THE NORTHERN LIGHTS PROJECT



Source: https://www.equinor.com/en/news/co2-ncs.html

ACRONYMS

ACEA: European Automobile Manufacturers' Association
BAU: Business as Usual
BEV: Battery-Electric Vehicle
CCS: Carbon Capture and Storage
CCU: Carbon Capture and Use
CDU: Crude Distillation Unit
CEFIC: European Chemical Industry Council
CH: Switzerland
CHP: Combined Heat and Power Plant
CNG: Compressed Natural Gas
COPERT: MS Windows Software Program aiming at the calculation of Air Pollutant Emissions from Road Transport
COP21: Conference of Parties
CRF: Catalytic Reformer
DAC: Direct Air Capture
DCU: Delayed Coker Unit
DECHEMA: Deutsche Gesellschaft für Chemisches Apparatewesen
EASE: European Association for Storage of Energy
EEA: European Environment Agency
EMS: Energy Management System
EOL: End-of-Life
ERTRAC: European Road Transport Advisory Council
ETBE: Ethyl Tert-Butyl Ether
ETOH: Ethanol
ETS: Emissions Trading System
EU: European Union
EV: Electric Vehicle
FAME: Fatty Acid Methyl Ester
FCC: Fluid Catalytic Cracker
FCEV: Fuel Cell Electric Vehicle
FCHV: Fuel Cell Hydrogen Cars
FGD: Flue Gas Desulphurisation Unit
FT: Fischer-Tropsch
GCI: Gasoline-Like Fuel
GEM: Gasoline-Ethanol-Methanol
GHG: Greenhouse Gas
HCK: Hydro Cracker
HEV: Hybrid Electric Vehicles
HDS: Diesel Hydro-Desulphurisation Unit
HVO: Hydrotreated Vegetable Oil
IATA: Air Transport Association
ICE: Internal Combustion Engine
IEA: International Energy Agency
IMO: International Maritime Organization
IPTS: Institute for Prospective Technological Studies
ISL: Island
JEC: JRC-Eucar-Concawe
KHT: Kerosene Hydrotreater
LCA: Life-Cycle Analysis
LNG: Liquefied Natural Gas
LP: Linear Programming
LPG: Liquefied Petroleum Gas
LULUCF: Land Use, Land-Use Change and Forestry
MCC: Molecule Carbon Capture
MiRO: Mineraloelraffinerie Oberrhein GmbH
MSW: Municipal Solid Waste
NCS: Norwegian Continental Shelf
NDC: Nationally Determined Contribution
NExBTL: Neste Renewable Diesel
NFR: Net Fiscal Revenue
NHT: Naphtha Hydrotreater
NOR: Norway
NSU: Naphtha Splitter Unit
OEM: Original Equipment Manufacturer
OMV: Österreichische Mineralölverwaltung (English: Austrian Mineral Oil Administration)
O&M: Operations & Maintenance
PCC: Pyridinium Chlorochromate
PEM: Polymer Electrolyte Membrane
PET: Polyethylene Terephthalate
PHEV: Plug-in Hybrid Electric Vehicles
PIV: Plug-in-Vehicle
PJ: Petajoule
PM: Particulate Matter
POW: Power/CHP Plant
PTL: Power-to-Liquids
RDE: Real Driving Emissions
RED: Renewable Energy Directive (RED II)
RON: Research Octane Number
R&D: Research and Development
SDA: Solvent Deasphalting Unit
SIBYL: Baseline for the passenger cars sector
SMR: Steam Methane Reformer
SRU: Sulphur Recovery Unit
TRL: Technology Readiness Levels
TTW: Tank-to-Wheel
US: United States
VBU: Visbreaker Unit
VDU: Vacuum Distillation Unit
VHT: Vacuum Gasoil Hydrotreater
WEO: World Energy Outlook
WTT: Well-to-Tank
WTW: Well-to-Wheel
ZEV: Zero Emission Vehicle

FuelsEurope
Boulevard du Souverain, 165
1160 Brussels
www.fuelseurope.eu

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