Concawe
Environmental Science for European Refining

Review

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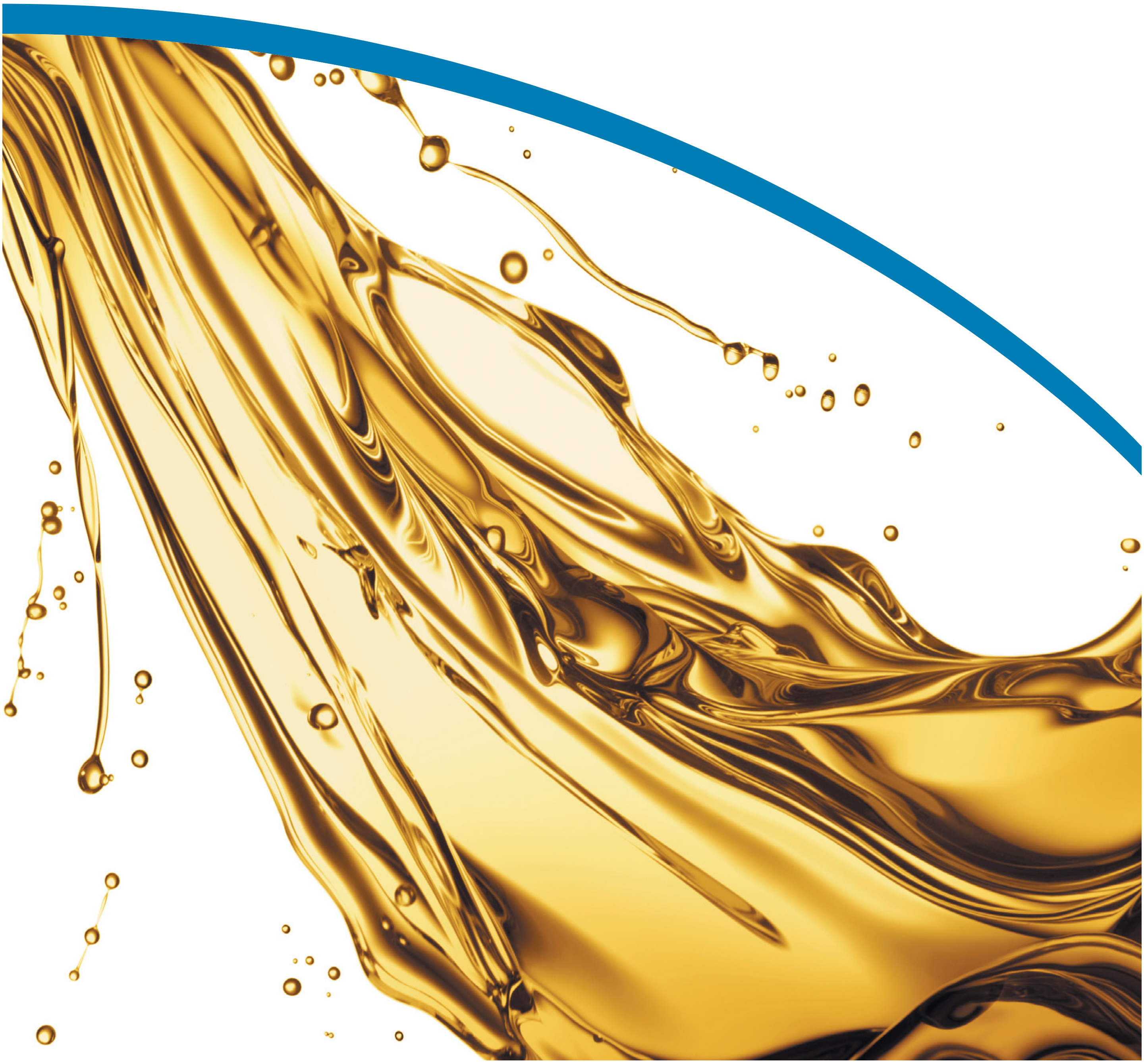

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Editor: Robin Nelson, Concawe

Foreword

I am very pleased to introduce the three articles in this edition of the Concawe *Review*. The first two emanate from Concawe's Low Carbon Pathways programme. The first article is a literature review summarising different perspectives on the availability and relative cost of biomass and e-fuels as lower-carbon alternatives to oil-based fuels in the medium and long term. I find this summary to be one of the most informative articles I have read on this subject and congratulate the authors for this. The article takes me back to the beginning of my career, as amongst others, it touches on what can be done to increase yields of biomass from crop species. In fact, it will be relatively easy to develop longer-stem varieties of cereal crops simply because in the 1980s plant breeders developed new varieties with higher yields of grain, by reducing the height of the crop. It also meant that the shorter-stem varieties were more wind-tolerant (longer stems are more prone to wind damage). As such, the characteristics we are now seeking for biomass are already in the genepool. However, as a note of caution, while it will be easy to return to longer-stem varieties, breeders will need to take care not to allow grain yield or resistance to wind damage suffer as a result.

Robin Nelson
Science Director
Concawe

While the first article is a succinct summary of the availability of, and challenges in developing, low-carbon liquid fuels, the second article is a summary of a study by Ricardo comparing different scenarios for the future of light-duty passenger vehicles and vans. This work shows that it is possible to meet the EU decarbonisation goals for light-duty transport using a range of powertrain options from full electric through plug-in with hybrids to the latest internal combustion engines utilising low-carbon liquid fuels. This is a common-sense approach because the combination of different technologies is more likely to increase the rate of decarbonisation of transport than any desire to electrify everything at all costs. Such a balanced approach will allow the time necessary to develop the charging infrastructure for widespread use of electric vehicles and the transition to a fully renewable electricity supply, and to address issues with raw materials for battery supply and their recyclability.

The third article summarises the 2018 update on the issue of theft as a major cause of damage leading to spillages from oil pipelines. I was horrified to hear the news, only a few weeks into 2019, of the theft of gasoline from the pipeline in Tlahuelilpan, Mexico which led to 96 deaths and 48 injuries. The latest figures on theft from pipelines in Europe is more encouraging and would suggest that the work to communicate this issue has resulted in a reduced number of incidents in 2017 and 2018. However, the Mexico incident serves as a stark reminder of the need to maintain vigilance to such a risk.

Contents

The European Commission has recently published its long-term strategic vision for Europe. Recognising that climate change represents an urgent threat to societies and the planet, the Commission has set the goal, in accordance with the 2015 Paris Agreement, of keeping global warming well below 2°C above pre-industrial levels, and pursuing efforts to limit it to 1.5°C by 2050. The EU transport sector, which accounts for nearly a quarter of the EU's greenhouse gas emissions, will be crucial to achieving these goals. Sustainable biofuels are one of the main low-carbon liquid alternatives to petroleum-based fuels for transport, as they are easily deployable using existing transport infrastructure. This article is based on a literature review of selected external sources, and looks into the medium- and long-term potential availability, demand, technology and cost of alternative low-carbon feedstocks and fuels. Some of the sources included in the report envisage a significant long-term role for advanced alternative fuels in Europe, identifying the main research and innovation, and policy conditions that would enable the potential of low-carbon fuels to be fully realised.

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As part of the Concawe Low Carbon Pathways programme, this article summarises the main results of an extensive study carried out by Ricardo where the impacts of three scenarios in the European light-duty vehicle market to 2050 were examined versus a European Commission Business-As-Usual (BAU) scenario:

- High EV scenario representing mass EV adoption to ~90% battery electric vehicle parc by 2050.
- Low Carbon Fuels scenario representing use of significant proportions of biofuels and e-fuels.
- Alternative scenario representing use of more PHEVs together with increased use of biofuels and e-fuels.

The results of this in-depth study are discussed in this article, and one of the main takeaways of the study is that both GHG savings and total costs were calculated to be similar for both the High EV and Low Carbon Fuels scenarios, and the costs for both scenarios are lower than for the business-as-usual case. The study shows that both electrification and low-carbon fuel technologies are complementary and require the adoption of policies based on a neutral approach to technology support, ultimately leading to the best choices and decisions for the future of the EU.

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A look into the maximum potential availability and demand for low-carbon feedstocks/fuels in Europe (2020–2050)

(literature review)

In light of the EU's ambitious targets for achieving a low-carbon economy by 2030, Concawe has completed a study of the long-term availability of low-carbon feedstocks and fuels, and the associated costs, based on a literature review. This article summarises the outcomes of the Concawe study.

Introduction

Over the past decades, different pathways such as biofuels or power-to-fuel technologies have emerged as viable options to reduce the life-cycle carbon emissions from the production and use of hydrocarbon fuels as well as feedstock for petrochemicals, lubricants and waxes.

Concawe, through its Low Carbon Pathways (LCP) programme, is conducting specific research on the potential integration of different well-to-wheel (WTW) opportunities to produce a holistic picture of the potential role of liquid fuels in a future EU low-carbon economy. Concawe's assessments explore the potential reduction in WTW CO_2 intensity that could be achieved in the medium (2030) and longer term (2050+), and estimate the associated abatement costs from different pathways that have the potential to contribute significantly to reducing the CO_2 intensity of the final refining products. This article looks into the medium- and long-term potential availability of alternative low-carbon feedstocks and fuels, and presents the associated costs based on a literature review. Some of the sources included in the report envisage a significant long-term role for advanced alternative fuels in Europe, identifying the main research and innovation (R&I) and policy conditions that would enable the potential of low-carbon fuels to be fully realised. Some of the ongoing Concawe LCP-related work on *The Refinery 2050*[1] draws support from the conclusions and main figures included in this article, and is scheduled for publication in April 2019.

The European Commission has recently published its long-term strategic vision for Europe, *A Clean Planet for all*.[1] Recognising that climate change represents an urgent threat to societies and the planet, the Commission has set the goal, in accordance with the 2015 Paris Agreement, of keeping global warming well below 2°C above pre-industrial levels, and pursuing efforts to limit it to 1.5°C by 2050. Efforts to improve the CO_2 efficiency of the EU transport sector, which accounts for nearly a quarter of the EU's greenhouse gas emissions, will be crucial to achieving these goals. Technologies for the production of low-carbon fuels is one area that is especially interesting in terms of helping the transport sector to accomplish these targets.

Sustainable biofuels, subject to the updated sustainability criteria currently proposed by the European Commission,[2] are one of the main low-carbon liquid alternatives to petroleum-based fuels for transport, as they are easily deployable using existing transport infrastructure. The Renewable Energy Directive (RED),[3] the Fuels Quality Directive (FQD)[4] and the 'ILUC Directive'[5] set out biofuels sustainability criteria for all biofuels produced or consumed in the EU to ensure that they are produced in a sustainable and environmentally friendly manner.

Current legislation (RED I and RED II) requires a 7% cap on the contribution of conventional biofuels, including biofuels produced from energy crops, to count towards the renewable energy directive targets regarding final consumption of energy in transport in 2020 and in 2030 . Secondly, the RED II directive (that entered into force on 24 December 2018) sets as a binding minimum a 0.5% target for advanced biofuels by 2021 and 3.5% by 2030. Thirdly, the directives harmonised the list of feedstocks (Annex IX) for the production of advanced biofuels across the EU. Those can be considered to count double (i.e. to be twice their energy content) in terms of their contribution towards the 2030 target of 14% for renewable energy in transport.

[1] One of series of publications being produced by Concawe as part of the organisation's Low Carbon Pathways programme.

These directives require that biofuels produced in new installations — starting after 1 January 2021 — emit at least 65 % fewer greenhouse gases than fossil fuels.

The Fuels Quality Directive allows gasoline fuels in Europe to contain up to 10% bio-derived oxygenates, usually in the form of ethanol, while diesel fuels can contain up to 7% fatty acid methyl ester, although other bio-derived components are also allowed.

What is a sustainable biofuel?

Burning harvested organic matter (biomass) has provided most of mankind's energy needs for millennia. Such fuels remain the primary energy source for many people in developing and emerging economies, but such 'traditional use' of biomass is often unsustainable, with inefficient combustion leading to harmful emissions with serious health implications. Modern technologies can convert this organic matter to solid, liquid and gaseous forms that can more efficiently provide for energy needs and replace fossil fuels.

A wide range of biomass feedstocks can be used as sources of bioenergy. These include: wet organic wastes, such as sewage sludge, animal wastes and organic liquid effluents, and the organic fraction of municipal solid waste (MSW); residues and co-products from agro-industries and the timber industry; crops grown for energy, including food crops such as corn, wheat, sugar and vegetable oils produced from palm, rapeseed and other sustainably produced raw materials; and non-food crops such as perennial lignocellulosic plants (e.g. grasses such as miscanthus, and trees such as short-rotation willow and eucalyptus) and oil-bearing plants (such as jatropha and camelina). Many processes are available to turn these feedstocks into products that can be used for electricity, heat or transport.

What are advanced biofuels?

Advanced biofuels are commonly accepted to be biofuels that:

- are produced from lignocellulosic feedstocks (i.e. agricultural and forestry residues), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams;
- produce low CO_2 emissions or high GHG reductions (at least 60% fewer GHGs than fossil fuels); and
- reach zero or low indirect land-use change (ILUC) impact.

The development of biomass resources in particular faces numerous challenges due to the complexity of land issues, related politics, cost/scale, infrastructure support, and environmental criteria. Furthermore, there is no evidence in the press or in public relations activities in Europe that any major developments are forthcoming in this area.

A look into the maximum potential availability and demand for low-carbon feedstocks/fuels in Europe (2020–2050) (literature review)

Scope: mid- to long-term outlook (literature review)

This study addresses the potential availability of low-carbon feedstocks, and looks at different demand scenarios to provide an outlook for biofuel potential for the 2020, 2030 and 2050 time-horizons in Europe and worldwide, covering the following scope:

- Potential biomass availability for the 2020, 2030 and 2050 time horizons
- Potential demand for the 2020, 2030 and 2050 time horizons
- Technologies conversion routes and technology readiness level (TRL)
- Potential production costs for the 2020, 2030 and 2050 time horizons
- Challenges: barriers and potential enabling conditions.

This study is based on a literature review of selected external sources. It highlights the uncertainty associated with the maximum potential availability of biofuels, which is heavily dependent on the key enabling framework conditions that would be required to unleash the full potential for low-carbon feedstocks/fuels in Europe.

The main source references used in this study are summarised in Table 1. Each source follows a specific approach in developing their estimations.

Table 1: The approach followed by each source reference in developing their estimations

	MAIN REFERENCES	MAIN APPROACH FOLLOWED BY THE SOURCES
Biofuels[6]	SETIS	Based on EU targets for renewable energy and installed capacity
	DG R&I Ecorys	Based on extensive R&I efforts in agriculture, mobilisation of resources and development of conversion technologies, and assumptions about feedstock availability, and the degree of support from the agricultural and transport sectors
	SGAB	Based on what the industry can deliver from the conversion facilities' points of view, given the appropriate policy framework and financing structure
	IEA	Based on EU targets for renewable energy and future demand scenarios
	IRENA	Based on assumptions about policies and biofuel availability and cost
	ICCT	Based on the availability of sustainable biomass
e-fuels[7]	Agora	Based on importation from regions with cheap and full load hours electricity
	LBST and Dena	Based on demand scenarios competing with other technologies
	ICCT	Based on future electricity prices and financial parameters

Note: IEA and IRENA provide a worldwide scope, while SETIS, Ecorys, SGAB, ICCT, Agora and Dena focus on a European framework. Most of the studies only cover the potential availability and demand for advanced sustainable biofuels, and do not include an assessment of first-generation biofuel potential by 2030/2050.

Potential biomass availability for the 2020, 2030 and 2050 time horizons

In this study, potential biomass availability is analysed worldwide and across Europe. The analysis considers the availability of bioenergy throughout Europe as a whole, as well that related specifically to the transport sector (as a subgroup of the bioenergy system). The whole bioenergy system covers all sectors, such as electricity, heat, the chemical industry and transport. All these sectors compete for the same sustainable biomass resources; therefore, even at maximum levels of sustainable bioenergy production, cross-sectoral competition is high.

Worldwide biomass availability

World sustainable biomass availability is generally expected to increase continuously from a total of 2,500 Mtoe/y by 2020 (IRENA reference) to 5,700–7,000 Mtoe/y by 2050 in the max scenario (IEA/IRENA reference) mainly based on agricultural residues and energy plants (>70%).

The IEA 2050+ scenario forecasts a lower potential availability as defined by IRENA in their 2050 base scenario, with the main difference being the envisaged potential for algae. Indeed, the potential deployment of algae is uncertain (mainly due to the current efficiency levels and high cost), and while several sources recognise its role in the 2050 scenario (e.g. according to IRENA, algae could reach 478 Mtoe/y by 2050), other sources such as IEA are more conservative in this regard and do not consider that there will be any relevant penetration of algae within the 2030–2050 time frame.

Some references, such as ICCT,[8] claim that there is not enough bioenergy to decarbonise all sectors together. These have a more conservative view, and assume that the maximum global amount of low-carbon biomass that could be supplied for energy by 2050 will be around 2,150 Mtoe/y.

Figure 1 notes:

Energy contents: (1 toe = 41,868 GJ)

Conversion factors[9] used by Concawe for comparison purposes (simplified approach) are:

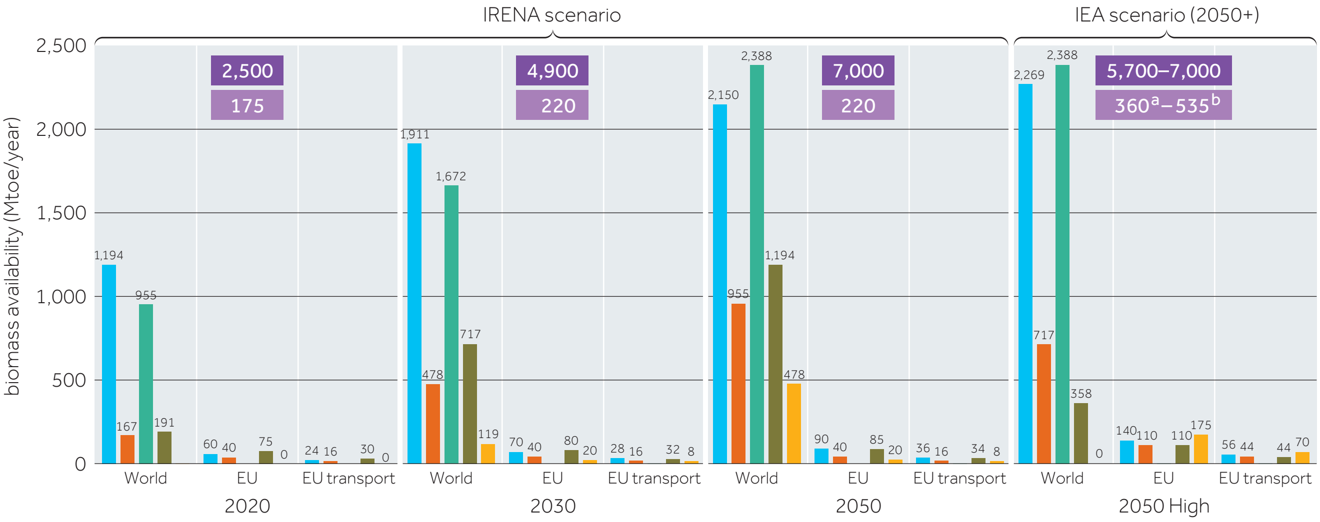
- Agriculture residues energy content: 0.56 toe/t
- Forestry energy content: 0.21 toe/t
- Waste energy content: 0.76 toe/t
- Aquatic (algae) energy content: 0.48 toe/t

Legend:

- total world bioenergy, Mtoe/year
- total EU bioenergy, Mtoe/year
- a ICCT has the most conservative view, assuming that the maximum global biomass availability in 2050 is around 2,150 Mtoe/y
- b biomass availability if the full potential for algae is realised
- agriculture (non-food related)
- forestry
- energy plants
- waste
- aquatic (algae)

Figure 1: World maximum biomass availability, 2020–2050

Source: Concawe own assessment based on data from IRENA and IEA for world availability; ICCT, DGR&I Ecorys and SGAB for EU availability



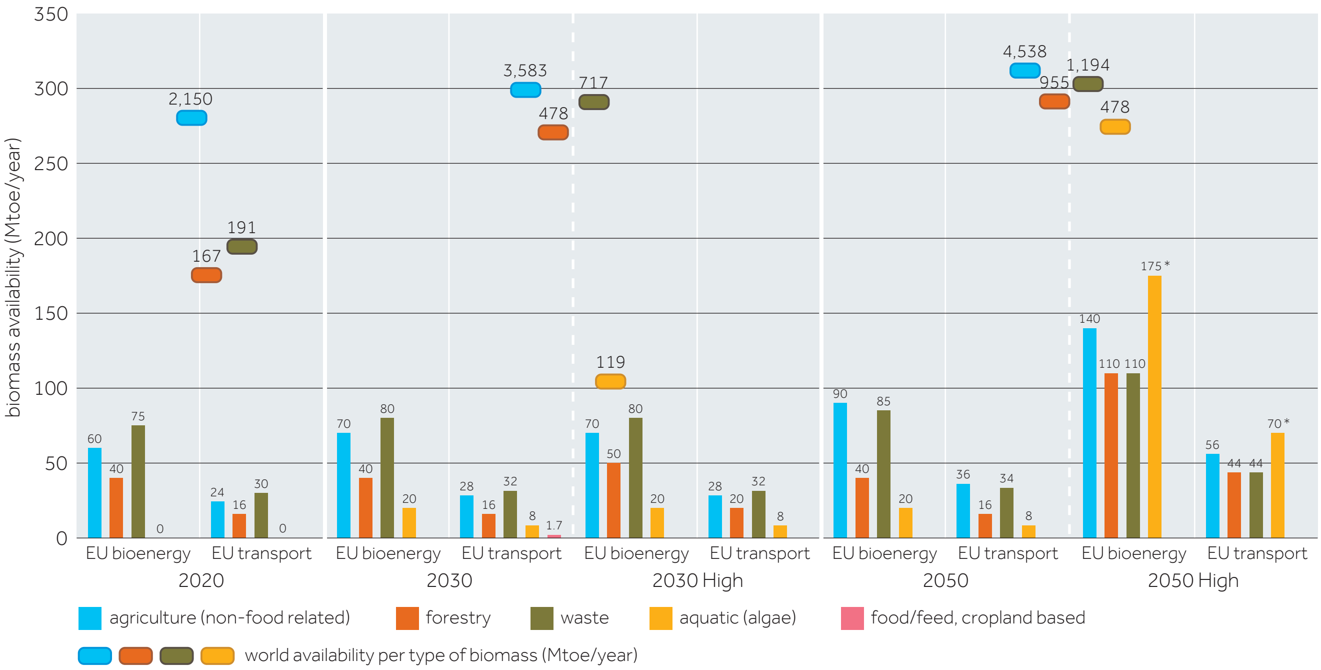
European biomass availability

When considering the availability of sustainable biomass in Europe, it should be noted that the whole of the bioenergy system is estimated to grow from 175 Mtoe/y (2020) to approximately 350–535 Mtoe/y by 2050. According to DG R&I Ecorys, the amount of biomass that will need to be available to meet the demand for bioenergy is expected to be 360 Mtoe/y. It is estimated that 15 Mtoe/y of this will be imported, hence the maximum level of biomass that will need to be available in Europe could be approximately 350 Mtoe/y. If the full potential for algae is realised, this could increase the level of available biomass from around 350 up to 535 Mtoe/y; however, according to DG R&I Ecorys, the full potential for algae is not expected to be reached because of its high cost. According to the European Commission,[0] the production of feedstock in Europe will be lower by 2050, and could range from 210 to 320 Mtoe/y (the majority coming from the waste sector). It is assumed that most of the biomass used in the EU economy will be produced within Europe (imports of sustainable solid biomass will be limited to 4–6% of the solid biomass used for bioenergy by 2050).

For the transport sector, different sources estimate that the biomass contribution could range from a total of 70 Mtoe/y (2020) to 140–210 Mtoe/y by 2050. In terms of energy content, agricultural residues and wastes are expected to contribute the most, followed by forestry residues and algae.

Figure 2: European biomass availability, 2020-2050

Source: Concawe own assessment based on data from IRENA and IEA for world availability; DG R&I Ecorys for EU availability



Notes:

* Algae uncertainty in 2050 high Ecorys scenario. High scenario considers high learning rates for all technologies.

- For the purpose of this assessment, it is assumed that a percentage of 40% of total bioenergy could be allocated to transport (based on Ecorys demand scenarios).
- Energy contents: 1 toe = 41,868 GJ
- As a general reference, the energy content of one hectare of miscanthus is 12 toe/ha.
- ICCT provides a more conservative EU availability by 2030 (only a total of 84 Mtoe/y for bioenergy) while SGAB provides a more optimistic view (350–400 Mtoe/y).
- IRENA worldwide values are based on average data. There is high variability in extreme data (e.g. energy plants by 2050 could vary from 10 to 1000 EJ).

Potential demand for the 2020, 2030 and 2050 time horizons

The previous section assesses the maximum potential for R&I to enable secure, low-cost and sustainable biomass feedstock for energy (including the transport sector). In contrast, this section focuses on the potential contribution of biofuels towards achieving the EU's ambitious climate change objectives from the perspective of what might be demanded by the different bioenergy sectors (demand scenarios).

The maximum potential demand for advanced biofuels in the EU, assuming there is sufficient availability, is estimated to grow from ≈ 0 Mtoe/y in 2015 to 70–140 Mtoe/y by 2050. According to the European Commission,[0] advanced biofuels could represent a smaller contribution to the transport sector fuel mix by 2050 (up to 50 Mtoe/y). Power and industrial sectors would absorb most of the biomass (< 20% allocated to transport).

Based on resource availability and allocation across all European bioenergy sectors, there could be significant variability in potential demand according to different references. The DG R&I Ecorys 2050 high scenario is significantly higher than the rest, followed by IEA.

There is also high variability regarding e-fuels. According to the Dena reference, e-fuels play a role by 2030 (36 Mtoe/y) and 2050 (80 Mtoe/y). However, DG R&I Ecorys have a more conservative view: they estimate a potential e-fuel production of 10 Mtoe/y (~10 Mt/y) in their 2050 high scenario. According to ICCT, e-fuels are not expected to play a role without significant policy support. According to the European Commission,[0] e-fuels could represent from 0 to 71 Mtoe/y of transport energy demand in 2050.

Figure 3 notes:

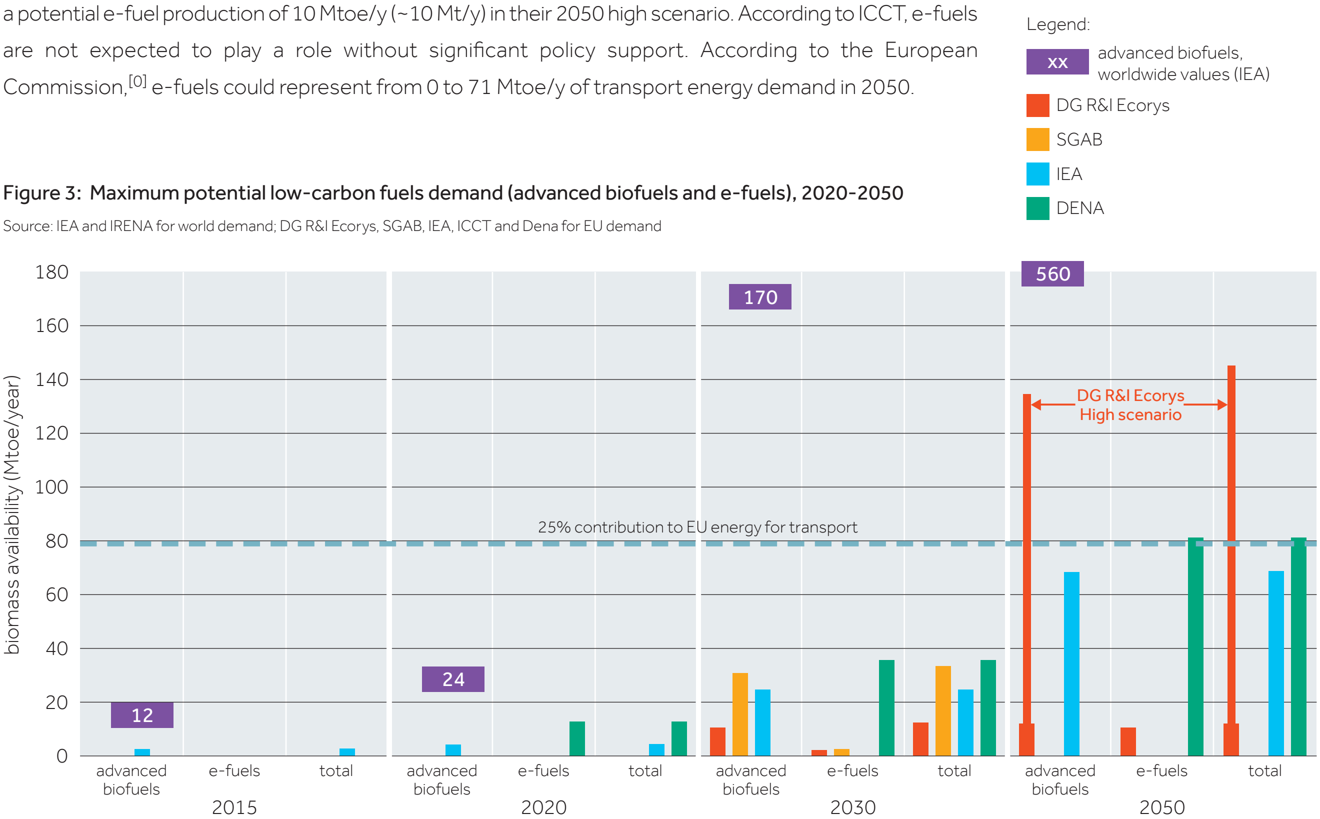
As a general reference, the energy content in a typical road tanker full of gasoline is assumed as the conversion factor = 23 toe.

In 2050, wider and shorter red columns refer to the DG R&I Ecorys base scenario.

In 2030, the IRENA worldwide value is 100 Mtoe/y (below the IEA's estimation of 170 Mtoe/y), considering a lower heating value (LHV) of 44 MJ/kg (100% HVO/FT diesel). For oxygen-containing biofuels, the LHV would be closer to 37 MJ/kg.

Figure 3: Maximum potential low-carbon fuels demand (advanced biofuels and e-fuels), 2020-2050

Source: IEA and IRENA for world demand; DG R&I Ecorys, SGAB, IEA, ICCT and Dena for EU demand



These assessments are summarised in Figure 3, and compared to the potential worldwide demand. In the most optimistic scenarios, European demand for advanced biofuels would be equivalent to 16% of what could become available in the rest of the world. Future demand scenarios outside Europe have not been included in this comparison.

The DG R&I Ecorys high scenario is significantly higher. This is due to the approach taken by the study. It examines the R&I potential for advanced biofuels under future scenarios where EU targets are met. DG R&I Ecorys have developed base, medium and high scenarios, each assessed using different assumed levels of R&I efforts.

The key factors necessary for realising the full potential of biofuels in Europe are:

1. Improvements in feedstock supply

   Examples include:

   - An increase in conventional (food/feed) crop yields due to breeding efforts which aim to build up the resistance to biotic and abiotic stresses (drought, pests and diseases) as well as to increase residue to crop ratios (straw/grain ratio). This can lead to an absolute increase in main crop biomass and crop residues, and potentially provide more space for growing energy crops (if demand for food/feed can be satisfied with less land).
   - An increase in yields from energy crops due to the development of hybrid crops specifically dedicated to energy. This can include the development of more robust, stress-resistant energy crops as a result of prebreeding and breeding activities, as well as the domestication of new energy crop species.
   - Increased production by growing dedicated energy crops on unused agricultural lands. Further expansion of energy crops on non-agricultural land (marginal lands) is anticipated in the future. Expansion on marginal lands will be possible because of breeding efforts targeted at developing more robust plants which are able to grow in less suitable conditions.
   - The effects of developments in genetic research over the longer term.
   - Fertilisation of forests growing on poor soils.

2. Improvements in the efficiency of the whole biomass to biofuel process chain

   Examples include:

   - Improved agricultural management practices (e.g. selection of crop varieties, crop rotation and intercropping, fertilisation, water management, adoption of precision agriculture practices) to bridge the current gaps in yields among EU member states.
   - Improved harvesting practices and machinery (development of new equipment for both conventional and dedicated energy crop harvesting, improving harvesting practices, development of precision farming).
   - Increased mobilisation of agricultural biomass by optimising supply chain logistics (mobilisation of unexploited biomass by using cleaner, more efficient and more cost-effective technologies, technology transfer, streamlining biomass supply chains with existing practices, and development of new supply chains for dedicated energy crops).
   - Harvesting trees more efficiently, thereby reducing harvest losses

3. Decrease in conversion costs
    - Improvements in the efficiency of the process chain can reduce conversion costs (as mentioned above).

4. The high potential of algae
    - Increased R&I efforts for the development of photobioreactor (PBR) systems.
    - Targeted R&I efforts on algae strains with high productivity rate and lipid content such as chorella.
    - Adaption of harvesting methods that are commercially available for the food and feed sector such as flocculation, sedimentation and filtration, as well as centrifugation for microalgae-to-biofuel value chains.
    - R&I efforts on the direct conversion of microalgae to biofuels via hydrothermal liquefaction (HTL) at pilot scale.
    - Increased R&I efforts in the field of aquaculture production of macroalgae, while the harvesting of wild seaweeds is decreased.

5. High learning rates for all technologies
    - The learning rates represent the effect of R&I in the learning-by-doing mechanism, which will have an influence on the capital costs of conversion technologies as capacity increases.

6. Significant investments in advanced biofuels capacity
    - To achieve the 2020 targets, the currently installed capacity for advanced biofuels will need to increase from 0.2 GW to close to 1.1 GW, at an estimated cost of €4.5–5 billion. Advanced biofuels also have the potential to reach the 2030 and 2050 targets if capacity is increased to 30 GW in 2030 and to 250 GW in 2050.

7. Substantial efforts and coordination between stakeholders
    - Increased awareness and capacity of the various actors involved in the biomass supply chain.

8. R&I policies
    - Targeted policies, e.g. R&I for feedstock and conversion technology, are crucial to unlocking this potential. Such policies should also address the substantial investments needed for the market transition to large-scale production of advanced biofuels; a lack of sufficient investment could be the greatest obstacle for the development of advanced biofuels. These policies may include efforts to attract foreign capital. Most EU countries (apart than Finland, France, Germany, Italy, Poland, the Netherlands, Spain, Sweden and the UK) do not currently produce advanced biofuels, but they do have potential for the production of sustainable feedstock and advanced biofuels in the future.

Technologies conversion routes and technology readiness level (TRL)

Currently, several conversion and upgrading technologies are available, with different technology readiness levels (TRLs), from research status (TRL 1) to commercialisation (TRL 9). A high-level overview is presented below. Biofuel production costs will vary depending on the conversion technologies, feedstocks and TRL.

Figure 4: Commercialisation status of advanced fuels conversion technologies

Source: IRENA

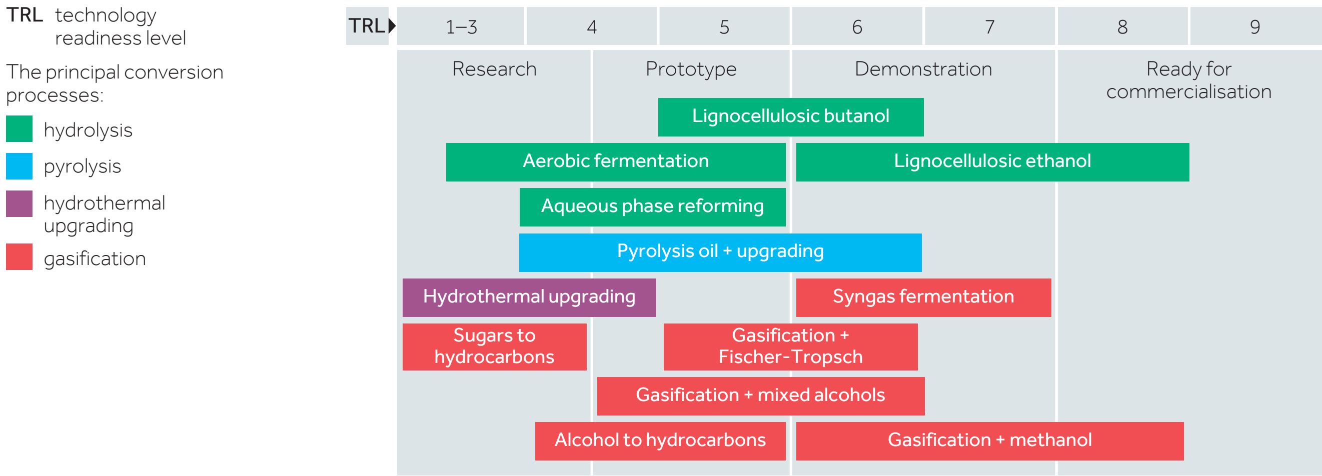
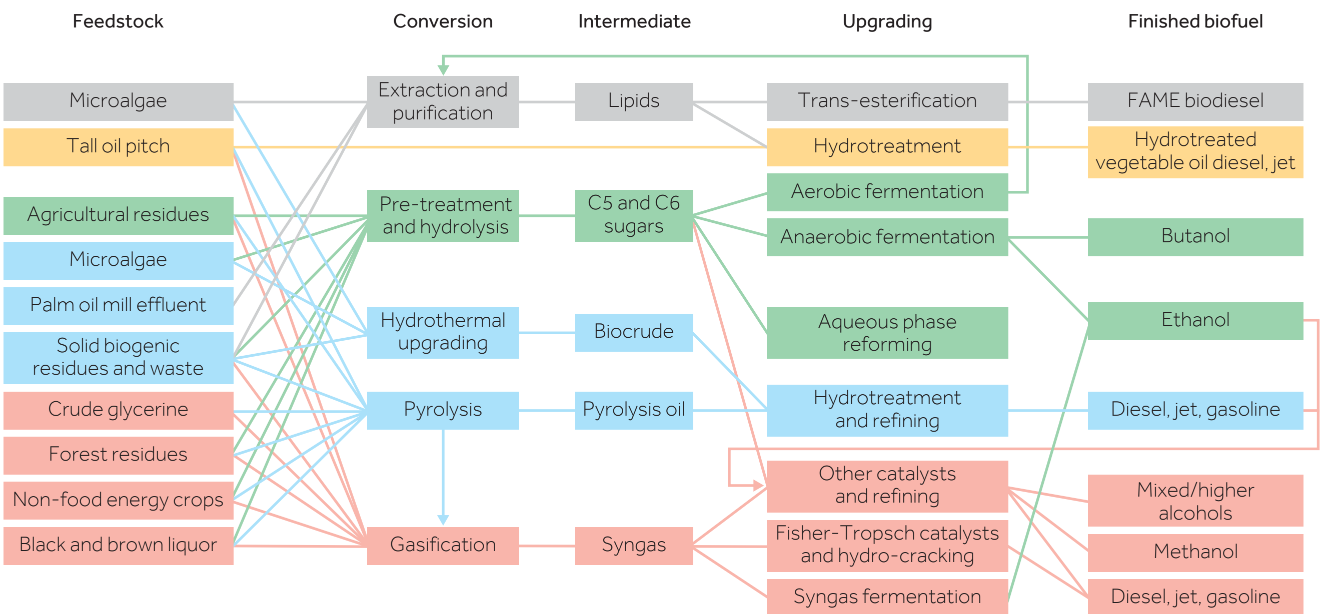


Figure 5: Advanced biofuels pathways

Source: IRENA



Potential production costs for the 2020, 2030 and 2050 time horizons

Production costs for advanced biofuels and e-fuels are higher compared to the costs for equivalent oil-based gasoline or diesel. Different source references note the potential for the production costs of both feed cropland-based biofuels and conventional gasoline/diesel production costs to be significantly reduced by 2050 (<2 €/litre diesel equivalent); this will be highly variable depending on the conversion technologies used.

IRENA claims that, based on potential improvements in conversion efficiency, capital cost reduction, scaling up, learning rates and efforts to reduce the costs of feedstock supply, the production costs for advanced biofuels could become competitive with fossil fuel at an oil price above 100 $/bbl. At an oil price below 80 $/bbl, advanced biofuels pathways are unlikely to be able to compete directly with gasoline and diesel over the next three decades unless very low or negative cost feedstocks are available.

An overview of future costs associated with both feedstock prices and conversion technologies follows, and shows the high uncertainty around the projections developed by the different sources consulted.

Figure 6 notes:

Key data: 1 toe = 41,868 GJ

Diesel LHV: 44 MJ/kg

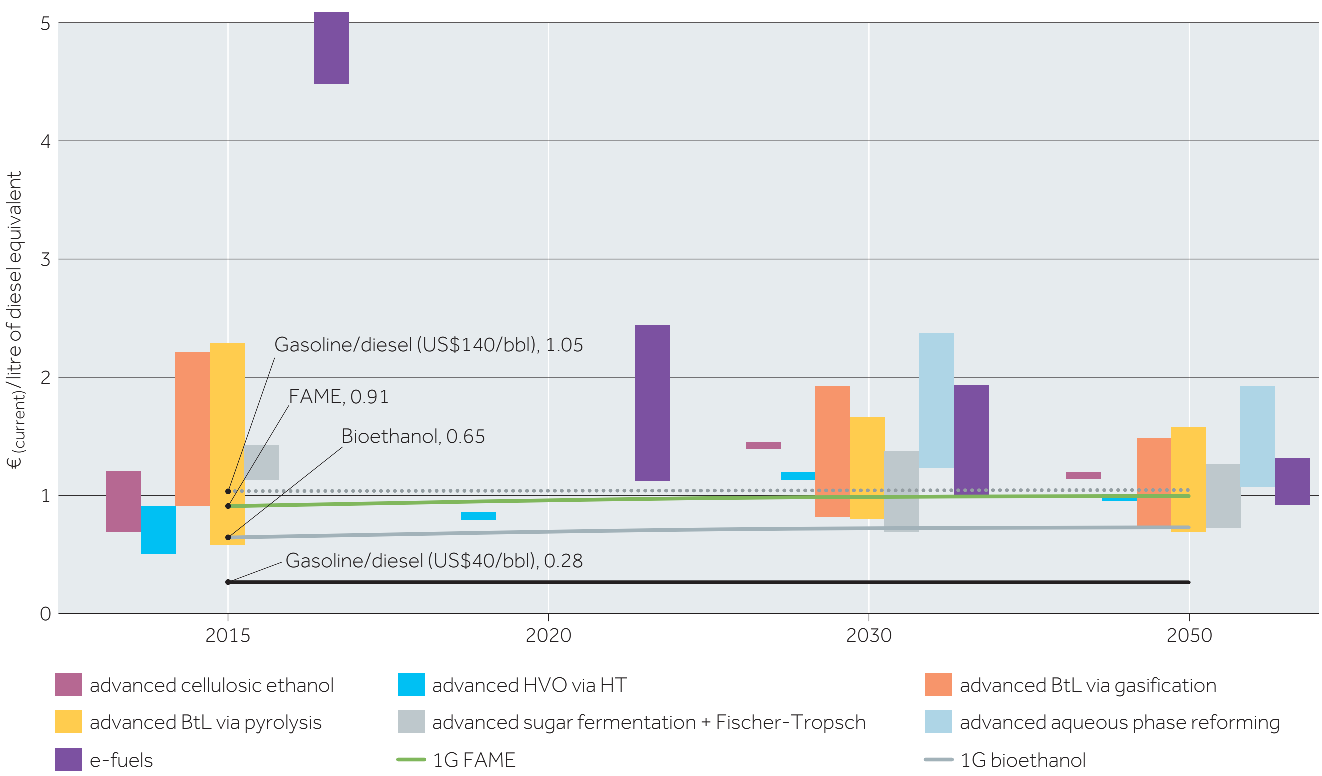
Diesel density: 0.832 kg/l

Gasoline/diesel production costs are reported without taxes.

Production costs for feed cropland-based biofuels (FAME and bioethanol) are expected to be in the same range as the costs of conventional gasoline or diesel at a crude oil price of US$100/bbl, according to the IEA.

Figure 6: Potential production costs, 2015–2050

Sources: DG R&I Ecorys; SGAB; IRENA; IEA; ICCT; IPIECA; CEFIC; Dena; and Frontier Economics/Agora.



An overview of the different conversion technologies

Figure 7: Potential production costs according to different references and technologies, 2015–2050

Sources: DG R&I Ecorys, SGAB, SETIS, IRENA, IEA, ICCT, IPIECA

Figure 7 notes:

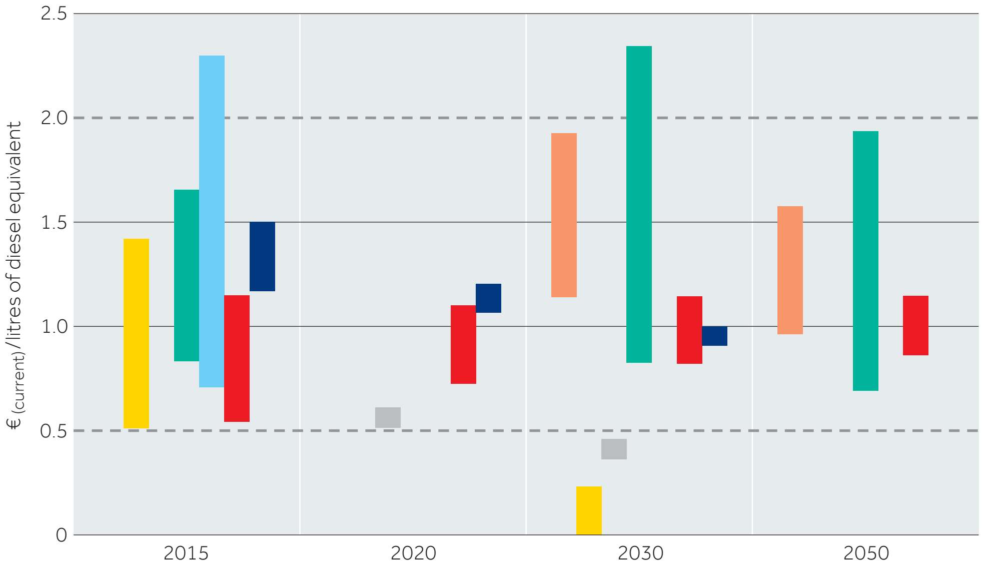
Key data: 1 toe = 41,868 GJ

Diesel LHV: 44 MJ/kg

Diesel density: 0.832 kg/l

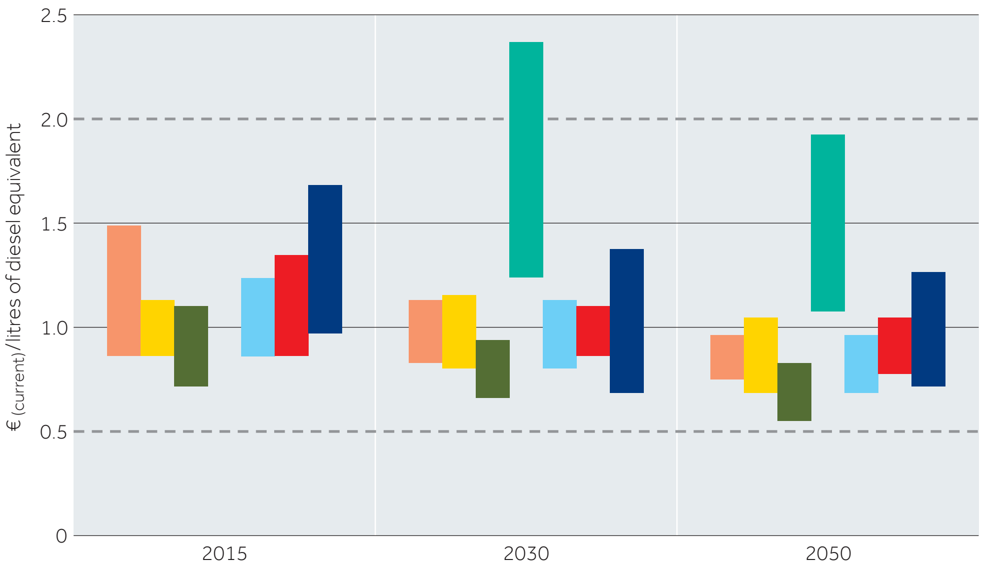
Change: $/€ $_{2014}$: 1.329

a) Biofuel costs according to all references



Ecorys
SGAB
SETIS
IRENA
ICCT
IEA
IPIECA
average cost band

b) Deep dive per type of technology (example from IRENA)



Fischer-Tropsch synthesis
pyrolysis oil upgrading
methanol to gasoline
aqueous phase reforming
mixed alcohol synthesis
syngas fermentation
lignocellulosic fermentation
average cost band

The average costs are expected to remain the same, from 0.5 to 2.0 €/litre diesel equivalent, although the variability among different references suggests an uncertain future for the development of conversion technologies as they are scaled up. The costs of aqueous phase reforming for biofuels are claimed to be higher than the average (from a maximum of 2.4 €/litre by 2030 to 1.9 €/litre by 2050, according to IRENA); cost reductions and an increase in yields are the main challenges to be overcome before this technology is likely to be adopted for widespread use in the transport sector.

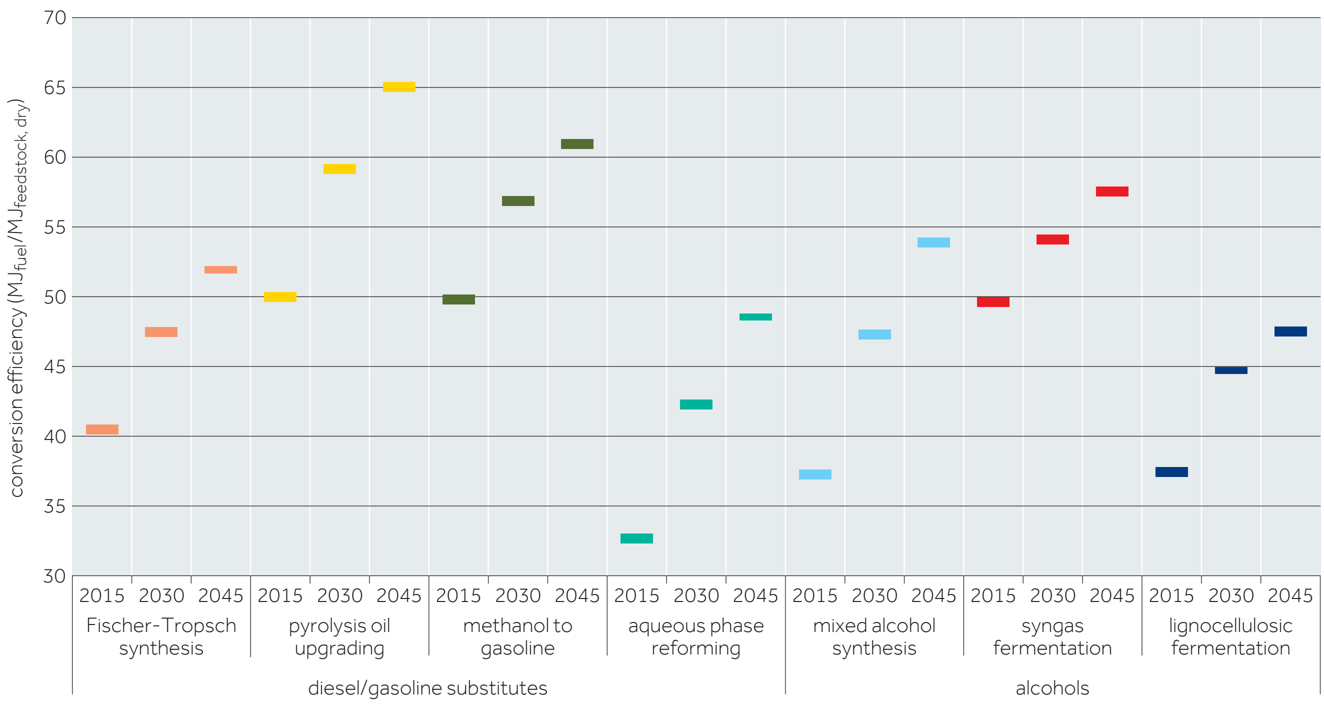
According to IRENA, gasification (Fischer-Tropsch (FT) synthesis), pyrolysis pathways and methanol-to-gasoline technology show higher maximum theoretical conversion efficiencies compared to other pathways. The majority of these pathways may still achieve significant improvements in overall conversion efficiency, with the exception of fermentation. This will potentially enable these technologies to achieve lower production costs over the next decades.

Lignocellulosic fermentation and syngas fermentation pathways for ethanol production are currently operating close to their maximum theoretical yields. There is thus less scope to increase yields in these cases.

Figure 8 shows the forecasted improvements in process efficiencies in the next decades.

Figure 8: Comparison of process efficiencies

Source: IRENA



Biomass supply costs

The forecasted cost of biomass is one of the main uncertainties due to future competition for resources among different bioenergy sectors (including transport).

According to IRENA, for example, biomass costs could potentially range from -2 to 8 €/GJ depending on the origin of the biomass: the costs of producing energy crops as feedstocks are claimed to be higher than for waste, followed by agriculture residues and, finally, forest residues.

According to DG R&I Ecorys, the cost of biomass supply is expected to increase from 2020 to 2050, but is expected to decrease according to IRENA.

IRENA claims that the feedstocks used in most pathways account for 40–70% of production costs, using typical wood or agricultural residue cost assumptions. As learning rates increase and efficiencies improve, the contribution of the feedstock cost to overall costs may increase over time. Reducing the feedstock supply cost is key to reducing production costs.

Figure 9: Biomass supply costs according to three different references, 2015–2050

Source: DG R&I Ecorys, SGAB, IRENA

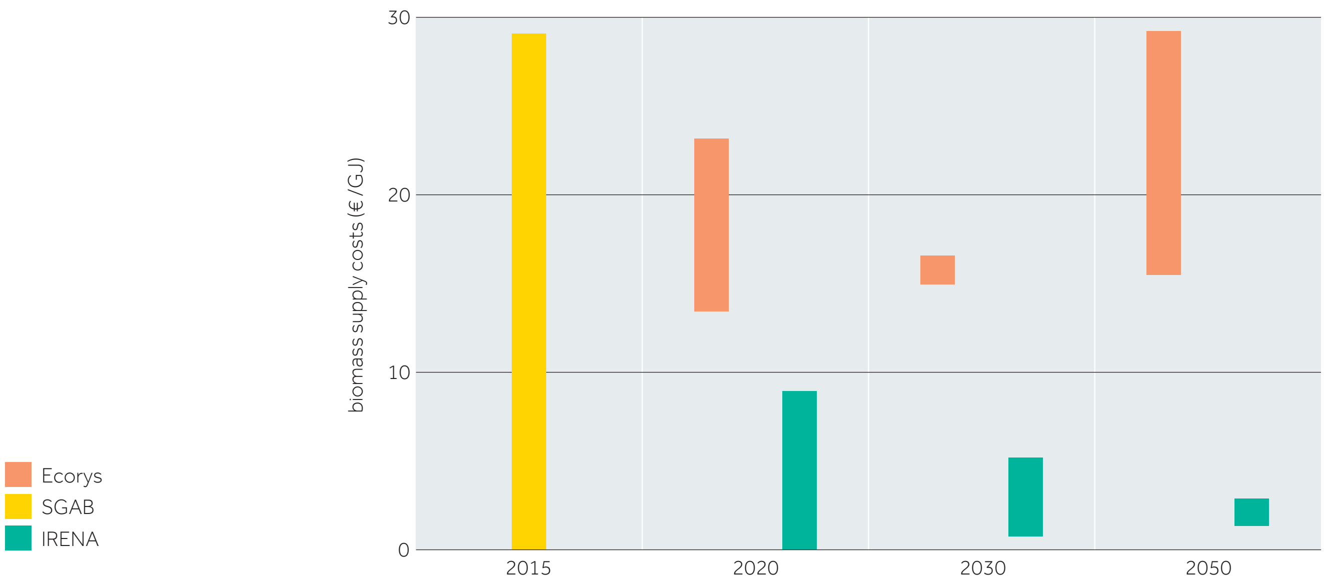
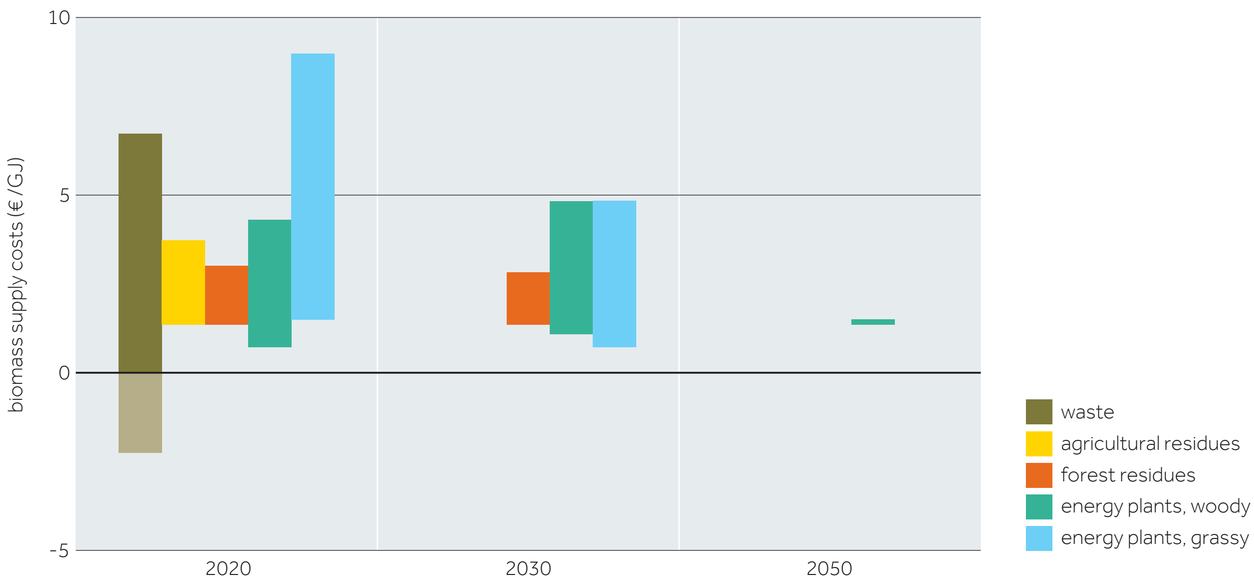


Figure 10: Biomass supply costs for different feedstocks, 2020-2050 (example from IRENA)

Source: IRENA



Challenges: barriers and potential enabling conditions

A stable demand outlook for advanced biofuels is needed to establish a market and boost development. Maximising the cost-competitiveness of biofuels will require production levels sufficient to achieve economies of scale. In addition to policy-related challenges, a range of enabling conditions will play a key role in promoting the further development and mass deployment of low-carbon fuels.

Currently, the main reasons behind the slow uptake of technology are claimed to be:

- high barriers to entry, including long investment cycles, the capital-intensive nature, and high fuel certification standards; and
- high production costs for advance biofuels compared to fossil fuels and conventional biofuels.

To overcome some of these barriers, the main enabling factors cited by several sources are summarised below:

- Support for emerging technologies at low TRLs to increase efficiency, as well as for continued R&I efforts in high-TRL technologies to comply with reduced cost projections, GHG emissions goals and deployment.
- Supporting sustainable feedstock mobilisation is perceived as a key enabler to boost availability and minimise supply chain risks. The development and use of currently unexploited sustainable waste, biomass and land resources to supply the advanced technologies, with particular emphasis on the application of the principles of a circular economy, are perceived as one of the key enablers to release the full potential of advanced biofuels.

- Development of infrastructure and logistics across the whole value chain from the production stage to the transport and conversion stages to produce the final fuel for end-use or intermediate customers.
- Recognition of the role of renewable fuel/bioenergy in transport, through a holistic approach across the whole well-to-wheels or even life-cycle value chain, is perceived to be one of the key drivers to establish a market across all means of transport in Europe and boost technology development.

Concawe, as part of the Low Carbon Pathways programme, is exploring the concept of an EU refining system being integrated in a hub of industries to take advantage of the opportunities that both economies of scale and the use of existing infrastructure may offer to deploy low-carbon feedstocks across the whole economy.

Annex

Advanced biofuels currently under discussion and included in Annex IX of RED II (Directive (EU) 2018/1001)[10] are summarised below:

Vegetable oils

- Algae, if cultivated on land, in ponds or in photobioreactors.
- Used cooking oil.

Waste (municipal/industrial)

- The biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.
- Bio-waste, as defined in point (4) of Article 3 of Directive 2008/98/EC, from private households subject to separate collection as defined in point (11) of Article 3 of that Directive.
- The biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food, fish and aquaculture industries.

Straw

- Straw.
- Palm oil mill effluent and empty palm fruit bunches.
- Bagasse.
- Grape marcs and wine lees.

Forestry and agricultural residue

- Tall oil pitch.
- Nut shells.
- Husks.
- Cobs cleaned of the kernels of corn.
- Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. bark, branches, pre-commercial thinnings, leaves, needles, tree tops, sawdust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil.
- Other non-food cellulosic material.
- Other lignocellulosic material, except saw logs and veneer logs.

Animal residues

- Animal manure and sewage sludge.
- Crude glycerine.
- Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009.

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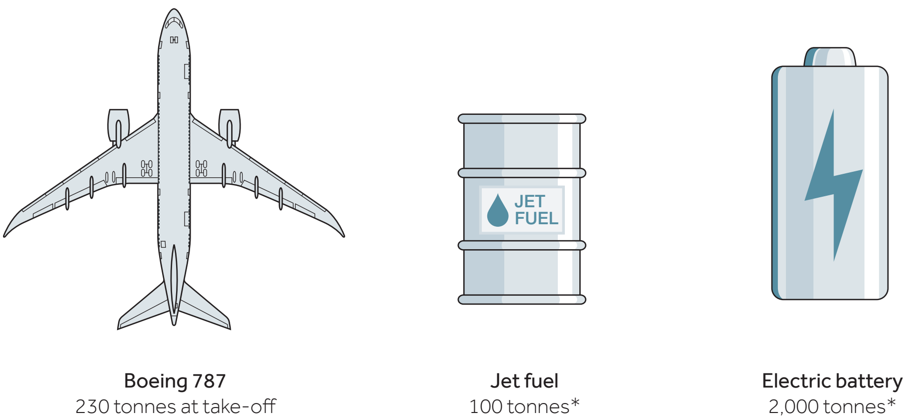
Impact analysis of mass EV adoption and low-carbon intensity fuels scenarios

Introduction

It is widely accepted that low-carbon liquid fuels will be essential in the long-term for sectors that have limitations in using electricity directly, such as the long-distance heavy road transport, aviation, maritime, and petrochemicals sectors. There is, however, a view that all light-duty road transport, and many of the other transport sectors, should be electrified in order to meet the European Union's climate objectives. There is also a growing awareness that achieving this level of electrification will be challenging (Figure 1), and that there is no single solution to building a low-carbon transport system, not least for the heavy-duty transport, marine and aviation sectors, but even for the passenger car segment.

A Concawe study examined several options for achieving a low-carbon transport system in the EU by 2050. Significantly, a mass EV adoption scenario and a low-carbon fuels scenario both achieve similar reductions in total parc greenhouse gas emissions, at similar cost.

Figure 1: Battery weight versus fuel tank volume (e.g. for aviation)



* The jet fuel capacity of a Boeing 787 Dreamliner is about 223,000 pounds, [...]. The estimated weight of a battery pack with equivalent energy would be 4.5 million pounds, [...]. (Los Angeles Times, 9 September 2016, http://www.latimes.com/business/la-fi-electric-aircraft-20160830-snap-story.html)

This article discusses a study,[1] carried out by Ricardo on behalf of Concawe, to investigate various scenarios associated with future passenger car transportation, and to improve the understanding of the possibilities and potential outcomes of different options for the segment.

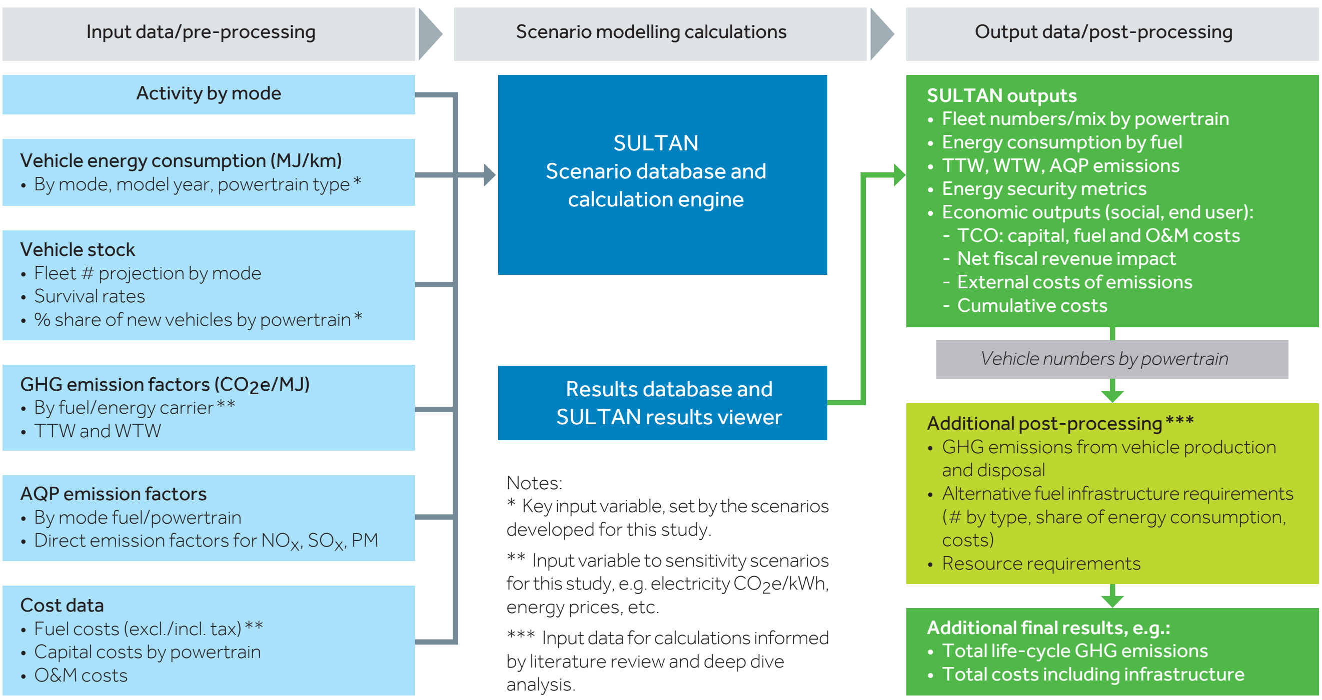
The Ricardo study

Ricardo were commissioned by Concawe to carry out an extensive study to examine a scenario involving the near-complete electrification of passenger cars and light commercial vehicles in the EU by 2050 (the 'High EV scenario'), and to compare this scenario with the combined use of electrification and low-carbon liquid fuels (e-fuels and sustainable biofuels) in highly efficient internal combustion engine (ICE)-based vehicles (the 'Low Carbon Fuels scenario'). These two scenarios were compared with a business-as-usual (BAU) scenario, as well as with an alternative scenario based on a higher proportion of plug-in hybrid electric vehicles (PHEVs) and an increased use of e-fuels and biofuels.

This in-depth study includes the quantification of greenhouse gas (GHG) reductions (in terms of CO_2 equivalent), total parc annual cost, and total cost of ownership for final users as well as the cost of infrastructure, materials, resources and power requirements. The study also sets out the challenges and opportunities associated with such a range of alternative options.

The main tool used to conduct the scenario modelling part of the study was Ricardo's SULTAN model (originally developed by Ricardo for the European Commission's Directorate-General for Climate Action — DG CLIMA). The functions of the model are shown in Figure 2 along with the inputs and outputs. In addition, an extensive literature review was carried out as input for some of the post-processing calculations including several deep dives into a number of areas of interest including life-cycle analysis, battery resources, and materials and infrastructure.

Figure 2: Overview of the SULTAN model



A number of sensitivity cases were also included, covering: GHG emissions, e.g. the sensitivity of GHG intensity with respect to electricity use (baseline trajectory equivalent to 0.1 kg CO_2/kWh GWP); the degree of improvement of battery energy density (average battery pack size of 82 kWh with 800 Wh/kg energy density in 2050 for an EV passenger car); embedded emissions from vehicle production and disposal; and the availability of biofuels. Cost analyses included low/high cost sensitivities relating to future battery costs (assuming a battery pack cost of $60/kWh by 2050 in the central case, based on a learning-based cost analysis developed by Ricardo as part of the work undertaken for the European Commission) and recharging infrastructure requirements (and costs) for EVs (home vs grazing, managed vs unmanaged network). A sensitivity analysis of a potential 'high-cost' scenario for low-carbon fuel prices (equivalent to ~20% increase on the base prices) was also carried out.

The High EV scenario

The High EV scenario in the study assumes that full electrification of transport for passenger cars and light-duty vans in 2050 will reach 90% of the vehicle parc on the basis of 100% registration of battery-electric vehicles from 2040 onward. The full breakdown of registrations and vehicle parc is shown in Figure 3. The carbon reduction trajectory is consistent with the upper limit of the percentage improvement in emissions from light-duty vehicles proposed by the European Commission in November 2018 in their post-2020 emissions targets through to 2030 (i.e. at least a 30% improvement in 2021 tailpipe gCO_2/km by 2030). The energy mix in the High EV scenario (see Figure 4 on page 24) shows a rapid decline in the use of fossil fuel from 2030, a rapid rise in electricity use and an end to biofuel use by 2050. In addition to this requirement, a lower level of improvements in the efficiency of internal combustion engines is assumed, due to the high uptake of electric vehicles and the resultant lack of incentives to improve ICE technology beyond 2025+.

Figure 3: High EV scenario — new registrations and vehicle parc

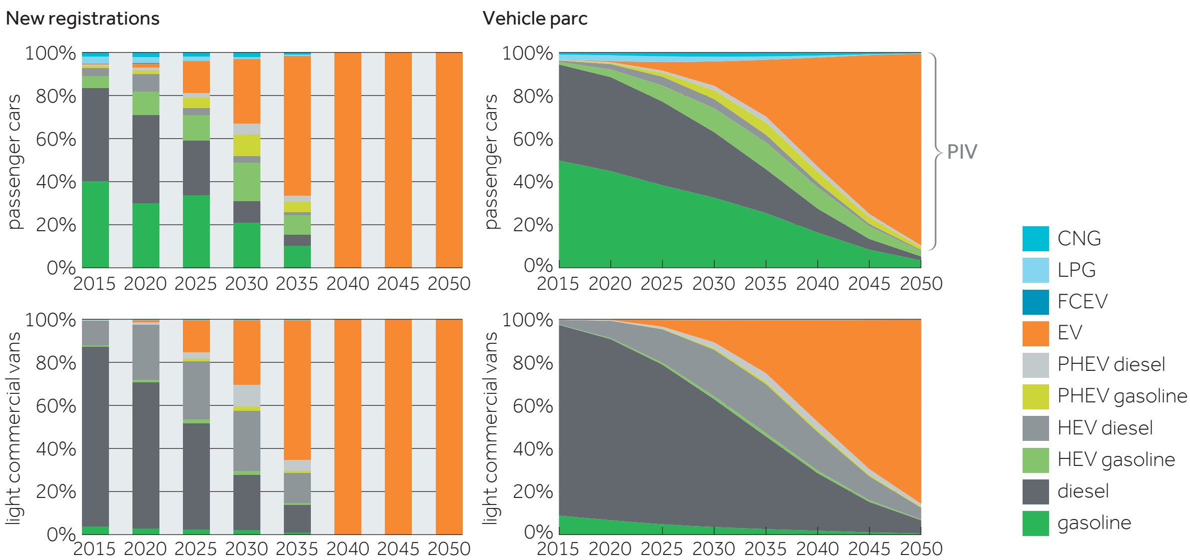
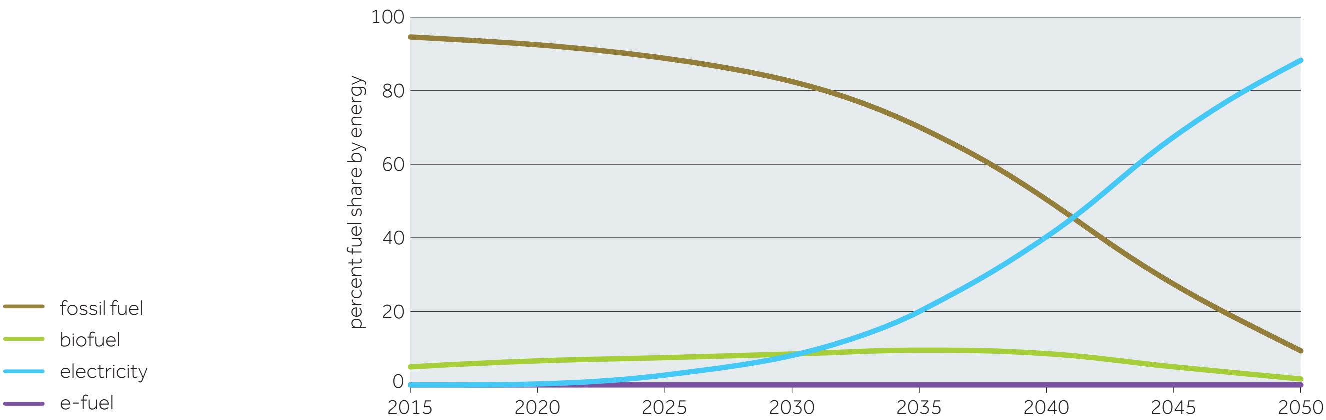


Figure 4: Fuel share for the High EV scenario



The Low Carbon Fuels scenario

The Low Carbon Fuels scenario assumes that, in 2050, the vehicle parc will consist of highly efficient ICE vehicles, with a high penetration of low-carbon fuels (68% fuel share by energy) complemented by 23% electricity and a minor quota of fossil fuels (Figure 5). The biofuel/e-fuel share is higher in 2020–2030 compared with the High EV scenario, and increases rapidly post-2025 with 100% substitution for diesel in 2050 as shown in Figure 6 (page 25). The carbon reduction trajectory (tailpipe gCO_2/km) is set at a slightly lower percentage improvement versus the High EV scenario. The tailpipe CO_2 trajectory is further extrapolated using the same percentage improvement out to 2050. There are also increased improvements in the efficiency of ICE and hybrid electric vehicle (HEV) passenger cars compared to the High EV scenario.

Figure 5: Low Carbon Fuels scenario — new registrations and vehicle parc

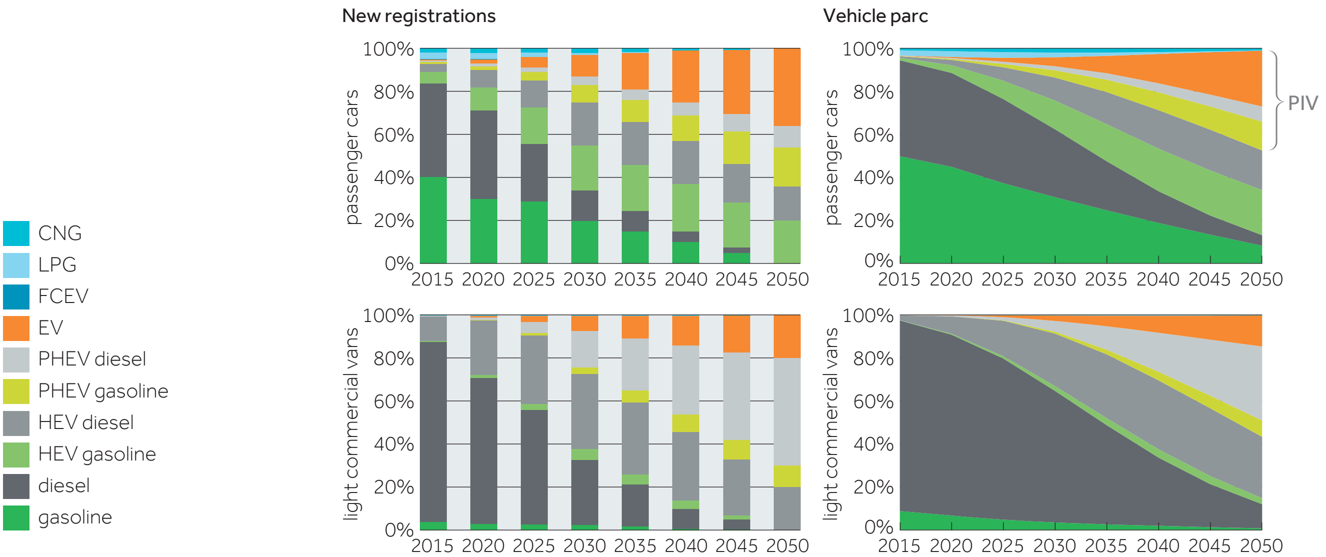
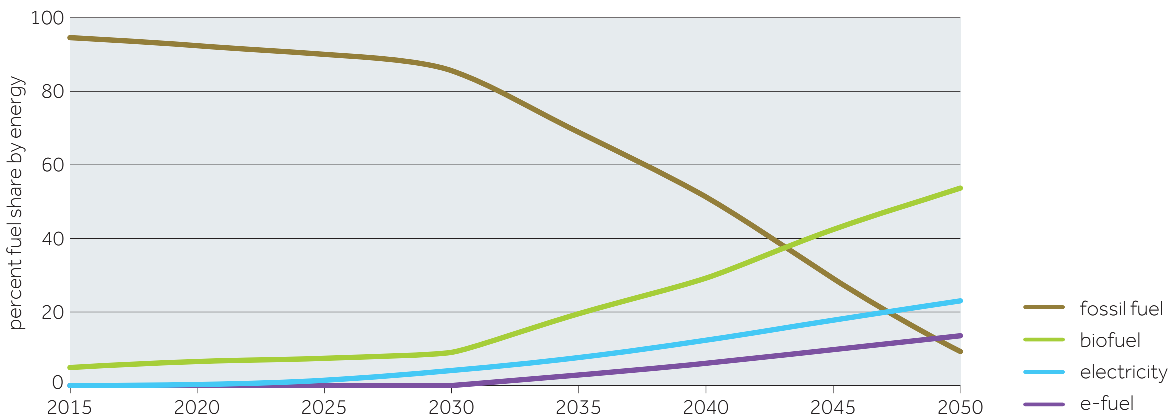


Figure 6: Low Carbon Fuels scenario — fuel share by energy



Results: comparison of life-cycle GHG emissions and energy consumption

Life-cycle GHG emissions, including well-to-tank (WTT) and tank-to-wheels (TTW) emissions as well as annual vehicle disposal and annual vehicle production emissions, were compared with the business-as-usual scenario and with each other. The results for the High EV scenario and the Low Carbon Fuel scenarios are shown in Figure 7 on page 26. All scenarios demonstrate broadly similar reductions in total GHG emissions by 2050. Embedded emissions from production and disposal of vehicles account for around 8% of total emissions in 2015 (including accounting/reduction for end-of-life vehicle recycling). This share rises to ~25% by 2050 for both the Low Carbon Fuels and High EV scenarios.

When energy consumption in these two scenarios is compared (Figure 8), it can be seen that there is a significant reduction in overall energy consumption resulting from both scenarios, with 550 TWh (1980 PJ/year) of electricity consumption for the High EV scenario.

The High EV scenario shows a reduction of more than 74% in overall energy consumption by 2050 versus 2015, and a 97% reduction in liquid fuel use in the same period. Electricity consumption is almost 90% of total energy use by 2050, at ~550 TWh (1980 PJ/year). This demand, excluding additional potential requirements across other sectors such as industry or for buildings, represents ≈17.5% of the EUs' electricity generation in 2015.

The Low Carbon Fuels scenario shows a 49% reduction in overall energy consumption, comprising of a 60% reduction in liquid fuel use which would be equivalent to a 96% reduction in oil-based liquid fuels (excluding low-carbon fuels). Low-carbon fuel accounts for an 88% share of liquid fuel use in 2050, equivalent to almost 3,000 PJ/year or 70 Mtoe for the whole light-duty segment. It should be noted that EU production of e-fuels will add +17% to the electricity use shown (and overseas electricity consumption would add a further +108%).

Figure 7: Comparison of GHG emissions on a life-cycle basis for the EU light-duty fleet

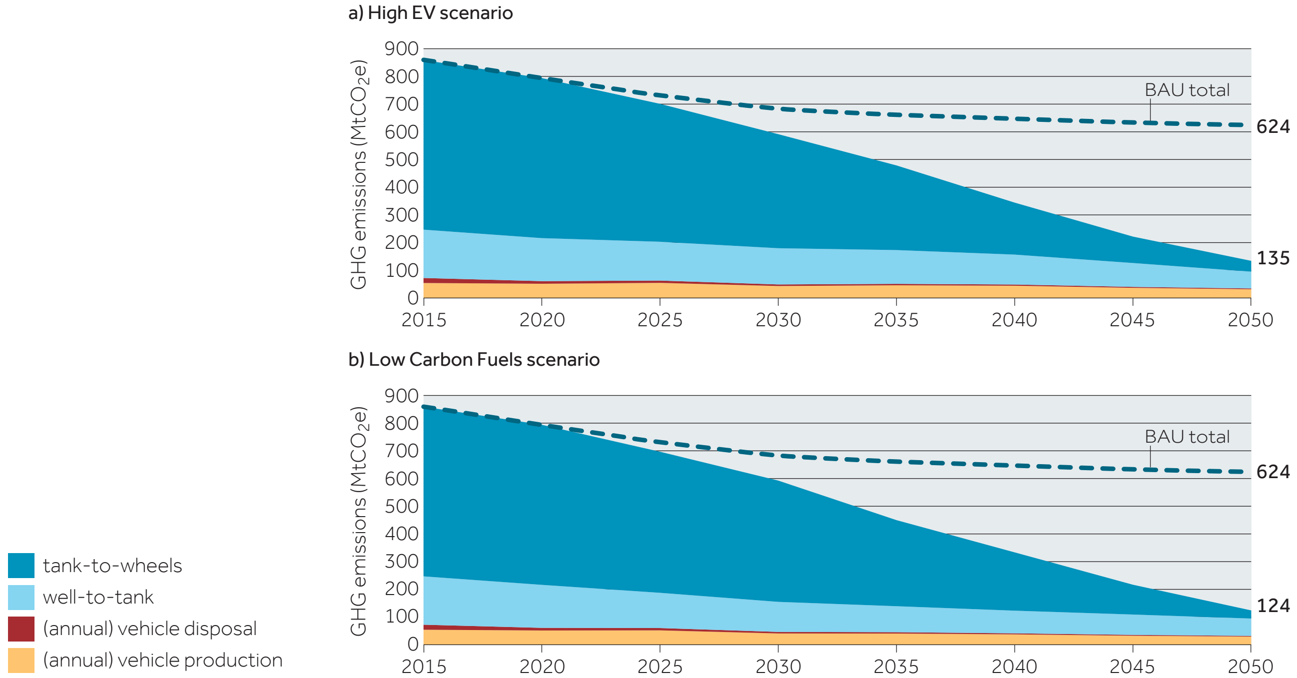
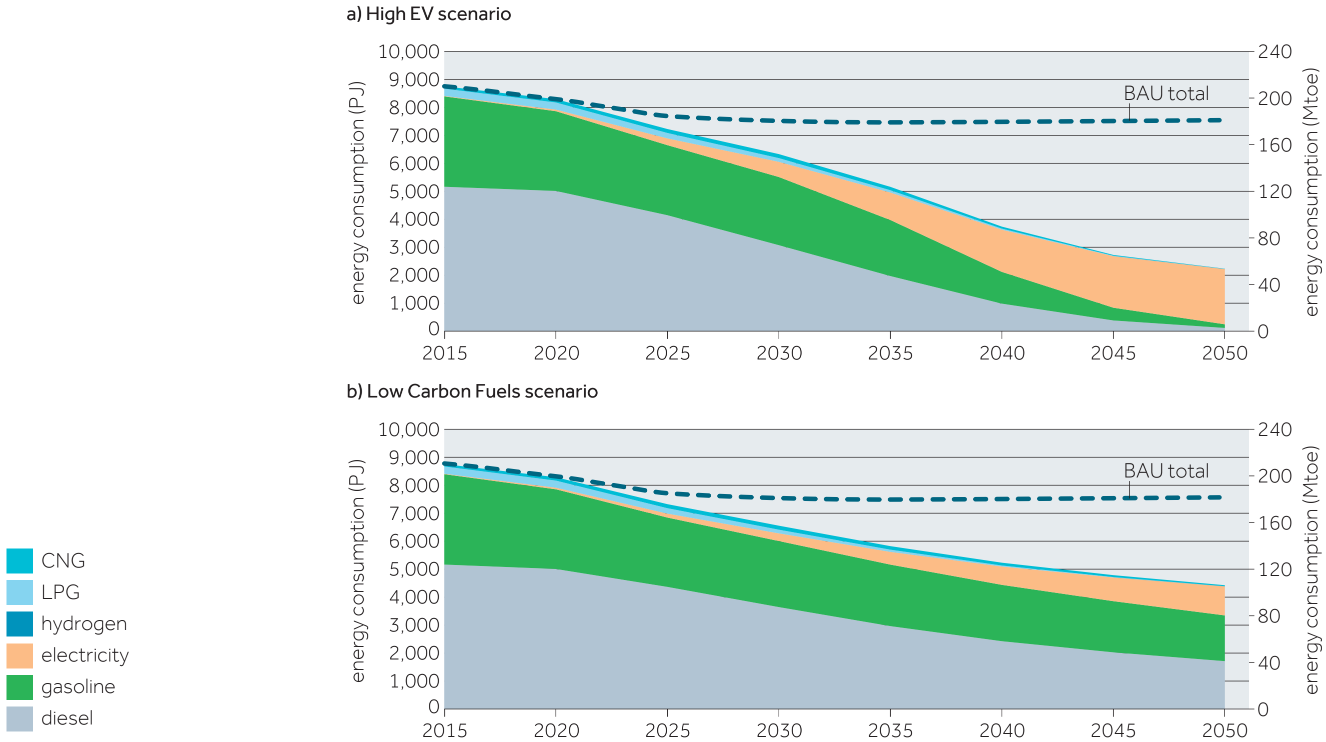
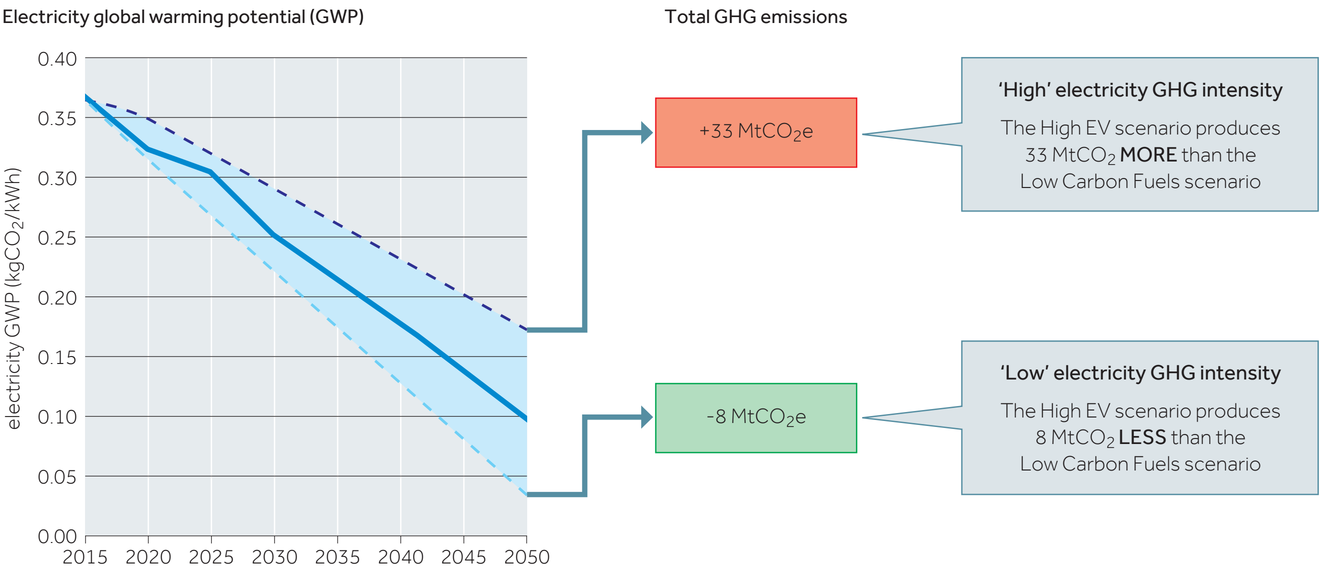


Figure 8: Comparison of energy consumption (TTW) of the EU light-duty fleet



A sensitivity study shows that the level of GHG emissions under each scenario is heavily dependent on the electricity GHG intensity of the different scenarios (Figure 9), with the High EV scenario giving higher emissions when the electricity GHG intensity is high, and the Low Carbon Fuels scenario giving higher emissions when the electricity GHG intensity is low. Clearly the availability of low-carbon fuels will also influence this outcome.

Figure 9: The effect of electricity GHG intensity on GHG emissions: High EV scenario vs Low Carbon Fuels scenario



Results: comparison of costs

When costs for the two main scenarios are compared (Figures 10 and 11) it can be seen that, while costs for the High EV scenario are higher in the period to 2035, the net costs are ~€70 billion lower per year than for the Low Carbon Fuels scenario up to 2050. Including the Net Fiscal Revenue (NFR) loss (vs BAU) closes the gap to €9 billion per year. Both scenarios reduce GHG emissions and meet reduction objectives at a lower overall cost to the end user, primarily due to lower fuel and energy costs than under the BAU scenario. It should be noted that the BAU scenario does not meet the GHG reduction objectives.

The study shows that the total parc end-user annual costs of vehicles under the High EV scenario or the Low Carbon Fuels scenario are likely to be similar with no competitive advantage for the EV vs the ICE.

Figure 10: Total parc annual costs to end use — High EV scenario

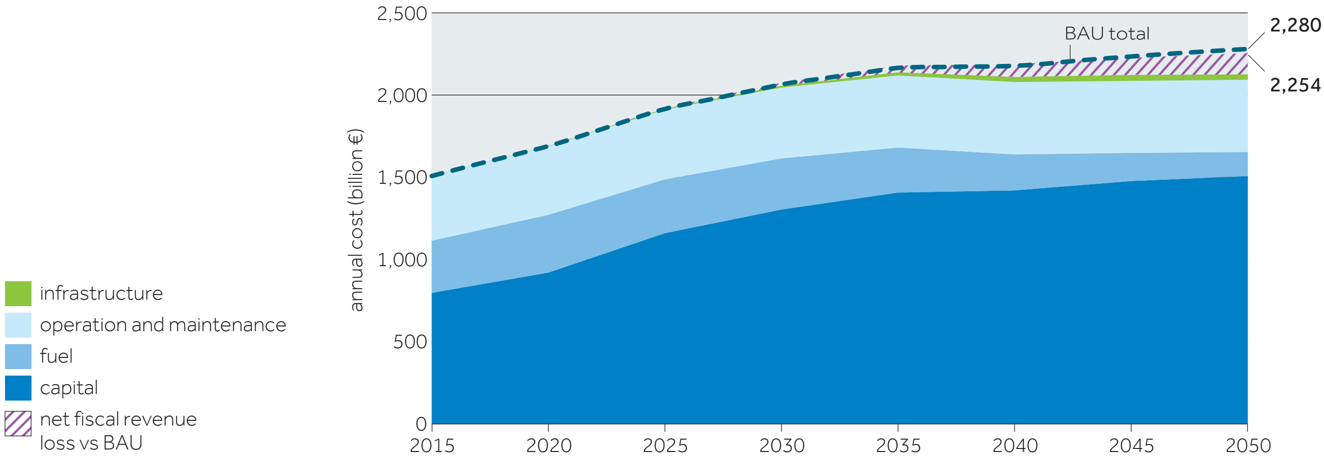
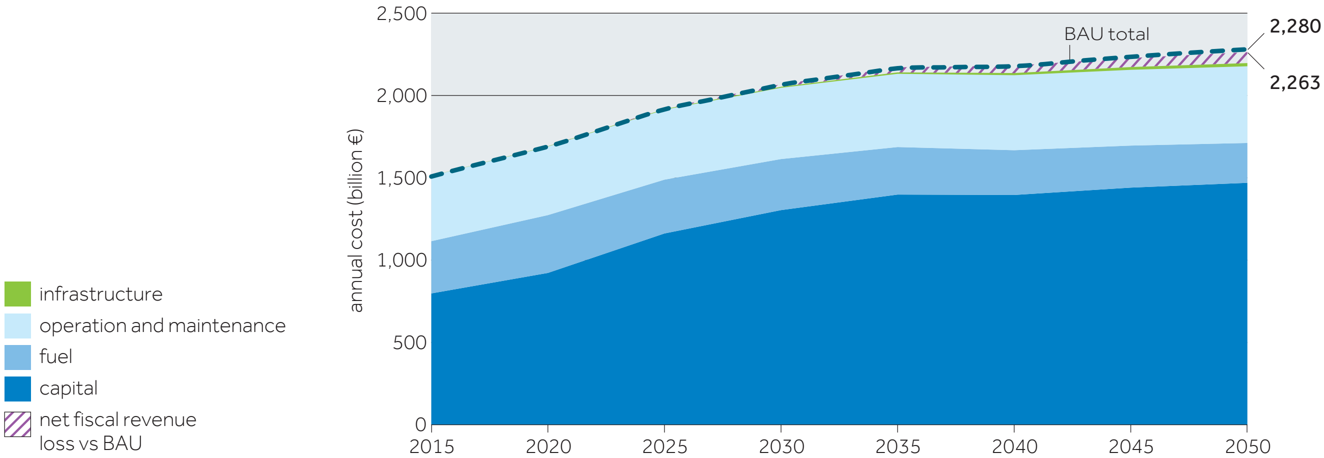
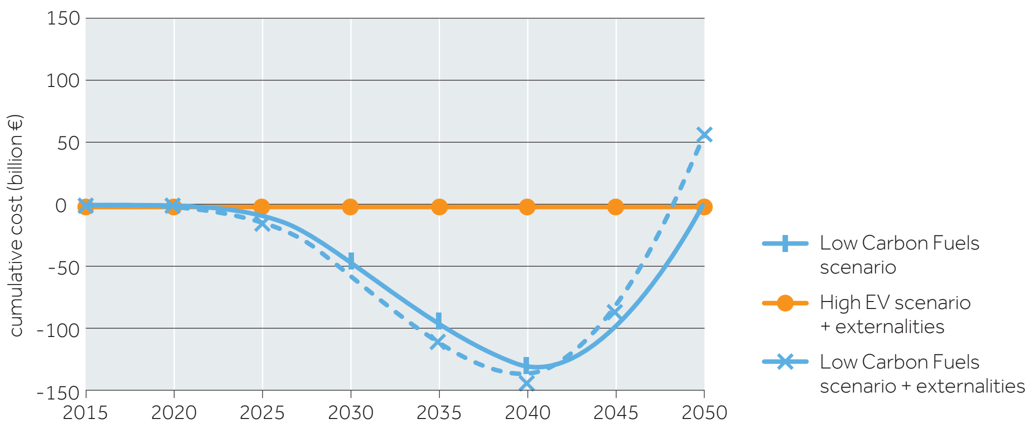


Figure 11: Total parc annual costs to end use — Low Carbon Fuels scenario



Ricardo also assessed the cost of each scenario from the societal perspective after inclusion of 'externalities' for GHG and air pollutant emissions. Externalities are the monetary values attached to the impacts of GHG, air quality pollutant emissions and other impacts such as noise and congestion (not calculated here) due to indirect effects, for example on public health and other elements. Figure 12 on page 29 shows that the net cumulative societal costs (i.e. excluding taxes), including externalities related to the Low Carbon Fuels scenario, are similar to the full electrification scenario.

Figure 12: Cumulative net societal costs (excluding taxes) relative to the High EV scenario

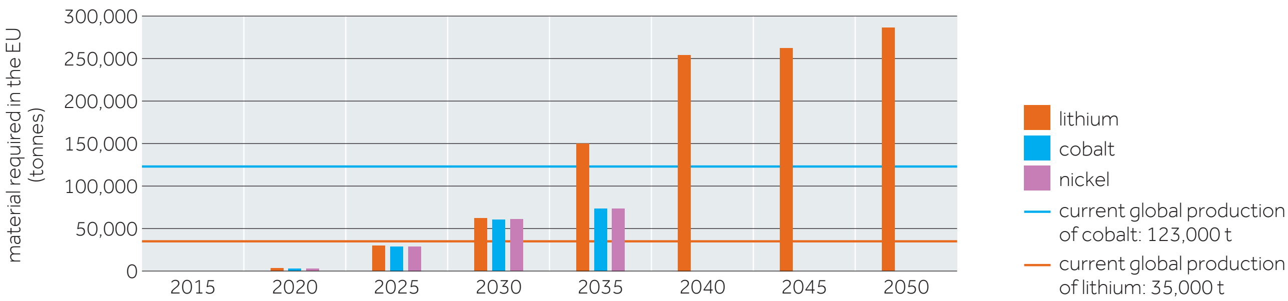


Results: comparison of implications for resources and materials

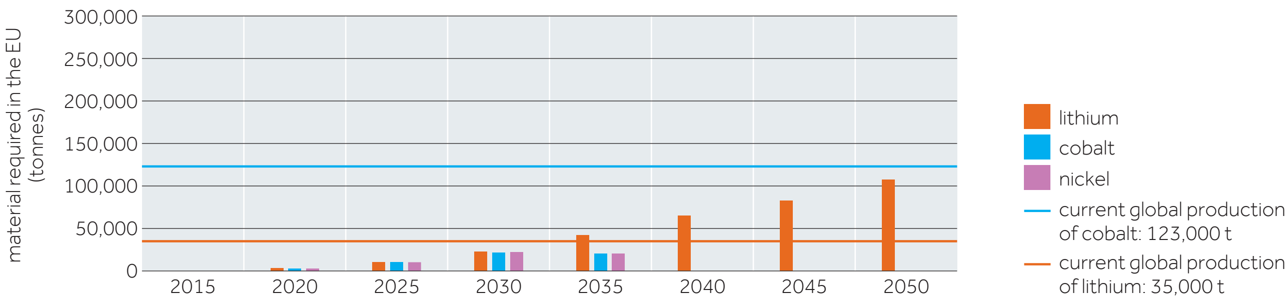
In all the scenarios, the availability of raw materials for battery production was explored in detail. Assuming current chemistry mixes the resource requirements for lithium, cobalt and nickel would increase substantially over the period to 2050, which would pose a potential availability risk (Figure 13).

Figure 13: Materials required for battery production in the EU (lithium, cobalt and nickel)

a) High EV scenario



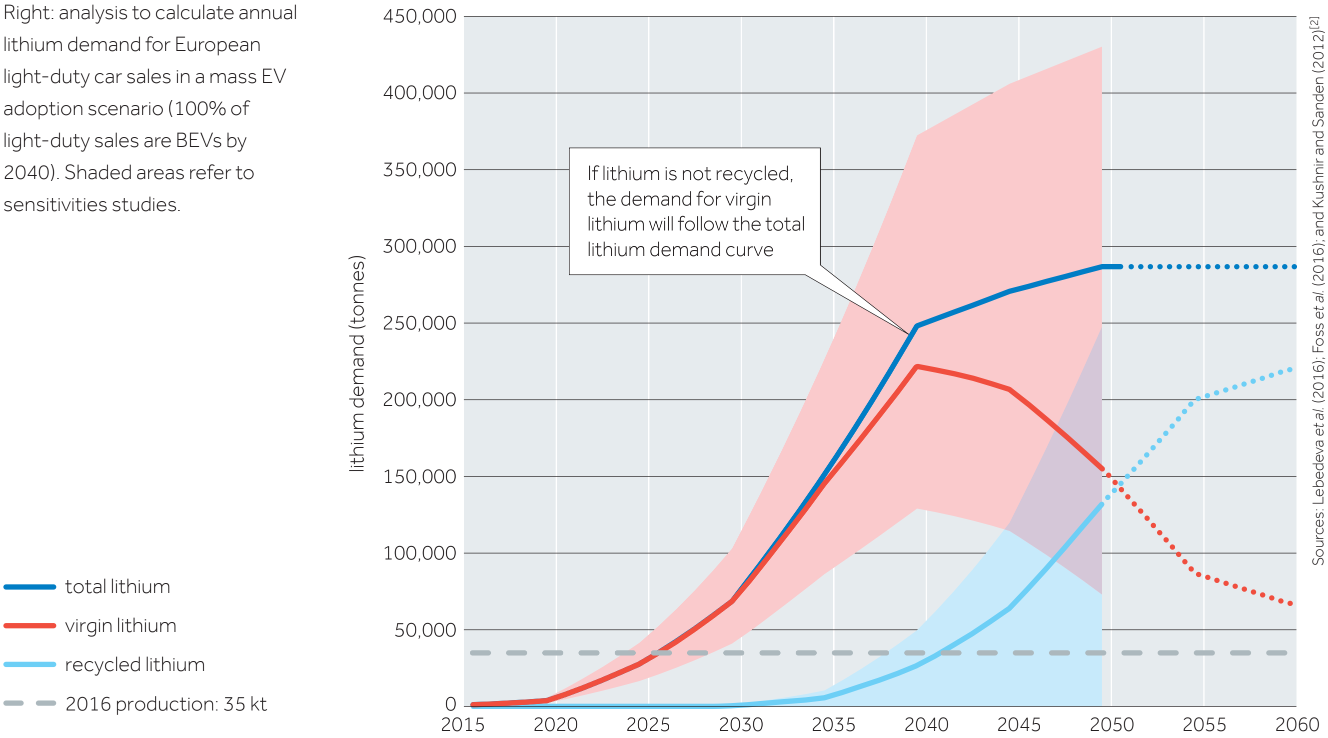
b) Low Carbon Fuels scenario



Mass EV adoption in Europe will consume a larger share of global lithium reserves than the European share of global vehicle sales, potentially causing a shortage of lithium if other regions also undergo mass EV adoption. Therefore, new lithium resources will likely need to be accessed to meet the required demand, although the supply of such resources will vary according to feasibility, production capacity and local impacts; it should also be noted that very few countries have lithium reserves. Battery recycling technologies that enable the recovery of lithium could help to reduce the total virgin demand, but these are expected to have a limited impact by 2050. Research is also under way into non-lithium battery chemistries, but it is unclear to what extent these might contribute in the future.

Figure 14: Analysis of annual lithium demand (High EV scenario)

Right: analysis to calculate annual lithium demand for European light-duty car sales in a mass EV adoption scenario (100% of light-duty sales are BEVs by 2040). Shaded areas refer to sensitivities studies.



Advantages and uncertainties for the two main scenarios

a) High EV scenario

The High EV scenario is expected to achieve a reduction of up to 87% of the 2015 GHG life-cycle emissions levels by 2050, and is an efficient use of renewable electricity. The use of electrification in the passenger car sector would also free up other renewable fuels for other sectors. However, uncertainties exist in a number of areas, for example:

- Network reinforcement will be required beyond 15–20% EV penetration to deliver adequate EV recharge power, requiring an estimation of the associated capital cost at EU level (EV charging infrastructure and charging facilities).
- An estimate of the cumulative investment in EV charging and network infrastructure lies between €630 billion and €830 billion to 2050, and the electricity demand for charging EVs is assumed to be equal to 17.5% of the EU's 2015 overall electricity generation.
- The construction of 15 gigafactories to supply batteries to the European EV market (550 TWh) and a large battery recycling industry would need to be developed using low-carbon electricity as the main energy source.
- The installation of increased peak power of 115 GWh (15% of current installed peak power generation) would be required to meet electricity demand.
- There would be a need to address the annual loss of €66 billion in fiscal revenue from fuel sales.
- Resources requirements for cobalt, nickel and lithium would increase substantially over the period to 2050, posing a potential availability risk and creating a new import dependency for the EU. Given that the majority of lithium and cobalt is located in a small number of countries, there is a further potential risk for resource prices and security of supply. For example, the increase in lithium extraction to support the full electrification of European cars and vans alone is estimated at six times the 2016 worldwide volume of lithium production. Battery recycling to recover lithium could become a large industry by 2050; however, it may not be economically feasible for all battery types (for example, current LFP batteries have little recyclable material of value, and potential future lithium-sulphur chemistries might also be problematic).

b) Low Carbon Fuels scenario

It is expected that the Low Carbon Fuels scenario will also reduce, by 2050, the 2015 life-cycle GHG emissions level by 87%, equivalent to the High EV scenario. However, the Low Carbon Fuels scenario would require significantly lower cumulative investments in infrastructure because only 50% of the recharging capacity of the High EV scenario will be needed (€326 to €390 billion) and only half of the peak power generation will be required compared to the High EV scenario. It would also require only 5 or 6 gigafactories for battery production (compared to 15 for the High EV scenario), and the demand for raw materials would be reduced to less than half of the demand required under the High EV scenario. The availability of low-carbon fuels is intended to reflect a scenario where the whole biomass supply chain is optimised to maximise the use of bioenergy across different sectors.

Uncertainties in the Low Carbon Fuels scenario include the following:

- low-carbon fuels technologies, supply chain and scale-up including costs.
- The scenario estimates that the amount of biofuels required for light-duty transport would be around 35% of today's total (petrol and diesel) fuel volumes. This would result from, and is reliant on, significant efficiency gains for the ICE, resulting in a reduction of the total volumetric demand by 60% compared to today's volumes.
- Estimates for the use/availability of the (larger) imported e-fuel share for this scenario in a competitive marketplace is uncertain (estimated at 19% of the total low-carbon fuel supply in 2050).

One of the main takeaways of the study is that both GHG savings and total cost were calculated to be similar for both scenarios, and the costs for both scenarios are lower than for the business-as-usual case. The study shows that both electrification and low-carbon fuel technologies are complementary and require the adoption of policies based on a neutral approach to technology support, ultimately leading to the best choices and decisions for the future of the EU.

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Successfully limiting product theft from European oil pipelines

Oil pipelines typically run over long distances across farmland and open countryside. They are therefore vulnerable to both accidental and malicious interference by third parties.

Concawe's Oil Pipelines Management Group continues to play an important role in helping to reduce the number of theft-related incidents from European oil pipelines.

For many years, illegal interference with oil pipelines with a view to stealing the product has been a peripheral issue in Europe with just a few cases each year, most of which have occurred in South Eastern Europe. Since 2010 however, theft attempts, often successful, have been recorded in many different countries across the continent with significantly increasing frequency. From just a few cases in 2010, the number of reported theft attempts rose to nearly 150 in 2015. Although not all theft attempts have been successful, many have caused significant damage to the pipeline, with more than half of the recorded cases resulting in loss of containment and product spillage.

Beyond the financial cost associated with product loss and disruption of operations, this represents a serious threat for pipeline operators in terms of safety (to the operators' own personnel and to the public) and potential environmental damage. The criminals involved display a wide range of technical knowledge and skills in the way they attack the pipelines. As mentioned above, pipeline leaks are becoming increasingly common, and can result from a failed tapping or from ancillary equipment such as hoses, connections, containers, etc. When faced with a large leak, perpetrators commonly flee the scene, leaving the pipeline in a condition that could potentially lead to a major spill and/or fire/explosion.

Recognising the widespread nature of the phenomenon, EU pipeline operators decided to use Concawe's Oil Pipelines Management Group (OPMG) as a conduit to share experiences, information on perpetrators' modus operandi, and deterrence, detection and remediation techniques.

In 2015 the OPMG conducted a survey of EU operators to assess the true scale and geographic spread of the problem, confirming the somewhat alarming rate of increase in the number of reported cases. This was followed in the Spring of 2016 by a seminar dedicated to pipeline product theft, which brought together EU pipeline operators with guests representing law enforcement authorities. This was an opportunity to bring participants up to date with recent relevant experience.

Left: an illegal tapping commonly includes a valve welded to the pipeline wall, and a length of flexible hose leading to a collection point which may include temporary storage facilities.

Subsequent to the seminar, the OPMG took the decision to develop a guidance document for operators, addressing all relevant facts, techniques and recommendations to tackle product theft. An ad hoc working group was established for this purpose. The final guidance document was completed at the end of 2017 and disseminated among the OPMG membership. Recognising the sensitivity of some of the information (e.g. on detection techniques and capabilities) in terms of their value to potential criminals, the document is not publicly available, although it is available to other EU pipeline operators on request. The document addresses all aspects of the issue, including:

- the modus operandi of perpetrators, and the types of illegal tappings and collection systems;
- prevention and detection systems;
- identification and discovery of illegal tappings; and
- remediation.

This information highlights the range of techniques used by perpetrators to breach the pipeline and extract and store product, as well as their implied understanding of pipeline operations.

Through these actions, pipeline operators across the EU, including those in areas or countries thus far not targeted, have been made aware of the potential threat. This has encouraged them to take action to enhance prevention and detection, and be prepared for what to expect if and when they discover an illegal tapping.

Being aware of a problem is the first step towards resolving it. In the short period between 2015 (when product theft from pipelines became recognised as a major issue) and today, operators have developed various strategies to deal with this problem:

- Personnel have been made aware of the potential for interferences, and are now systematically checking for tell-tale signs, both in the control room during monitoring operations and in the field when 'walking the line'.
- More sensitive leak detection systems have been installed, which are capable of detecting very small 'leaks' as well as pinpointing the location of the leak.
- In cases of suspected but hitherto undetected tappings, in-line inspection devices have been used to locate them.

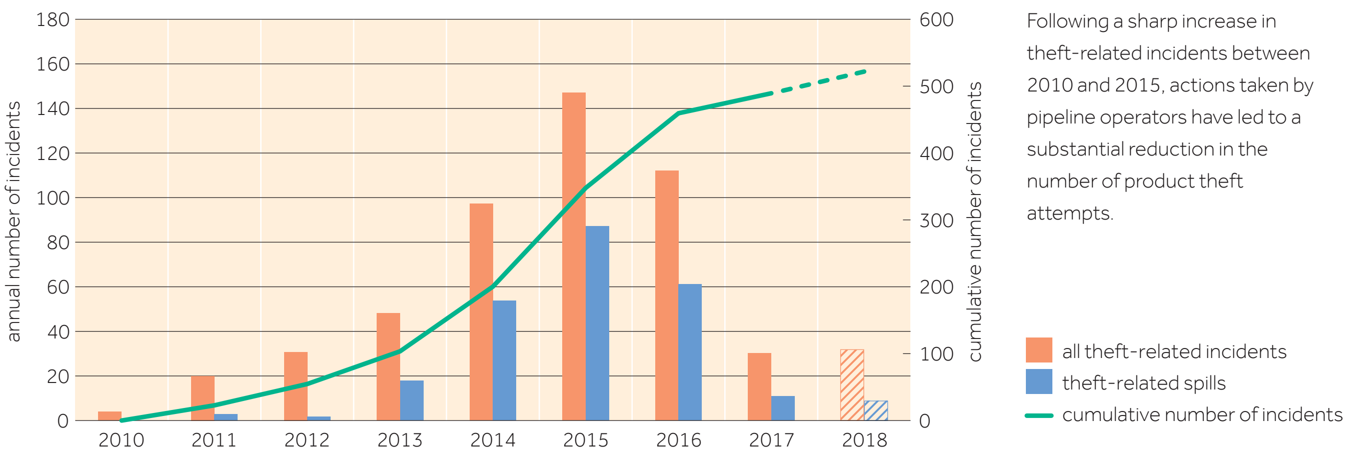
As a result of these actions, many operators have been successful in detecting illegal activities within a very short period of time (days and sometimes hours), and in shutting down and removing tappings soon after they have been installed. This has proved to be a powerful deterrent as it makes such practices uneconomic for the perpetrators.

Law enforcement authorities have also been involved, and in some countries, the legislator has been lobbied to increase the penalties faced by perpetrators when caught. In parallel with this, operators have also developed fit-for-purpose temporary and permanent repair techniques to enable safe resumption of normal operations with the minimum delay.

The results of all these actions have been very encouraging. Figure 1 shows the evolution of the annual number of theft attempts reported since 2010. Since the peak in 2015, numbers have dramatically decreased, with only 30 events recorded in 2017. Although it is still early days, the partial 2018 data currently available suggest stabilisation at this level.

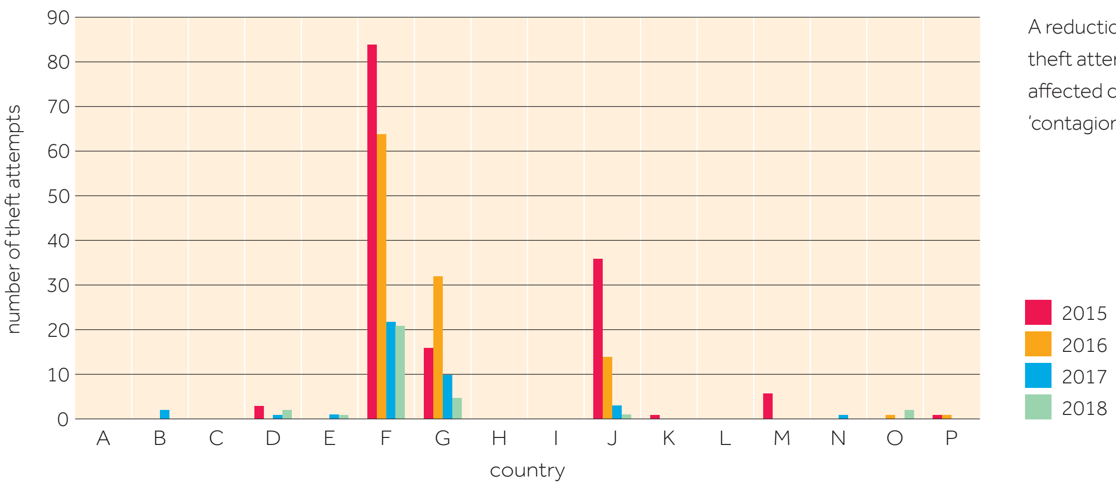
It is also worth mentioning that the reduction has been witnessed in all affected countries (Figure 2) while 'contagion', which was a concern a few years back, has not happened, and most countries have seen only a handful of cases.

Figure 1: Evolution of the number of theft-related incidents since 2010



Following a sharp increase in theft-related incidents between 2010 and 2015, actions taken by pipeline operators have led to a substantial reduction in the number of product theft attempts.

Figure 2: Theft attempts in affected countries, 2015–2018



A reduction in the number of theft attempts has occurred in all affected countries, while 'contagion' has not taken place.

The foregoing is a testimony to the effectiveness of experience-sharing and decisive action in the face of a serious threat. The figures show that the issue of product theft from EU pipelines is under control but has not disappeared. Continued attention by operators will be required to keep criminals at bay, and Concawe's OPMG can assist by providing a forum for sharing experiences and learning lessons.

Abbreviations and terms

Agora	Agora Energiewende (a think tank supporting energy transition in Germany)
BAU	Business-As-Usual (scenario)
BBL	Barrel
BtL	Biomass to Liquid
CEFIC	European Chemical Industry Council
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
Dena	Deutsche Energie-Agentur (German Energy Agency)
DG R&I Ecorys	Directorate General (of the European Commission) Research and Innovation, and Ecorys
EJ	ExaJoule
EU	European Union
EV	Electric Vehicle
FAME	Fatty Acid Methyl Ester
FCEV	Fuel Cell Electric Vehicle
FQD	Fuels Quality Directive
FT	Fischer–Tropsch
GHG	Greenhouse Gas
GJ	GigaJoule
GWP	Global Warming Potential
HDV	Heavy-Duty Vehicle
HEV	Hybrid Electric Vehicle
HTL	HydroThermal Liquefaction
HVO	Hydrotreated Vegetable Oil
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IEA	International Energy Agency
ILUC	Indirect Land-Use Change
IPIECA	The global oil and gas industry association for environmental and social issues
IRENA	International Renewable Energy Agency
LBST	Ludwig-Bölkow-Systemtechnik
LCP	Low Carbon Pathways (programme)
LDV	Light-Duty Vehicle
LFP	$LiFePO_4$ (Lithium-iron-phosphate)
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
MSW	Municipal Solid Waste
Mtoe	Million tonnes of oil equivalent
NFR	Net Fiscal Revenue
NO_x	Nitrogen Oxides (NO, NO_2)
O&M	Operation and Maintenance
OPMG	Concawe Oil Pipelines Management Group
PBR	PhotoBioReactor
PHEV	Plug-in Hybrid Electric Vehicle
PIV	Plug-In Vehicle
PJ	PetaJoule (10^{15} joules, or 278 gigawatt hours)
PM	Particulate Matter
R&I	Research & Innovation
RED	Renewable Energy Directive
SETIS	Strategic Energy Technology Information System (of the European Union)
SGAB	Sub-Group on Advanced Biofuels (of the Sustainable Transport Forum)
SO_x	Sulphur Oxides
toe	Tonnes of Oil Equivalent
TRL	Technology Readiness Level
TTW	Tank to Wheels
WTT	Well to Tank
WTW	Well To Wheels

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