Smart Freight Centre

Low Emission Fuels and Vehicles for Road Freight

Introductory guide to support the transition to zero emissions

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GLEC GLOBAL LOGISTICS EMISSIONS COUNCIL

ACT Action towards Climate friendly Transport

TRANSPORT DECARBONISATION ALLIANCE

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Disclaimer

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About Smart Freight Centre
Smart Freight Centre (SFC) is a global non-profit organization dedicated to an efficient and zero emissions freight sector. We cover all freight and only freight. SFC works with the Global Logistics Emissions Council (GLEC) and other stakeholders to drive transparency and industry action – contributing to Paris Climate Agreement targets and Sustainable Development Goals.

Our role is to guide companies on their journey to zero emissions logistics, advocate for supportive policy and programs, and raise awareness. Our goal is that 100+ multinationals reduce at least 30% of their logistics emissions by 2030 compared to 2015 and reach net-zero emissions by 2050.

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Executive Summary

More governments and companies are setting climate targets. The end goal is zero-emission transport for all road transport, and in this transition phase road freight transportation with low emission fuels or electric vehicles (LEFV) is an important part of an effective strategy in the transition to net zero emissions. However, it is often unclear what 'low' or 'zero' emissions really means.

The 'Low Emission Fuels and Vehicles for Road Freight' report serves as an introductory guide for different stakeholders who all have a role to play in this transition: freight transport operators ('carriers'), freight transport buyers ('shippers'), energy and infrastructure providers, vehicle and engine manufacturers ('OEMs') and policy makers.

The aim is to create a common starting point for these stakeholders in order to make emission calculations more consistent and reliable, and to inform better and aligned decision-making regarding uptake of low emission fuels (natural gas, biofuels) and electric vehicles (electricity and hydrogen) for the road freight sector.

Key messages are:

- Companies need to balance what they can do in the short term (e.g. biofuels and urban electric freight vehicles) with preparing for a full switch to electric/hydrogen for the entire trucking fleet.
- The true climate impact from fuels and vehicles can only be determined by calculating emissions from the full fuel/energy life cycle, or 'well-to-wheel' rather than fuel combustion only or 'tank-to-wheel'.
- The total emissions of operation (TEO) should be considered alongside the total cost of operation (TCO) of electric freight vehicles so that companies can be assured that their investment makes economic and environmental sense.

Key information all stakeholders should know

The report explains the fundamentals of low emission fuels and energy sources, the current landscape, industry experience and perspectives, and the total emissions of operation concept.

Fundamentals of low emission fuels and energy sources

First it is important to have a common understanding of what low emission fuels and energy sources are. Fundamentals are explained and include:

- **Terms and definitions** of carbon neutrality or 'net zero', and different types of vehicles, fuels and energy
- **Full fuel cycle approach** that considers both the fuel supply (upstream/indirect) and fuel use (operational/direct) emissions, also called 'well-to-wheel' – there are fundamental differences between conventional fuels, biofuels and electricity from the grid, and hydrogen
- **Fuel and energy pathways** that explain key processes within the fuel or energy life cycle, as well as corresponding emission factors to provide comparable emission calculations
- **Relation between theoretical emission factors and operator experiences**, which explains that the GHG emissions calculation need to take into account the following inputs: energy content of liquid/gaseous fuels, efficiency of the engine or motor, vehicle operation, and loading efficiency.

Overview of the current landscape

Efforts that make use of existing studies, reports, guidelines, tools and databases will be more effective. To gain insight into the fuels and energy sources used in road freight transport and their uptake, an overview is provided of:

- **Policy landscape**, explains studies by the International Transport Forum (ITF) and International Energy Agency (IEA), and EU Directives for renewable energy (RED II) and fuel quality (FQD)
- **Established fuel emission factor datasets**, including GREET, EU Renewable Energy Directive, national databases, international regulations and related databases for maritime shipping and aviation, the European Commission's JEC collaboration, and other sources
- **Emission intensity values**, such as provided by the Handbook of Emission Factors Automotive (HBEFA) and datasets developed for the UK and France and within emission calculation tools – it is noted that the development of emission intensity values for transition fuels and energy is still at an early stage
- **Fuel and Fuel Pathway Certification Schemes**, such as the Roundtable of Sustainable Biomaterials (RSB), International Sustainability and Carbon Certification (ISCC), and the Californian Air Resources Board (CARB) – Low Carbon Fuel Standard (LCFS) Pathway Certified Carbon Intensities
- **Research institutions and independent NGOs**, of which there are many who regularly issue reports, papers and articles on the topic. Examples are provided for the Centre for Sustainable Road Freight (CSRF), Transport and Environment (T&E), International Council on Clean Transportation (ICCT)
- **CORSIA for aviation fuels**, which is strategy for management of aviation emissions that is focused on the use of sustainable aviation fuel with offsetting of remaining emissions. Setting aside potential issues with offsetting schemes, the aviation industry has agreed a set of emission factors for sustainable aviation fuel from the most likely feedstock and production pathway combinations as a crucial first step.

Industry experience and perspectives

It is critical that low emission fuel and energy solutions work for business. After all, freight transport operators and buyers will assess risks and benefits before deciding to invest; for example, ROI, capital costs, and technology availability. To help companies and those that want to support them, an insight of existing experiences is provided through

- **End user experiences and operational evaluation projects**, including barriers to the adoption of fuel saving technologies in the trucking sector and anticipated progress of these technologies from 2015 through to 2030 by the ITF
- **Emission factor challenges** especially which emission factors to use and requirements for fuel tracking and certification schemes – companies want and need to be confident about their emission calculations
- **Low emission fuel trials**, which describes the UK Low Emission Freight Trials (LEFT) Programme and its results as an example
- **GLEC partner interviews**, which highlights key general, GHG calculation, technology, infrastructure and policy barriers that limit the adoption of low emission fuels and vehicles, as well as some proposed actions to help overcome these barriers.

Total Emissions of Ownership (TEO) models

Companies considering investing in electric vans or trucks want to know the 'Total Cost of Ownership (TCO)': the purchase price of the vehicle as well as the operating costs over the time that the operator keeps the vehicle. In a climate-constrained world, it is important to also consider the Total Emissions of Ownership (TEO) – you don't want to buy a vehicle that makes financial sense but it does not deliver substantial emission 'well-to-wheel' reductions over the vehicle's lifetime.

Initial guidelines for the TEO calculation for electric road freight vehicles are proposed, based on emission reductions that could be realistically achieved under three scenarios: conservative, moderate or ambitious. An example application of the TEO calculation to a 7.5T truck in the UK shows that

- For an electric truck average emission reductions of -8%, -19% and -31% can be achieved over the 12-year vehicle ownership
- If a diesel biofuel blend of 5% were to be increased to 10% after year 5 this would result in a 1% additional emission reduction, and if pure biodiesel would be used from year 7 onwards then this would lead to 17% emission reductions over a 12-year period
- A carbon price would tilt the financial benefits even more towards operators that invest in electric freight vehicles or switch to biofuels. There is a noticeable differential in favor of the EV, particularly for the later years when the carbon price is higher and the electricity generation has had the maximum chance to decarbonize.

The above calculations succeed in proving the TEO concept, whilst also showing the benefit that can arise from use of electric trucks, provided that the power sector moves towards low carbon energy sources. The approach was also shown to work when applied to liquid biofuel substitution as a transition fuel, and could also be used for other alternatives such as hydrogen and biomethane.

Key recommendations

Next steps are recommended for improving emissions calculation and increasing uptake of low emissions fuels and vehicles.

Improving emission calculations

Companies find it challenging to calculate emissions from low emission (transition) fuels and electric vehicles that take into account the full fuel life cycle, also called 'well-to-wheel'. Reasons vary but it all comes down to the need for a common approach and support systems for emission calculations.

Key recommendations to improve reliability and trust in reported emissions are:

- Develop reporting standards for low emission fuel/energy suppliers to enable fair comparisons between conventional fuels and low emission alternatives
- Compare existing emission certification schemes and develop common, consistent protocols
- Establish a mechanism for regular/ongoing updates of emission factors for transition fuels that consider the full fuel life cycle
- Develop a protocol for trials/pilots of transition fuels and electric vehicles to capture data and emission calculations in a consistent manner, to be fed back into emission intensity datasets that are kept by established research and other organizations and used for policy and other 'official' purposes

- Apply the 'Total Emissions of Ownership' (TEO) concept to emission calculations associated with vehicle purchase decisions
- Conduct further research into emissions from both vehicle production and dismantling as well as the required transportation infrastructure, to give a full technology life cycle picture

Uptake of low emission fuels or electric vehicles

Companies find it challenging to start using low emission fuels or electric vehicles in practice. Cited reasons are lack of coordination and collaboration, vested interests and hidden agendas, and inconsistent policies. Other concerns include the availability of feedstocks for biofuels, the energy efficiency or losses around hydrogen supply, practicality of battery electric vehicles, upfront costs of battery or hydrogen fuel cell vehicles, and re-fueling infrastructure.

Key recommendations to accelerate uptake are:

- Collate trials and pilots that are taking place, starting with those across Europe, and summarize the costs and benefits realized by operators and shippers
- Develop mechanisms that can help consortium building of different stakeholders for collaborative projects on low emission fuels and electric vehicles
- Develop mechanisms for cross-border collaboration that removes the barriers due to differing policy and lack of consensus
- Consult with a wide range of TCO model developers to promote incorporation of the TEO approach and the link to carbon pricing, or shadow carbon pricing

Contents

1. Introduction

1.1 Background

Action towards Climate-friendly Transport (ACT) is a global coalition of over 100 organizations aiming to catalyze transport as an enabler of sustainable development in line with the 2030 Agenda and the Paris Agreement. Component 3, led by the **Transport Decarbonisation Alliance (TDA)**, supports the creation of a mass market for zero-emission freight vehicles by increasing their global demand through commitments made by governments, cities and private companies. The **Dutch Enterprise Agency (RVO),** as the current Chair of the TDA, initiated the Dutch Ministry of Infrastructure and Water Management to commission the **Smart Freight Centre (SFC)** to review the landscape of alternative energy and fuel options currently being considered within the road freight sector. Understanding the current landscape in the context of a full fuel cycle or "well to wheel" approach across all fuel types and technologies is key. This is in contrast to taking into account only emissions at point of use, or "tailpipe", which effectively ignores emissions that occur in other sectors of the economy, and could lead to decisions being made that are detrimental to the overall climate impact.

Smart Freight Centre is developing and running projects with the Global Logistics Emission Council (GLEC) members on a range of topics that support the uptake of a broader range of measures leading to a smarter and more sustainable logistics industry as a whole. The current work on low emission (transition) fuels and energy in the road transport sector provides the basis for further, deeper industry engagement aimed at unlocking the potential for emission reductions of these innovations. This will also link to the possible enhancement of GLEC Framework for Logistics Emission Accounting and Reporting through the provision of enhanced information on the expected emissions from operation using transition fuels.

More governments and companies are setting climate targets and road freight transportation with low emission fuels or electric vehicles can be an important part of an effective strategy to reduce emissions in the transition to net zero emissions. However, it is often unclear what 'low' or 'zero' emissions really means. For example how to consider the full fuel life cycle, such as electricity generation or the production of hydrogen or LNG? What are the specific factors for electricity in different countries or for different types of biofuels? How to deal with blended fuels? These are just a few of the questions this report is trying to address.

This project should be seen as a pre-cursor to further in-depth projects that address the issues highlighted in this report. The subject of low or zero emission transition fuels and vehicles and the questions around associated infrastructure are complex. Starting to lay out the role and opportunities for transition fuels and energy and vehicles will help lay the foundations of the transition to zero emission road freight. Clarification of the terms and definitions used, combined with a better understanding of what is currently available, will ultimately make emission calculations more consistent and reliable and lead to better decision making within the road freight industry.

It should be noted that the subject matter of this report is rapidly developing with new technology research, reports and guidance coming to market and being published all the time.

1.2 Objectives and scope

The objectives of the project and this associated report are to contribute to removing the barriers that companies face in their efforts to adopt low emission fuels and vehicles in road freight transport. Aiming to help inform policy and decision making and to highlight areas for further in-depth research and potential pilot projects. There are numerous reports and guidance currently available; however, there can be ulterior motives and hidden agendas, with the appropriate degree of transparency somewhat lacking. This leads to conflicting views and confusion and when combined with the policymakers' wish to be "technology neutral" the result can be inaction, with new technologies remaining just that and "business as usual" prevails.

We hope that this report provides improved accessibility to the information presented so acting against these barriers.

1.3 Report structure

The report follows the following structure

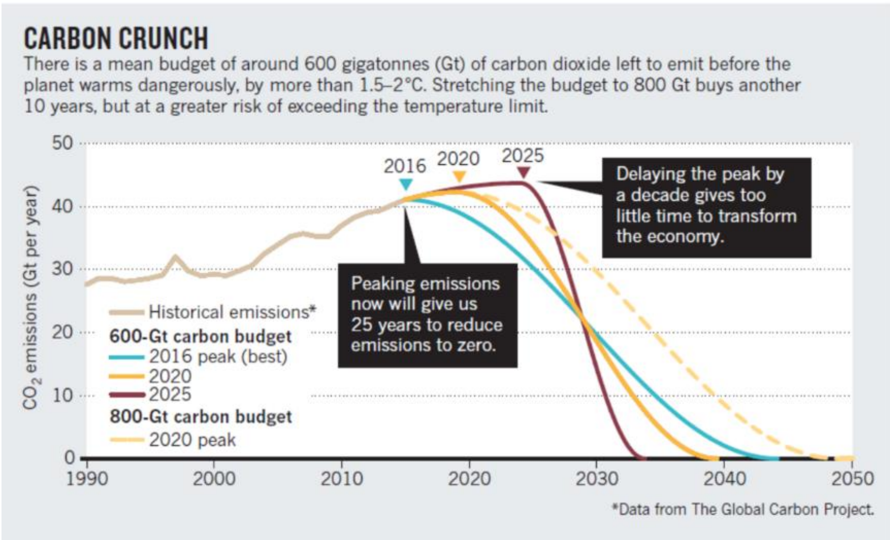
- **Section 2** presents main challenges and questions of different stakeholders
- **Section 3** explains the fundamentals of fuel and energy in relation to GHG emission calculation and reductions, including terms and definitions and present an overview of the full fuel cycle and fuel pathways
- **Section 4** gives an overview of what currently exists in terms of studies and reports, guidelines and tools that give insight into the fuels and energy sources used in road freight transport and their uptake
- **Section 5** provides the business perspective with examples of industry experience, barriers to adoption and where gaps or inconsistencies exist that make decision making difficult.
- **Section 6** explores initial guidelines for calculation of the Total Emissions of Ownership (TEO) for electric road freight vehicles that would complement Total Cost of Ownership (TCO) models (also referred to as Whole Life Cost)
- **Section 7** provides recommendations on how to deal with these issues and suggest proposals for future projects that will enhance guidance and understanding in more detail and the process to fully develop and test
- References
- Annexes

2. Challenges

2.1 Choosing between different fuels or energy sources

All stakeholders associated with the road freight industry are struggling to some degree with the same problems: knowing which low or zero emission drivetrain technologies to adopt, to promote or to set policy around, and which pathway is the best to follow.

There is a significant number of potential fuels, energy sources and technologies for all stakeholders to consider, and large variations even within individual fuel types that can create a very confusing situation. The end result is often seen to be inaction and remaining on a trajectory that does not meet climate change goals. In turn this will push back the peak and make an easy "blue run" (smooth and controlled) into a more difficult "red run" (steeper and less controlled)



This report aims to provide insight towards answering some of the questions raised by stakeholders across the various perspectives that exist within the road freight transport sector. These are listed in the following table.

STAKEHOLDER	KEY QUESTIONS
Freight transport operators	▪ Which vehicles and fuel types should we invest in? ▪ Will the fuel infrastructure be there? ▪ What if we invest in a technology that doesn't last and create stranded assets? ▪ What will the real impact be for my operation? ▪ Will we have to change how and where we operate? ▪ Can we trust our energy providers' claims? ▪ Can we invest in alternative technology without the certainty of continued business? ▪ Can we anticipate legislative action and future proof our operations?
Shippers or freight buyers	▪ Can we understand how alternative energy sources will influence our Scope 3 emission inventories? ▪ Can we influence/help our freight transport operators to change and help us achieve our sustainability goals in partnership whilst maintaining required service levels? ▪ Can we better understand service cost implications related to low emission fuel adoption?
Energy and infrastructure providers	▪ Can we differentiate ourselves from others in the same product category or against other energy/fuel types? ▪ Can we demonstrate clear methods and standards for our claims regarding the expected benefits and real impact in order to gain trust?
Policy makers	▪ Need to assess their climate goals, Nationally Determined Commitments (NDCs) and GHG inventories ▪ Which technologies to encourage and where to deploy, either geographically or in which segments of the freight transport sector, based on robust and reliable evidence? ▪ Which ones to invest public funding in, if needed, to stimulate change? ▪ Which technologies will be transitional, which will be the "end goal"; what are the transition pathways and what are the timescales involved? ▪ Which fuels and technologies match national agreements or commitments? ▪ Can a technology neutral approach help or hinder progress? ▪ Whether to deploy legislation and offer support to promote deployment on a consistent emissions basis?
Vehicle manufacturers	▪ Which technology pathways to follow? ▪ What will the operators buy? ▪ What financial factors will play a role in vehicle choice? ▪ Can legislative action be anticipated? ▪ Can global platforms help or hinder profitability when regulation and policy is different across regions and countries?

2.2 General approach and understanding

In order to gain an understanding of the full "well to wheel" impact of low emission fuels, and the important inclusion of GHG Protocol scope 3 reporting, requires consideration of the indirect emissions. This is sometimes considered out of the control of the vehicle operator, so the information given needs to be clear and communicated in a way that is accepted by the truck operator. This starts with clear terms and definitions that help the transport sector understand rather than add to further confusion.

The approach of presenting fuel emissions by energy content can be misleading and information of how the fuels perform in real-life operations is required to be presented alongside to understand the impact of the particular low emission fuel adopted.

Within the logistics sector's subcontracting arrangements there needs to be a better sharing of data from scope 3 (or indirect) emissions; consistency in how to calculate these emissions is also needed.

A move to a "beyond the tailpipe" mentality and approach is required. This is also true of policymakers with much of government policy focused on tailpipe emissions only. As the energy transition progresses there will be more energy system integration that leads to a wider stakeholder community becoming involved in decision making that impacts upon transport decarbonization. Greater collaboration will be needed to avoid unintended consequences.

There are genuine concerns around the availability of feedstocks for biofuels, the energy efficiency or losses around hydrogen supply and practicality of battery electric vehicles. There will be competition between sectors for available feedstocks either between transport modes, between transport services for passengers and freight and other sectors such as heating and cooling.

2.3 GHG emissions calculation

Depending on the intended use, the emission calculation may require different levels of detail; for example, for a certain fuel the use of a conservative default value for generic reporting is appropriate, but more detailed knowledge of what is actually taking place is required when measuring the impact of implementing emission reduction actions. Therefore there is a need to be able to determine how to certify and track the low emission fuels that are actually used so that trust can be built in the claims made by fuel suppliers, operators and, ultimately, the reporting of those further up the supply chain.

Transition fuels such as electricity, hydrogen and biofuels require a consistent and practical approach to be applied and to enable fair comparisons between conventional fuels and low emission alternatives. This will lead to better decision making in the long term when combined with the standards that are needed in their application.

There is a need for better mechanisms to test and bring forward the adoption of alternative fuels and vehicles. The latest information gained from trials and pilot projects should be fed back into the existing 'official' information. This needs to be done in a timely manner so that decisions are based on the latest and most reliable information. Official data can sometimes lag behind market developments.

2.4 Policy and collaboration

Policy making guidance is required based on objective evidence in order to have a fully integrated energy system that meets the requirements of the transport sector and achieves the overall object of net zero carbon emissions (or carbon neutrality).

Coordination of activities between transport modes and sectors, between countries and international bodies and energy system providers is essential, and the scale of collaboration needed cannot be underestimated. Breaking through the vested interests and the hidden agendas with impartial, reliable and trusted information that is backed up by good quality data should help with the faster adoption of low emission energy solutions.

The lack of consensus even between experts demonstrates that more research is required, following an agreed, consistent approach, and that the results of the research are transparent, offering the full picture rather than just extracting the parts that suit the researcher or funder. Robust certification of low emission fuels with independent verification at its core will help build trust, along with standard protocols that make sure pilots and trials are conducted and reported appropriately. This also requires consistency in the emissions factors used to determine the results of trials and can feed into standards that determine an ultra-low emissions truck compared to a conventional truck.

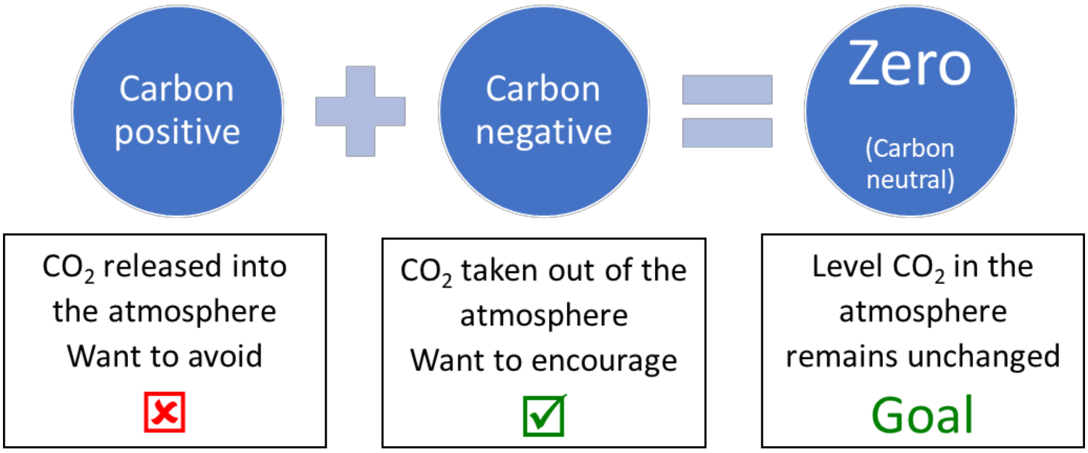
3. Fundamentals of low emission fuels and energy sources

3.1 Terms and definitions

This report is focused on road freight transport therefore terms and definitions are generally related to this particular mode of freight transport.

3.1.1 Carbon neutrality or net zero

Carbon neutral: making or resulting in no net release of carbon dioxide into the atmosphere, especially as a result of carbon offsetting. Also can be referred to as ***net zero carbon*** or to achieving an overall balance between emissions produced and emissions taken out of the atmosphere.



Carbon Offsetting: the mechanism for compensating for carbon emissions of a process through the prevention of the release of, reduction in, or removal of, an equivalent amount of GHG emissions outside the boundary of that process, provided such prevention, removal or reduction is quantified, permanent and additional to a business-as-usual scenario (Source: adapted from ISO 14021:2010)

Carbon Capture and Storage (CCS)*:* is the process of capturing and storing carbon dioxide before it is released into the atmosphere. By capturing carbon dioxide emitted from fossil fuel electricity generation or from industrial processes, it can then be transported and stored securely underground such as depleted oil and gas fields or saline aquifer formations thereby preventing its release to the atmosphere.

Full fuel lifecycle: an approach where all the GHG emissions are considered from the processes of extraction, production, transport and distribution (also referred to the upstream phase or "Well to Tank") to the operational processes (also referred to the operational phase or "Tank to Wheel") typically from the combustion of fossil fuels. See Section 3.2 for more information.

Fuel or energy pathway*:* the consideration of all the processes within the supply chain of a fuel or energy carrier (e.g. electricity) ensuring that all potential sources of GHG emissions are taken into account leading towards the comparable outputs of emission calculations. See Section 3.3 for more information.

Emission Factor: refers to the emissions produced by the use of a reference amount of fuel[1]. This can refer to emissions both at the point of use and emissions generated in the fuel production and distribution phase; although these elements may be presented separately, ultimately they should be combined when making any judgement about the overall efficacy of a switch from one fuel to another. Also referred to as the **Carbon Intensity** by some practitioners.

3.1.2 Vehicles

A ***conventional internal combustion engine (ICE) vehicle*** has an onboard source of power that emits exhaust emissions into the atmosphere at the point of use.

Examples – Positive (or spark) ignition engine vehicle that uses a gasoline (petrol), Liquid Petroleum Gas (LPG) or natural gas in either compressed or liquefied form. Compression ignition engine vehicle that uses diesel or 100% biodiesel or a blend of the two fuel types.

Term	Abbreviation	Definition
Internal Combustion Engine Vehicle	ICEV	An ICEV generates power through the burning of petrol, gas or diesel. They come in a wide variety of types. They contain many more movable parts than electric vehicles, emit more tailpipe emissions and create more noise.

A ***"Dual Fuel"*** vehicle can use two fuels or energy carriers, either in the same engine or as separate systems. They are sometimes referred to as a hybrid, although this can be misleading in some ways. There are suppliers of dual fuel systems for trucks that can use hydrogen, methane (as CNG) or LPG in combination with a conventional diesel engine at varying degrees of diesel fuel substitution. Even a conventional diesel vehicle could be considered "dual fuel" if using a higher blend of biodiesel with mineral diesel than the standard limit allowed within B7 EN590.

A "***hybrid***" vehicle is generally accepted to have a minimum of two fuel or energy systems (most commonly an electric drivetrain and an internal combustion engine) for propelling the vehicle to some degree, although in some cases they are not independent of the other. In particular there can be some misconceptions with the use of mild hybrid (a vehicle with a larger regular battery and system that assists the ICE) or "self-charging" hybrid where there is only one primary source of energy from the fossil fuel used in the internal combustion engine. In theory a hydrogen fuel cell electric vehicle (FCEV) could be considered a series hybrid.

A ***zero-emission vehicle***, or ZEV, is a vehicle that, while operating, emits no exhaust gas from the onboard source of power into the atmosphere at the point of use. This term covers both GHG emissions and local air pollutants. Note that there will be emissions associated with the generation and distribution of the electricity used to charge the battery or supply hydrogen, as well as embedded emissions associated with vehicle manufacture.

Examples: Battery Electric Vehicle (BEV), Hydrogen Fuel Cell Electric Vehicle (FCEV), human powered cycle.

Term	Abbreviation	Definition
Electric Vehicle	EV	EV is a broad category of vehicles that contain an electric drivetrain for propulsion. EVs can be cars, buses, trucks, bicycles, scooters, trains, planes and motorbikes.
Battery electric vehicle	BEV	BEVs are 100% powered by electricity, substituting all conventional drivetrain components for an electric drivetrain. BEVs eliminate the need or requirements for fossil fuels like petrol or diesel.

[1] Fuel is used in a generic sense to include other energy carriers such as electricity and should be considered in this way unless specifically stated to the contrary.

Term	Abbreviation	Definition
Fuel Cell Electric Vehicle	FCEV	Fuel Cell Electric Vehicles are powered by hydrogen. They emit no tail-pipe emissions and can be zero carbon if the hydrogen is produced using renewable energy. In an FCEV, the fuel cell converts hydrogen to electricity.
Hybrid Electric Vehicle	HEV	Hybrid Electric Vehicles are almost entirely powered by an Internal Combustion Engine (ICE) that runs on fossil or alternative fuels, but it also has a small battery and an electric motor.
Plug-in Electric Vehicle	PEV	This term has been used to avoid the confusion between electric vehicles that have a plug and those that do not - it encompasses BEVs and PHEVs.

A ***zero emission capable (ZEC) vehicle*** has the ability to operate for a period of time as a zero emission vehicle, but has an onboard source of power that will emit exhaust gas into the atmosphere at the point of use when not operating in zero emission mode.

Examples – Plug in Hybrid Vehicle (PHEV), Range Extended Electric Vehicle (REEV)

Term	Abbreviation	Definition
Plug in Hybrid Electric Vehicle	PHEV	PHEVs use both fossil fuel (petrol or diesel) and electricity to power both an internal combustion engine (ICE) and an electric motor. PHEVs have a fuel tank and an electric battery for storage. PHEVs can be recharged by plugging the vehicle into electricity sources and refuelled at conventional fossil fuel stations. PHEVs may also be recharged by the ICE and through regenerative braking. There are two types of PHEVs: Series and Parallel. Series only allows power to be received from the battery, while parallel can receive power from both the battery and combustion engine. Depending on daily driving distances PHEVs will draw on petrol or diesel for part of their overall energy need, and therefore create related emissions.
Range Extended Electric Vehicle	REEV	A variant on the PHEV where range is extended by switching to the ICE either to generate electricity to drive the vehicle (series) or drive the vehicle directly (parallel).

CO_2 versus CO_2e

When fossil fuel is combusted small amounts of other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) are produced together with the main combustion product (CO_2). Although the amounts are small, the global warming potentials (GWP) of methane and nitrous oxide are high, so taking these into account in emission calculations is recommended for consistency, comparability and to see the full picture of GHG emissions inventories.

The latest diesel vehicles incorporate **Selective Catalytic Reduction** (SCR) systems which use urea (ammonia solution) injection into the exhaust stream in order to reduce the harmful NOx emissions. An undesired reaction in this process produces N_2O (nitrous oxide) a GHG with a Global Warming Potential (GWP) of 265 times that of CO_2 (IPCC AR 5 over 100 years). Nitrous oxide is not currently a regulated emission that the vehicle OEMs need to declare for their vehicles. This may change in the future, but at the moment there is a potential that GHG emissions from vehicles using SCR systems are underestimated. The UK Clean Vehicle Retrofit Accreditation Scheme includes the measuring of N_2O and in emissions tests for vans emissions of N_2O can add 3-6g CO_2e/km and for heavy duty vehicles the additional CO_2e can be between 20 and 30g/km.

This is another good reason to calculate and report in CO_2 equivalents rather than just CO_2.

3.1.3 Fuels and Energy

Gasoline (Petrol)

Conventional gasoline produced from refining petroleum; in Europe gasoline is required to meet EN228.

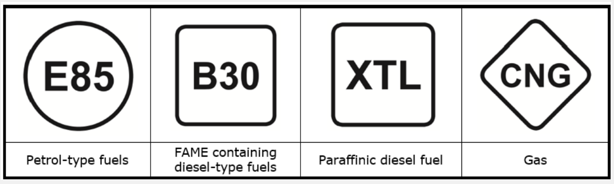
Bioethanol

Ethanol produced from biogenic feedstocks such as crop based sources and can be blended with conventional gasoline, for example E10 (10% ethanol).

Diesel

Conventional diesel produced by refining petroleum; in Europe diesel is required to meet the European standard EN590.

In Europe fuel labelling is being implemented to clearly mark fuel type and biofuel content in response to EU Directive 2014/94/EU. Examples below



Circle = petrol
Square = FAME diesel and Paraffinic diesel
Diamond = Gaseous fuels CNG, LNG and LPG

Biodiesel

First generation (1G) biodiesel is derived from food and/or feed crops such as rape seed or soybean. Second generation (2G) biodiesels are derived from non-food based crops or waste oil feedstocks.

Fatty Acid Methyl Ester (FAME) biodiesel is produced by the transesterification of vegetable oil or animal fats (e.g. tallow) with methanol.

In Europe B100 FAME biodiesel needs to meet the EN14214 European standard. Higher blends such as B20 (20%) and B30 (30%) need to meet a separate standard, EN 16709.

1st Generation (1G)
- Feedstock from food crops
- Rapeseed, soybean, corn, sugar, palm oil

2nd Generation (2G)
- Waste oil, used cooking oil (UCO)
- Lignocellulose from farm & forest residues

3rd Generation (3G)
- Feedstock from algae (in development)

Hydrotreated Vegetable Oil (HVO)

Referred to as a second generation (2G) biodiesel, HVO is a paraffinic fuel that is chemically similar to fossil fuel diesel and is classed as a “drop in” fuel in conventional diesel vehicles. Produced by hydrotreating virgin or waste vegetable oil that removes oxygen and splits it to form hydrocarbon molecules similar to conventional fossil diesel fuels.

In Europe HVO needs to meet CEN standard EN15940 for paraffinic automotive fuels derived from synthesis or hydrotreatment. The full fuel life cycle will depend on which feedstocks are used and where they are produced.

Paraffinic Diesel/Gas to Liquid (GTL)

Gas to Liquid (GTL) refers to fuels where natural gas (methane) is converted to longer hydrocarbon chain liquid fuels in a staged process of producing a synthesis gas and then using the Fischer-Tropsch process to form alkanes. This fuel contains less polycyclic aromatic hydrocarbons and less sulfur compared to diesel from petroleum refining (conventional diesel).

Renewable Fuels on Non-Biological Origin (RFNBO)
A fuel derived from the reaction of hydrogen with carbon dioxide at elevated temperature and pressures in presence of a catalyst to form methane and water. The resulting methane can then be processed to form longer chain hydrocarbons such as synthetic diesel or Sustainable Aviation Fuel (SAF). These fuels can sometimes be referred to as Development Fuels or eFuels.

Natural Gas (CNG and LNG)
Methane or natural gas can be used in two forms in road freight vehicles namely **Compressed Natural Gas (CNG)** and **Liquified Natural Gas (LNG).**

Biomethane
Methane derived from renewable feedstocks using processes such as **anaerobic digestion** (AD). Can be used in a CNG or LNG dedicated vehicle or a dual fuel vehicle. Can be mixed with fossil-based natural gas in a range of blended percentages (as for liquid biofuels). GHG emissions will depend on the feedstocks used, their origin and blend %.

Electricity
Electricity can be used to charge batteries in electric vehicles (BEV or PHEV) or to directly power vehicles via catenary power lines. The “well to wheel” GHG emissions vary significantly depending on the means of generation, with coal fired power stations at one end of the spectrum and wind, solar, hydro and nuclear at the other. The carbon intensity can vary on a minute by minute basis, but practically annual averages are published. As electricity generation decarbonizes over time so electric vehicles will become less carbon intensive, as will fuels where the production processes use electricity.

Hydrogen
Hydrogen can be used in fuel cell electric vehicles where it is combined with oxygen to produce electricity and drive electric motors, with the emission being water. Hydrogen can be produced by steam methane reformation (SMR), with or without carbon capture and storage, or by electrolysis of water using electricity.

Depending on the source of the methane in SMR, or the form of electricity generation (e.g. coal fired or renewable electricity such as solar or wind), the “Well to Tank” GHG emissions will differ greatly. Hydrogen can also be used in conventional ICE vehicles and dual fuel applications.

VECTO: Vehicle Energy Consumption calculation TOol
- Simulation tool for heavy duty vehicles (HDVs)

VECTO is the simulation tool that has been developed by the European Commission and shall be used for determining CO_2 emissions and Fuel Consumption from Heavy Duty Vehicles (trucks, buses and coaches) with a Gross Vehicle Weight above 3500kg.

As of 1 January 2019 the tool is mandatory for new trucks within certain vehicle categories in application to the certification legislation under type approval. The CO_2 emissions and fuel consumption data determined with VECTO, together with other related parameters, will be monitored and reported to the Commission and made publicly available for each of those new trucks.

Five different duty cycle profiles for trucks and five different duty cycle profiles for buses and coaches have been developed and implemented in the tool to better reflect the current European fleet. VECTO is a downloadable executable file designed to operate on a single computer.

The inputs for VECTO are characteristic parameters to determine the power consumption of every relevant vehicle component. Amongst others, the parameters for rolling resistance, air drag, masses and inertias, gearbox friction, auxiliary power and engine performance are input values to simulate fuel consumption and CO_2 emissions on standardized driving cycles.

- The VECTO tool is only for "tank to wheel" OEM declared values with limited flexibility to model operational performance across all potential duty cycles
- The VECTO tool does not calculate or report CO2e so misses the full Global Warming Potential of a heavy duty vehicle so this will be an area for further research.
- With fuel costs contributing to approximately 30% of overall costs then fuel efficiency has a significant influence on Total Cost of Ownership (TCO). Another area recommended for research is the adaptation of the VECTO tool (or at least the outputs) into a TCO model that sits alongside a Total Emissions of Ownership (TEO) model with the ability to input "drop in" alternative fuels or higher than standard blends of biofuel.

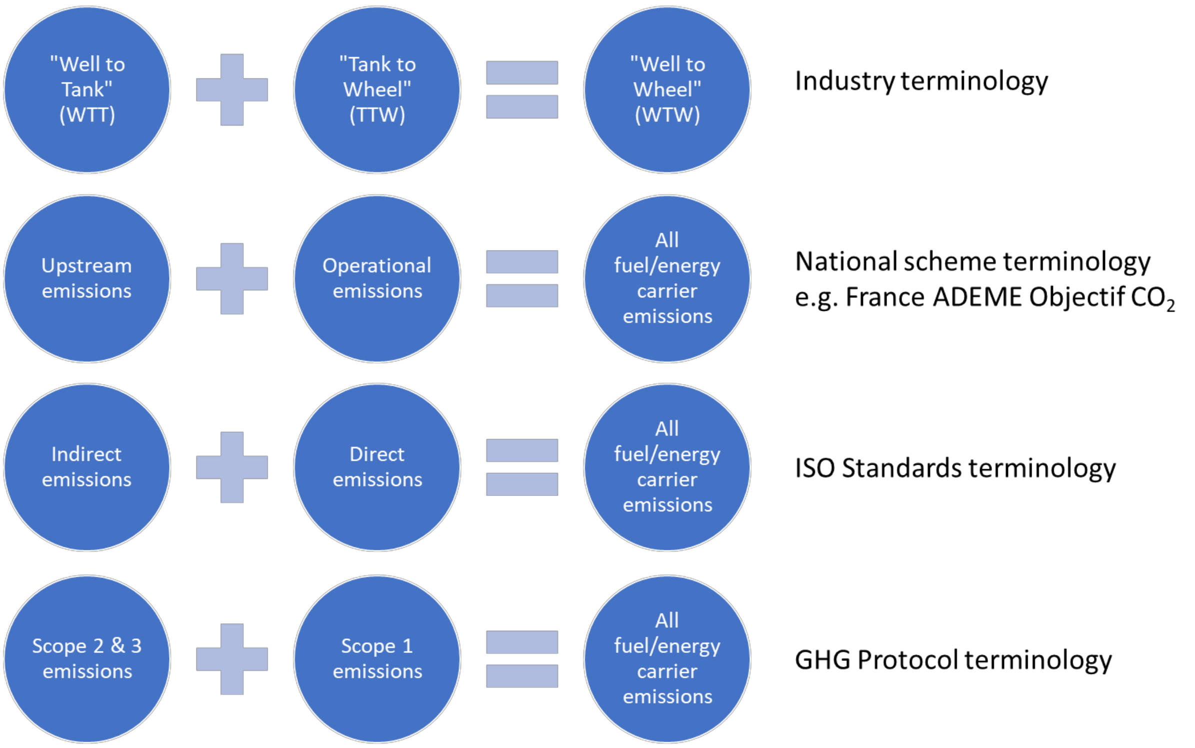
The VECTO tool has the potential to fill some gaps where operational data is missing, but it cannot be seen as substitute for real world data that would reflect the actual duty and drive cycles encountered by a truck. However, OEMs are mandated to use it and the EU policy objective of influencing the HDV manufacturers to reduce emissions and improve fuel efficiency will be measured by the outputs of VECTO. Therefore it has the potential as a starting point for TCO and TEO calculations when linked to real world operational data.

Source: EC

3.2 Full fuel cycle approach

In order to make the right choices and avoid unintended consequences a full fuel or energy carrier cycle approach is needed where all upstream and operational emissions are taken into account. This means all carbon positive and negative processes are considered with the aim of getting to a carbon neutral situation, also referred to as net zero, with respect to the fuel or energy used in road freight transport. There are a number of different sets of terminology that are used in different sectors and settings that essentially refer to the same thing, this is illustrated in the diagram below.

WTW explanation graphic



Fuels and energy carriers can have very different pathways from raw material to point of use, even for what can be considered the same fuel. It is important to understand the overall impact of the fuel chosen and be able trust the claims made by energy providers and suppliers. In the graphic below there are example fuel pathways for conventional diesel, biofuels and electricity. Each stage of fuel or energy production and use can either be carbon positive (adding CO_2 to the atmosphere) or carbon negative (removing CO_2 from the atmosphere) or carbon neutral (neither adding nor removing CO_2). In order to compare fuels and energy technologies it is very important to make sure the whole fuel pathway is included.

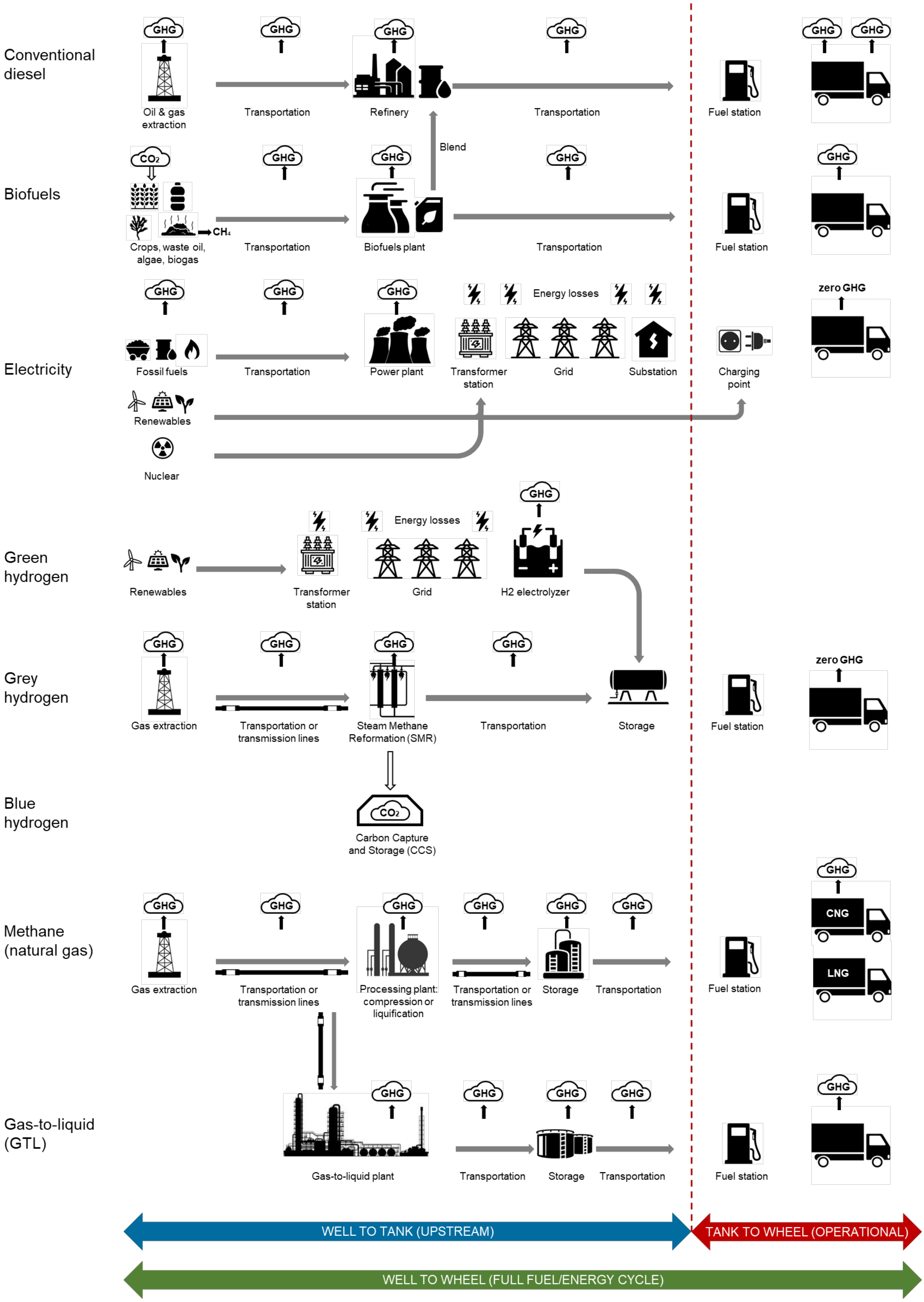
For conventional fossil fuels most elements in the fuel supply (upstream) and fuel use (operational phase) are carbon positive.

In contrast, for biofuels the upstream element of growing the crop is carbon negative. At the point of use (operation) the same carbon within the fuel is released back into the atmosphere (carbon positive), leading to an overall outcome that is carbon neutral, or close to it. There are, however, emissions associated with the production processes and the transport and distribution of biofuels.

With an electric vehicle there are no GHG emissions during operation but, as previously explained, the emissions in the upstream phase can vary widely depending on the source of the electricity. If fuel production or energy generation processes associated with transition fuels and energy are currently energy and carbon intensive, it follows that advances in process decarbonization will lead to improvements in well-to-wheel performance. This emphasizes the importance of feedback loops that include the calculation of upstream emissions in order to understand the full impact of the fuel.

Another way of assessing a fuel pathway is in terms of its overall energy efficiency. The overall energy efficiency of a fuel pathway is dependent on the number of stages and the energy losses at each stage. In the example below an electric and a hydrogen passenger car are compared. It should be noted that heavy duty vehicles have different operational requirements and constraints that current battery technology would struggle to meet; however, the well to tank energy loss processes for hydrogen would remain whether for passenger car or heavy duty vehicle.

Source: VW/C6


Conventional diesel
GHG
Oil & gas extraction
Transportation
Refinery
Transportation
Fuel station
Blend
Biofuels
CO_2
CH_4
Crops, waste oil, algae, biogas
Transportation
Biofuels plant
Transportation
Fuel station
Electricity
Fossil fuels
Transportation
Power plant
Energy losses
Transformer station
Grid
Substation
Charging point
zero GHG
Renewables
Nuclear
Green hydrogen
Renewables
Transformer station
Energy losses
Grid
H2 electrolyzer
Grey hydrogen
Gas extraction
Transportation or transmission lines
Steam Methane Reformation (SMR)
Transportation
Storage
Fuel station
zero GHG
Blue hydrogen
Carbon Capture and Storage (CCS)
Methane (natural gas)
Gas extraction
Transportation or transmission lines
Processing plant: compression or liquification
Transportation or transmission lines
Storage
Transportation
Fuel station
CNG
LNG
Gas-to-liquid (GTL)
Gas-to-liquid plant
Transportation
Storage
Transportation
Fuel station
WELL TO TANK (UPSTREAM)
TANK TO WHEEL (OPERATIONAL)
WELL TO WHEEL (FULL FUEL/ENERGY CYCLE)

3.3 Fuel and energy pathways

3.3.1 Conventional fuels

Diesel

For 100% mineral diesel (i.e. no biodiesel content) there are well-established full fuel cycle emission factors split out by WTT and TTW phases. Variations are relatively small and analysis has shown that values differ by only a few percentage points. This is due to a global market with well-established production processes and supply chains combined with a degree of harmonization in fuel quality standards and vehicle diesel engine technology.

Diesel/Biodiesel Blends

In Europe B7 (up to 7% biodiesel content) is the standard pump grade diesel fuel; anything above B7 is required to be labelled at the pump. Again, there are well-established emission factors; however, there can be variations in the biodiesel content from supplier to supplier, region to region and feedstock source, whilst differentiation is often not common due generally to low biodiesel blends. At these low biodiesel blends the overall emission factor is still dominated by the fossil diesel base component and so variation minimized.

However, the variation can lead to difficulty in precise base lining i.e. establishing the level of improvement is achieved and establishing "like for like" comparisons. This can be sometimes be a more academic stance than a practical industry problem.

Higher biodiesel blends (> 7%)

As the percentage of biodiesel increases so its relevance for the overall emission factor increases. Feedstock variations can have big impact on the GHG emissions savings achieved by using higher biodiesel blends. Hence use of higher blends brings a higher degree of uncertainty and a need for certification of fuel feedstock, production process and emission factor to reach a precise emission calculation outcome.

Gasoline (Petrol)

For 100% mineral based gasoline (i.e. no bioethanol content) there are well-established emission conversion factors or carbon intensity factors and WTT and TTW assumptions. Just as for diesel, this is due to a global market with established production processes and supply chains linked with a degree of harmonization in fuel quality standards and vehicle gasoline engine technology. It should be noted that in most global markets the vast majority heavy duty trucks are diesel powered.

Gasoline (Petrol) Ethanol blends

In Europe for E5 (up to E5 ethanol content) there are well-established full fuel cycle emission factors split out by WTT and TTW phases. There are variations in ethanol content within the range from supplier to supplier, region to region and feedstock source, with differentiation not common.

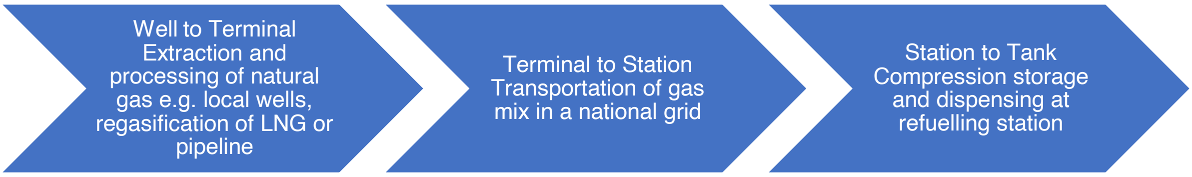
Higher Gasoline (petrol) Ethanol Blends (>5%)

Feedstock variations can have big impact on the GHG emissions savings achieved by using gasoline with higher bioethanol blends. This brings a higher degree of uncertainty without a certified level of fuel feedstock, production process and associated emission factor.

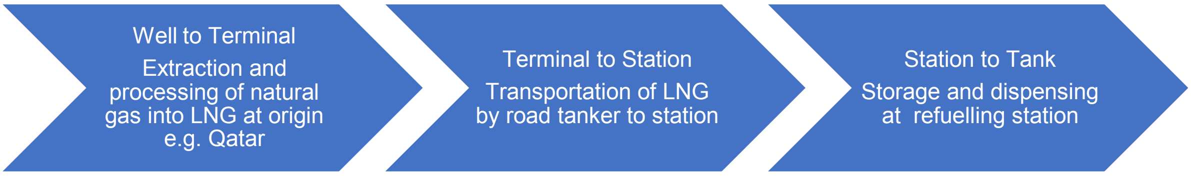
Natural Gas (CNG/LNG)

Fossil fuel methane or natural gas can be used in two forms within road freight vehicles namely **Compressed Natural Gas (CNG)** and **Liquefied Natural Gas (LNG).**

For CNG the pathway can have the following steps in the process



For LNG the fuel pathway can be as follows



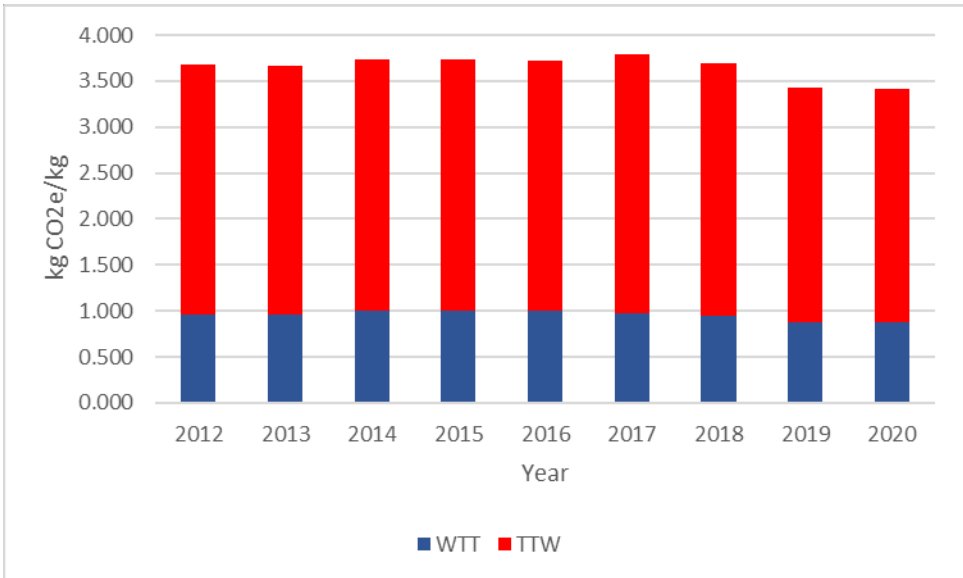
The Low Carbon Vehicle Partnership in the UK collated the following values for UK CNG/LNG WTT carbon intensities (CO_2e/MJ).

	BEIS 2019 (2017 NG stats)	Element Energy 2018 (2016 NG stats)	ETI 2017 (2015 NG stats)	DfT 2018 (2016 NG stats)
CNG	11.8	6.3	5.2	12.1
LNG	19.5	13.1	12.3	14.6

NG stats - natural gas statistics period associated with DUKES.

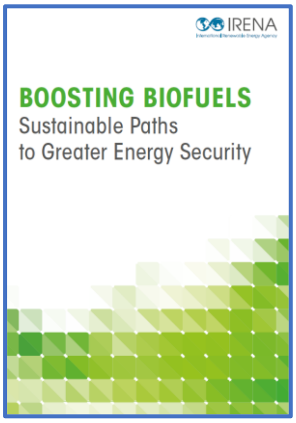
Source: *A review of well-to-tank GHG emissions values for natural gas, biofuels and hydrogen* (G. Esposito, October 2019)

A review of LNG GHG conversion factors within the UK Government GHG Conversion Factors for Company Reporting, published annually by the Department for Business Energy and Industrial Strategy (BEIS) and Department for Environment Food and Rural Affairs (Defra), showed a year-on-year variation, as illustrated below, which emphasizes the difficulty of making a decision based on marginal emission benefits based on the available information.

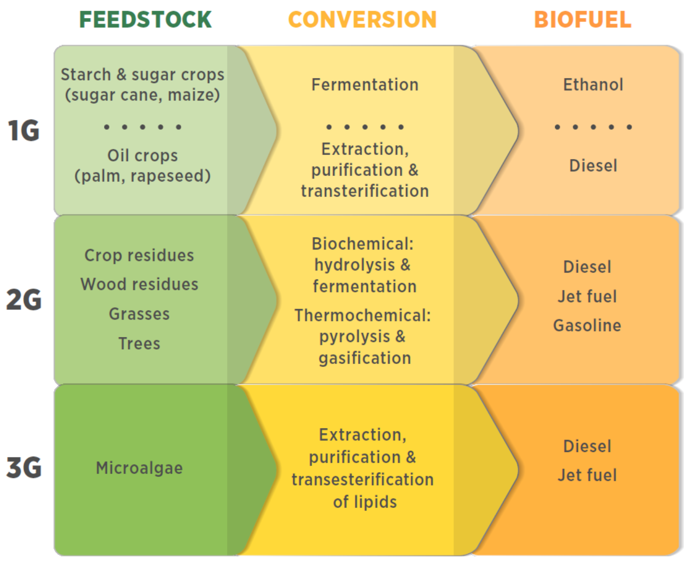


3.3.2 Biofuels (Biodiesel, HVO, Biomethane, BioPropane [BioLPG])

Biofuels have numerous feedstocks and production processes to produce what is effectively the same product that an operator would use interchangeably in a vehicle. A number of studies have been conducted to assess the benefits, performance and impact of biofuels leading to a vast array of emission factors and GHG saving claims that can be achieved by using biofuels. The possibility of having a drop-in fuel appeals to operators as vehicle and infrastructure modifications are minimal.



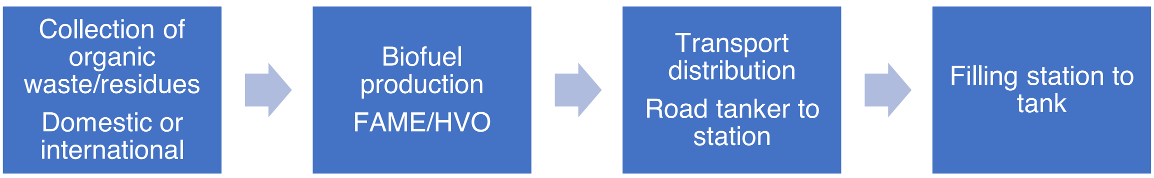
Source: Boosting biofuels ©IRENA 2016



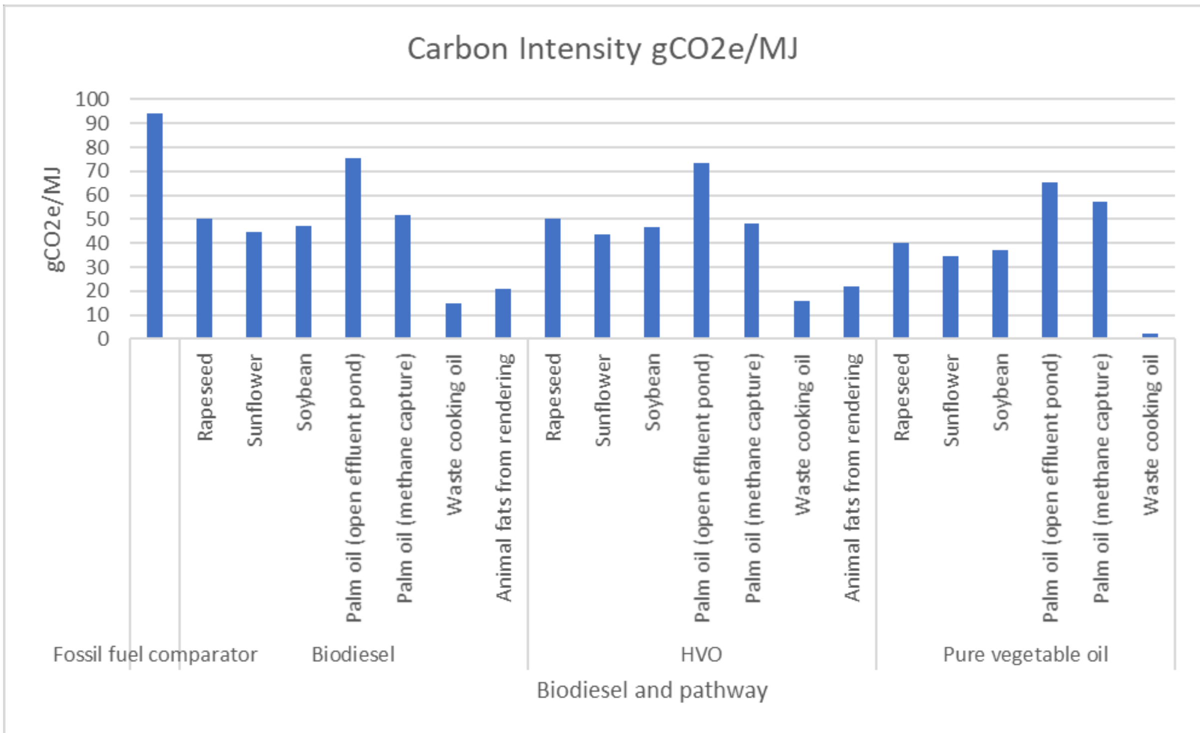
Biodiesel

GHG emission factors for biodiesel are dependent on the crop, residues or waste feedstock, how land use change is taken into account and the production processes used and the emission intensity of associated energy sources.

Typical biodiesel pathway elements are as follows:



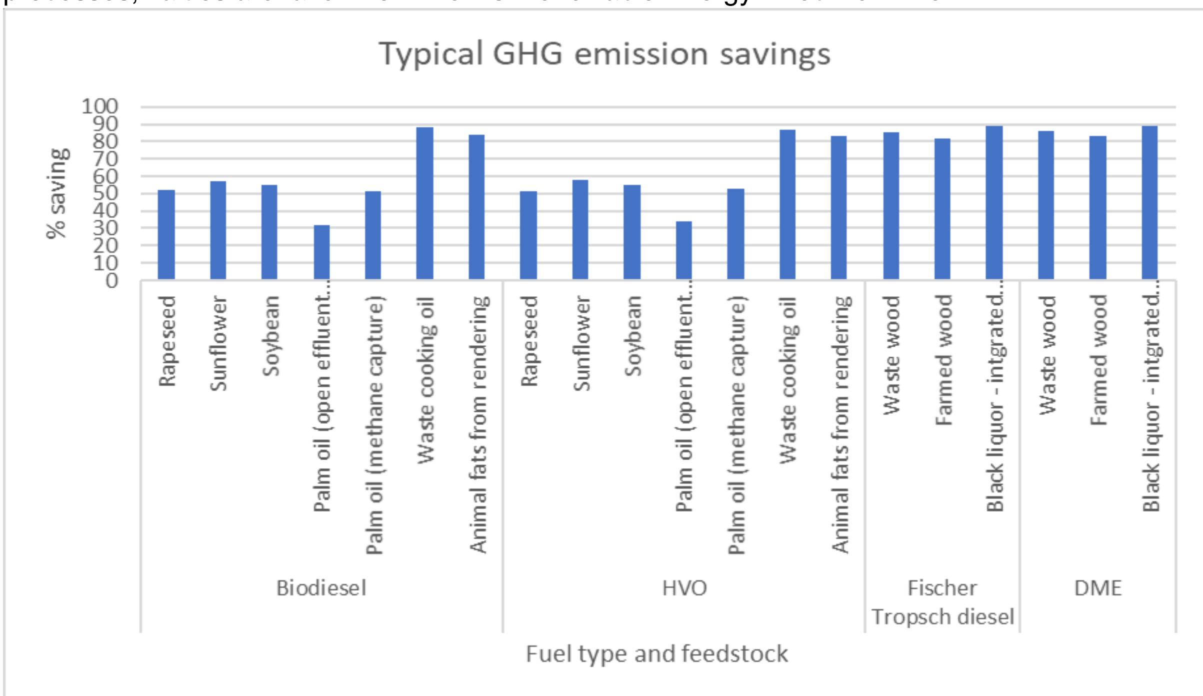
The following graph illustrates the variance in carbon intensity for a selection of biodiesel pathways; the values are taken from the EU Renewable Energy Directive (2018) default values.



The UK LowCVP published the following values for pure biodiesel used in the UK

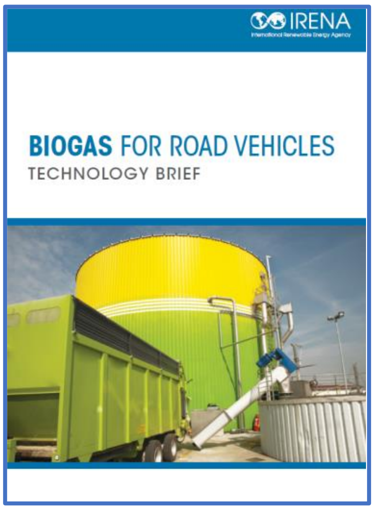
Aspect	**Biodiesel**	**HVO**
WTW carbon intensity range	8-13gCO_2e/MJ	7gCO_2e/MJ
WTW emission savings	87-92%	91%
Average emission savings	B100: 89% B20:17%	
Primary sustainable feedstocks	Brown grease, tallow, used cooking oil (UCO)	Waste oil pressings from vegetable oil production

The following are typical GHG emissions savings from biodiesel with varying feedstocks and processes, values are taken from the EU Renewable Energy Directive Annex V.



Biomethane

Biogas can be produced by microbiological process from different kinds of biomass. Potential feedstocks are wastewater, water treatment sludge, manure from animal production, industrial or municipal waste streams as well as energy crops. The biogas is then purified or upgraded to natural gas quality and then referred to as biomethane. It can then be used in **Natural Gas Vehicles (NGVs)** or dual fuel vehicles. Where they exist, biomethane is generally fed into national gas distribution grids where final use cannot be traced directly, so regulations are implemented that allow virtual use on a contract or certificate basis. It can also be distributed in tankers where gas grids do not exist.

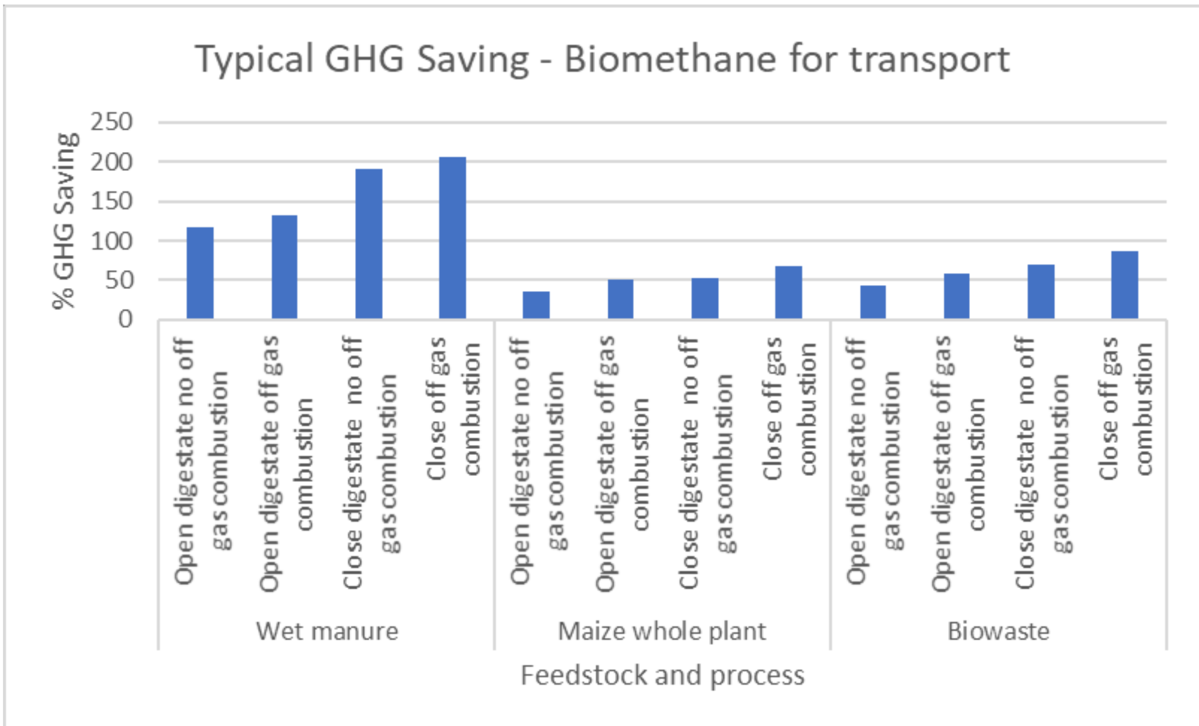


GHG savings over fossil fuel are typically 60-80%, although it can be shown to be carbon negative if the right feedstocks are used (where methane would alternatively have been released direct to the atmosphere).

Typical biomethane pathway elements are as follows:

Collection of organic waste/residues Domestic or international	→	Biomethane production Anaerobic digestion and upgrading	→	Transport distribution Injection into gas grid	→	Station to tank (compression, storage and dispensing)

Potential GHG savings achieved for pure biomethane for use in transport can also vary depending on the feedstock and processes used. The following values are taken from the EU Renewable Energy Directive 2018. To add to the variation there can be combinations of these feedstocks, for example a mixture of wet manure and maize.



Typical values published in the UK by the LowCVP are as follows

Aspect	Biomethane
WTW carbon intensity range	5-15gCO_2e/MJ
WTW emission savings	82-94%
Average emission savings	88%
Primary sustainable feedstocks	Food waste, manure agricultural residues

Biopropane

Biopropane is renewable liquid petroleum gas (LPG) and can be used as a drop-in replacement fuel. This biofuel is produced as a by-product from HVO production with feedstocks such as energy crops and waste material. It is generally not used in HGVs, but can be used in non-road machinery such as forklifts within logistics hubs, and some retrofit system suppliers use LPG as a dual fuel solution in heavy duty vehicles substituting diesel and gaining moderate GHG emission savings. Another application of BioLPG in the HGV freight sector is as a fuel for a range extender engine in hybrid vehicles.

Aspect	Biopropane (bioLPG)
WTW carbon intensity range	8-315CO_2e/MJ
WTW emission savings	63-90%
Average emission savings	76%
Primary sustainable feedstocks	Palm fatty acid distillate, waste oils and UCO

Biofuels summary

Major factors influencing the carbon intensity of all biofuels are

- Feedstock type and source
- Biofuel production processes and energy requirements
- Method of transportation and distribution e.g. compression or liquefaction
- Co-processing of products
- Carbon intensity of energy throughout the supply chain

The high degree of variability within all the biofuel pathways makes using one standard (default) value for each fuel only really applicable as a starting point for GHG emission inventory calculations. If taking this approach then it would be best to use a conservative default value that most likely overestimates emissions. As better and more reliable data and fuel tracing mechanisms become available then more precision can be applied to the calculation. This level of precision would be particularly important when evaluating projects specifically designed to assess emission reductions and where the biofuel feedstock and production processes are known.

Is there enough feedstock to cover transport fuel demand?

According to the IRENA report *Boosting Biofuels – Sustainable Pathways to Greater Energy Security* there is potential for agricultural crops to cover transport fuel demand, however there needs to be action in three distinct areas as follows:

- Yields need to be boosted on existing farmland, as food demand grows so will the availability of farm residues, if fully collected it is estimated that this feedstock source could cover a third of current transport fuel demand.
- By improving agricultural practices on current farmland there is the potential to grow the same amount of food on less land. The land released could be used to grow biofuel feedstocks that could cover a further third of transport fuel demand.
- By reducing waste and losses, currently about a third of all food is lost or wasted in the food chain. By avoiding this then the final third of transport fuel demand could be covered by advanced biofuel production.

Globally around 30 billion liters of biodiesel were produced in 2014 which equated to approximately 1.5% of diesel supply, generally this has been due to biofuel targets introduced in Brazil, North America and Europe. If current residues were collected more efficiently studies have shown there is the potential to supply 20-40% of all liquid fuel used in transport in 2012 or twice the amount of fuel used in marine shipping and aviation. It would appear that food and fuel crop production can be complementary rather than a conflict if the correct policies are put in place.

Debate remains over the degree of competition for the feedstocks and to what extent there will be competition from the combined heat and power generating sector for the biofuels produced. This will be an area for further research, discussion and policy development.

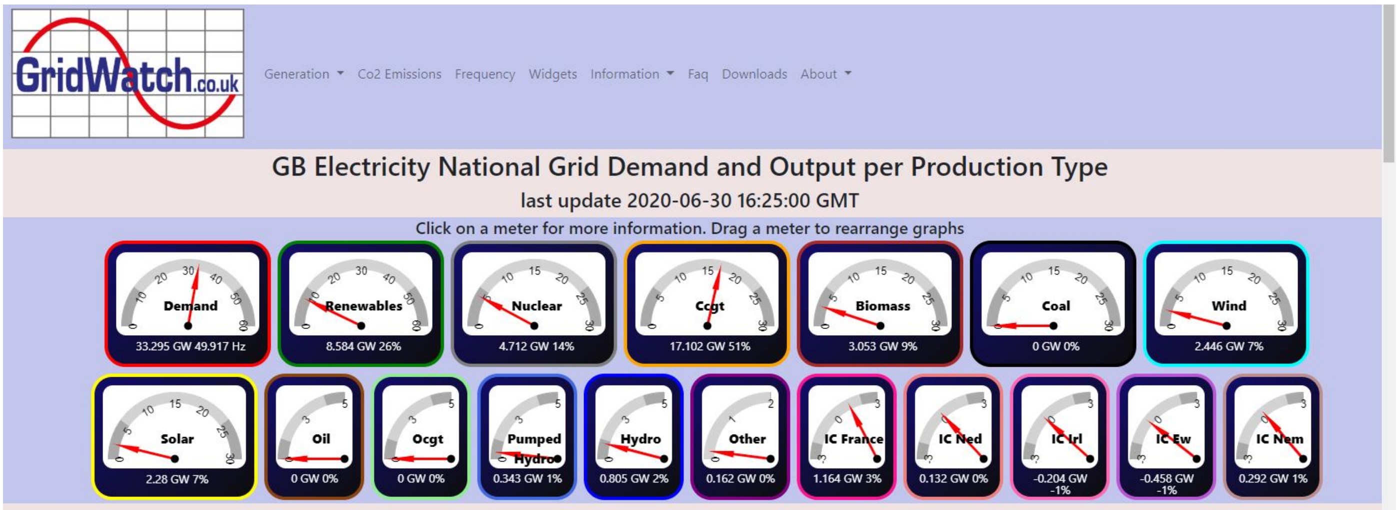
As with agricultural feedstock sources, there will also be similar issues around waste based feedstocks and again more research is required to understand the impacts of as new fuel production processes emerge and whether reductions in consumer waste will hinder the availability of feedstocks.

3.3.3 Electricity

The conventional primary energy sources used to generate electricity, particularly fossil fuels such as coal, oil and natural gas, are slowly being replaced by renewable sources with much lower GHG emissions such as hydro (including pumped hydro), onshore and offshore wind, solar PV or biomass. Also nuclear power generation is included in the electricity mix.

The carbon intensity of any electricity supply grid will be dependent on the mix of generation sources and will continually vary with time and from country to country. The electricity emission factor in a particular country can be further complicated by the trading of electricity between countries that have generation surpluses and deficits, meaning that a country's generation mix needs to be modified to truly represent what is actually supplied (the supply mix).

Live grid mix data may be available, an example below for the UK.



3.3.4 Hydrogen

There are several pathways to generate hydrogen and each one will have a varying ability to reach a net zero carbon position:

- "Grey" Hydrogen – Hydrogen produced from fossil based methane by steam methane reformation (SMR) without carbon capture and storage (CCS). This would be the highest carbon intensity.
- "Blue" Hydrogen – Hydrogen produced from fossil based methane by steam methane reformation (SMR) with carbon capture and storage (CCS). The degree of carbon intensity of this pathway will depend on the efficiency of the carbon capture and storage process.
- "Green" Hydrogen – Hydrogen produced by water electrolysis derived using wholly renewable electricity (e.g. wind, solar or hydro). This pathway would be the lowest carbon intensity that keeps fossil carbon sequestered.

There can be other pathways that sit somewhere in between the ones above, such as where biomethane could be used as the methane feedstock or where national grid electricity is used for electrolysis that may be a mix of electricity generation energy sources or methods i.e. coal, oil, gas and renewables.

Hydrogen is an energy carrier that is seen by some as the future for road freight transport and others dismiss it as being too energy inefficient, with much greater energy losses when compared to direct electrification. Either way a better understanding of the carbon intensity of hydrogen production pathways is needed in a robust and transparent manner to aid decision making.

The UK's Low Carbon Vehicle Partnership (LowCVP) produced a paper titled *A review of well-to-tank GHG emissions values for natural gas, biofuels and hydrogen* (G. Esposito, October 2019) and the table below has been extracted.

Summary of hydrogen production (WTT) GHG emissions gCO_2e/MJ

Source	SMR	SMR + CCS	Electrolysis (Grid)	Commentary
CONCAWE 2014	108	43	232	WTT - Extraction/processing of natural gas, EU pipeline to UK, SMR, distribution by road tanker, compression at refuelling station, EU-electricity grid 2014
DfT 2018	100	35	160	WTT - Electrolysis uses 2017 grid factor, SMR based on CONCAWE 2014 data.
E4Tech 2019	61-90	24		SMR/SMR+CCS includes natural gas upstream emissions
CCC 2018	83-99	11-26	80-99	Electrolysis only (based on 2017 grid) SMR includes natural gas upstream emissions
Balcombe et al 2019	80-96	6-41	138	SMR/SMR+CCS includes natural gas upstream emissions. Electrolysis only
CertifHy 2019	90	45	220	SMR/SMR+CCS includes natural gas upstream emissions. Electrolysis only, EU electricity grid 2014
Mahmeti et al (2018)	74-107			SMR + upstream

Source LowCVP

Figure 5: SMR pathway (red) and with CCS (green)

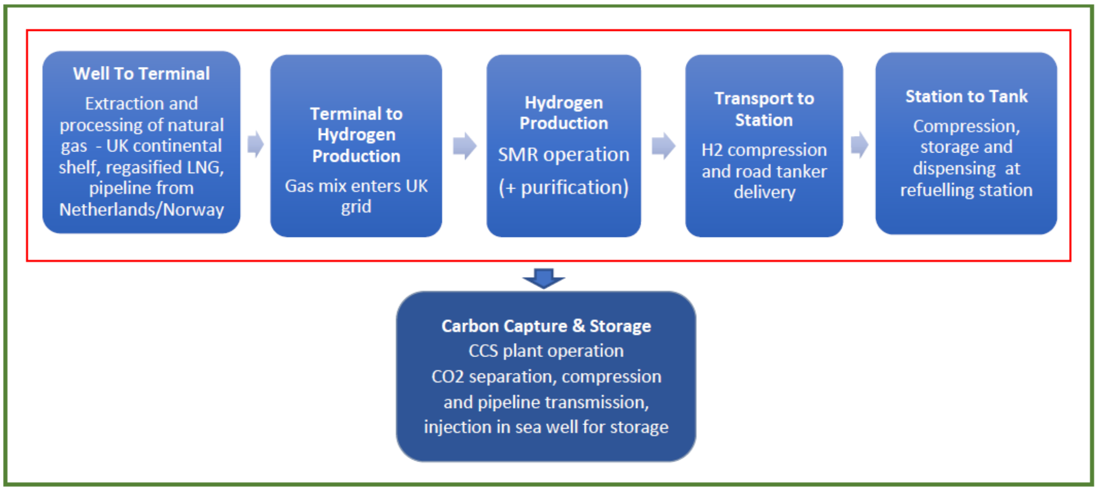
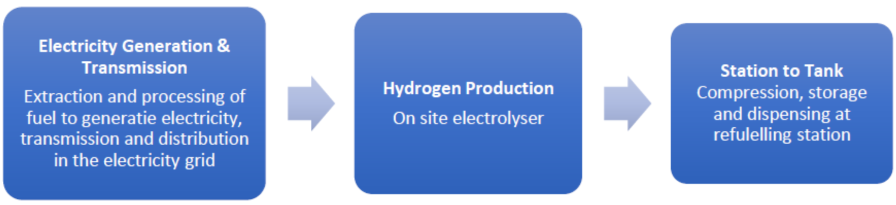
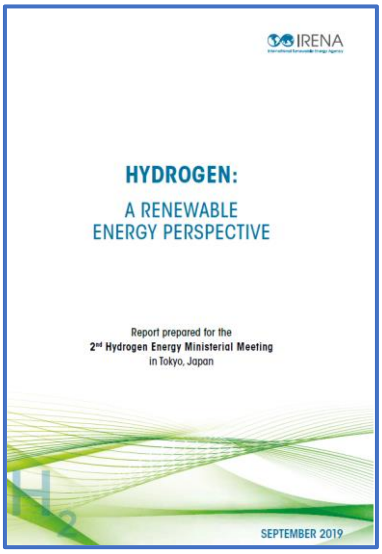


Figure 6: Electrolysis (Grid) pathway[4]



Source: *A review of well-to-tank GHG emissions values for natural gas, biofuels and hydrogen* (G. Esposito, October 2019)



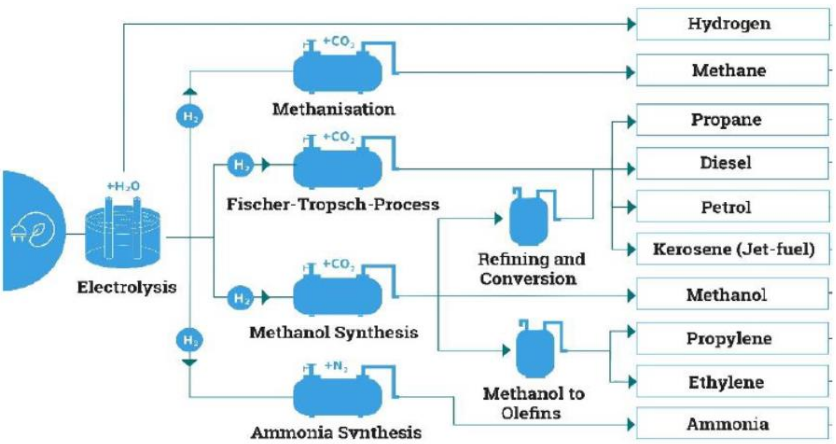
The IRENA report *Hydrogen: A Renewable Perspective* (September 2019) lays out the potential that hydrogen has to provide energy in hard to decarbonize sectors and the challenges faced with hydrogen as a fuel from an GHG and economic view point.

The main pathways of "grey", "blue" and "green" hydrogen are critical in determining the GHG reduction potential. The main findings are

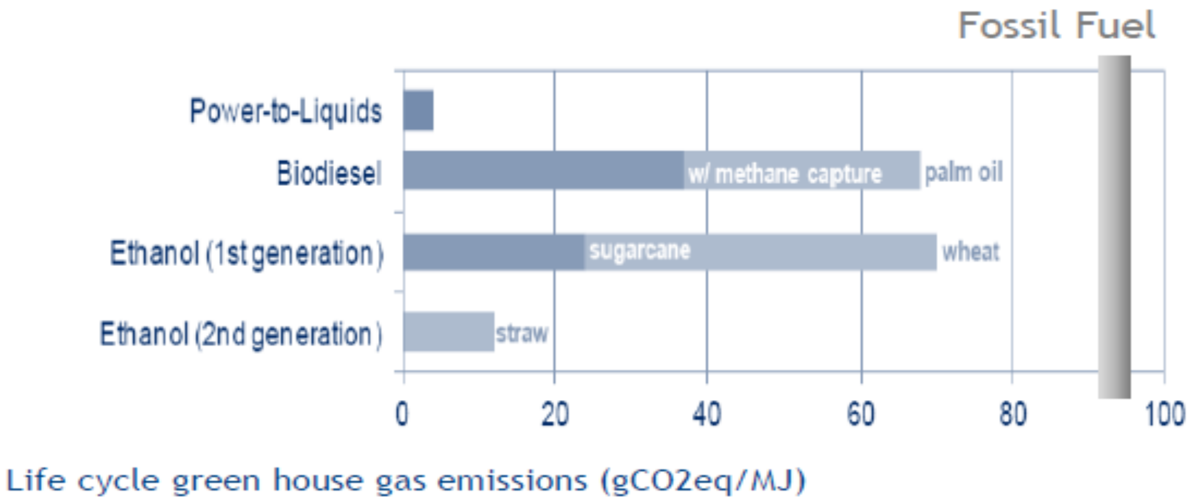
- Hydrogen has attracted more focus recently as green hydrogen has become cheaper to produce and better availability however the vast majority of hydrogen production is "grey" (95%)
- Ensuring low cost clean hydrogen ("Blue" and "Green" hydrogen is essential.
- Hydrogen is seen a potential energy storage solution to compensate the variability of renewable electricity
- Reducing the energy losses associated with the hydrogen supply chain is a key area for development
- Production costs are still high, use is limited and the sectors that need to adopt it see no hydrogen currently being used at all.
- Infrastructure needs substantial investment and currently restricts widespread use.
- A lack of vehicles and their cost prohibit the uptake of hydrogen as a transport fuel.
- Hydrogen from renewable sources can play a role in providing feedstock for electrofuels (e-fuels, also referred to as Power to X) however economics are a challenge.
- "Blue" hydrogen is seen by some as a transition towards a larger hydrogen economy, for this to happen carbon capture and storage needs to be developed and incorporated in to new projects from the start.

3.3.5 Advanced Liquid Fuels (Development Fuels or eFuels)

Development fuels, also known as electrofuels (eFuels), is an emerging market with very little publicly available data on carbon intensity that is comparable across fuel providers. These fuels offer "drop-in" utility but will take some time to scale up and become economically viable without subsidy or significant investment. Electrofuel production pathway uses renewable electricity to produce hydrogen by electrolysis and then combines with carbon through various reaction and refining processes to form synthetic hydrocarbons that have low life cycle GHG emissions. Also known as Power to X with X being liquid or gas.

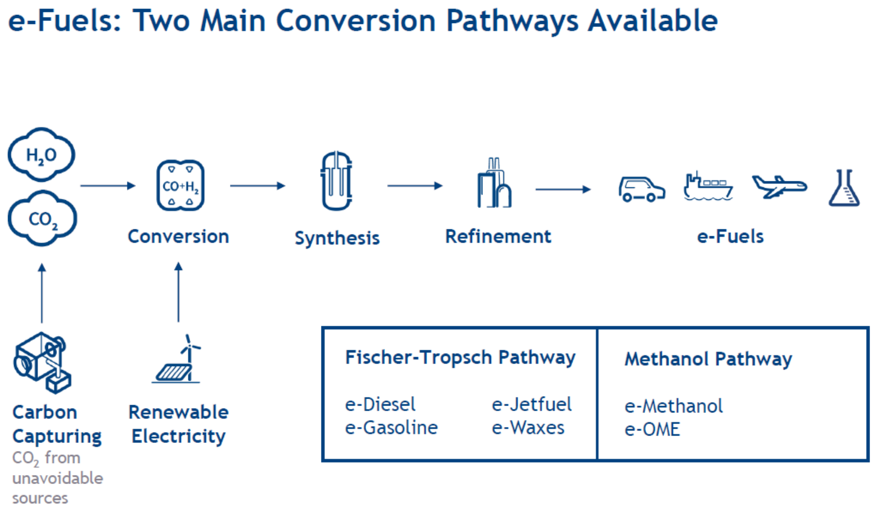


Source: Global Alliance Powerfuels Presentation, Stefan Siegmund, DENA



Source: Liquid hydrocarbons, Electrofuels - Karl Haptmaier/Nils Aldag, Sunfire 2018 ITF Workshop

Pathways can be as follows:



Source: Liquid hydrocarbons, Electrofuels - Karl Haptmaier/Nils Aldag, Sunfire 2018 ITF Workshop

3.4 Relation between theoretical emission factors and operator experiences

Although the emission factor of a fuel provides a starting point for the calculation of vehicle emissions, there are many other factors that influence the overall operational efficiency vehicle and the total emissions. It is possible to model the emissions by making certain assumptions about vehicle operation, duty cycle and loading; however, collecting information using good quality operational data is important to validate such modelling, both in the form of controlled trials of new fuels and to capture values associated with true operational characteristics.

The emission factors that are produced for the various possible fuels and energy sources are generally expressed in terms of the mass of CO_2, or better CO_2equivalent to cover all GHGs, per energy content of the fuel.

There are scientific reasons for this, but it is not particularly helpful for the operator of the vehicle because, except for electricity, they don't buy fuel in terms of the energy content. It's also further complicated by the convention of using kWh as the unit of energy for electricity.

Typical units for emission factors
gCO_2e / MJ for liquid and gaseous fuels gCO_2e / kWh for electricity NB 1kWh = 3.6 MJ

Liquid fuels are generally measured and purchased[2] by volume, whilst gaseous fuels are measured and purchased by mass.

As a result there are several steps between the emission factor of a fuel and the ultimate fuel and emission efficiency indicators that are used by the transport operator. These steps need to be understood if they are to make best use of the information available, as follows:

1. Energy content of the fuel. This applies to liquid and gaseous fuels.

The value is usually known for each fuel:

MJ per liter and / or MJ per kg

Multiplication by the emission factor allows conversion into a value that would be more meaningful, at least in theory, to the vehicle operator:

$$gCO2e/_{MJ} \times MJ/_{liter} = gCO2e/_{liter}$$

2. Efficiency of the engine or motor. Applies in all cases.

The theoretical energy available in the fuel (the input energy) is not all converted into the energy of the vehicle (output energy).

$$Efficiency = energy\ output/_{energy\ input}$$

There are many possible sources of energy loss such as rolling resistance, aerodynamic resistance etc. which depend on efficient vehicle design. However, even if all these factors are identical there is one remaining important influence – not all engines are created equal.

Engine manufacturers work to optimize their engines, but their efforts are limited by the constraints of the fundamental chemistry of the combustion process. In basic terms the spark ignition engine, which is commonly used to power gasoline and dedicated gas fueled vehicles, is less efficient than the compression ignition engine that is used for diesel and duel fuel gas vehicles. The result is that, even in controlled conditions, conversion from emission factor of the fuel to emission of the vehicle is also governed by the engine efficiency.

Electric motors tend to be considerably more efficient than internal combustion engines.

3. Vehicle operation. Applies in all cases.

As noted above, as well as engine efficiency there are many other sources of energy loss at work when a vehicle is operated. Fuel economy values can vary considerably based on the driving

[2] In the road sector – in the maritime sector liquid fuels are purchased by mass.

style, duty cycle, road layout and topography and any equipment on the vehicle designed to reduce losses such as low rolling resistance types or aerodynamic kits.

Typical units for fuel economy
Liquid fuels Liters / km or liters / 100 km Miles per gallon
Gaseous fuels Kg / km or kg / 100 km Miles per kg or miles per pound
Electricity kWh / km or kWh / 100km or mile / kWh

Vehicle operators are well used to monitoring their fuel economy as a basic KPI for vehicle efficiency in terms of fuel used per distance travelled.

The values measured by the vehicle operator will include the combined effects of all such losses, including engine efficiency. Vehicle manufacturers have become very sophisticated at modelling these effects, and are becoming increasingly good at predicting the results calculated by vehicle operators in actual operation.

4. Loading efficiency. Applies in all cases.

The operational efficiency of a vehicle is highly dependent upon its weight, including the weight of any load present. The purpose of freight transport is to transport the cargo from one location to another, and so it is important to factor this into any assessment of overall efficiency, particularly as the fuel consumption is a function of the total mass (vehicle + load).

It's also worth noting that the available payload weight can be significantly reduced compared to conventional vehicles by the weight of energy storage and conversion systems for alternative energy sources, such as batteries, cryogenic systems or reinforced fuel tanks. This should be taken into account alongside the decisions made by the vehicle operator or their customer in terms of how efficiently, or otherwise, the vehicles are operated – the key factors are maximizing payload weight compared to the legal limit and minimizing any empty running between one loaded journey and the next.

$$Loading\ efficiency = {}^{vehicle\ kilometers}/_{tonne\ kilometers}$$ [3]

5. Combination of influencing factors

Taking these factors together, the total GHG emissions from a given amount of transport activity measured in tonne kilometers can be expressed by the following equation, which shows the effect of the various influencing factors:

$$GHG\ emissions = {}^{gCO2e}/_{MJ} \times {}^{MJ}/_{liter} \times {}^{liters}/_{vkm} \times {}^{vkm}/_{tkm} \times tkm$$

NB the engine efficiency is incorporated within the liters per vehicle kilometer value.

[3] For more information on calculating tonne kilometres see the GLEC Framework

6. Overall format and use of information

Vehicle operators

The vehicle operator general knows the amount of each fuel used in liters or kg. Hence combining this with a value for emission per liter or per kg enables calculation of the total emissions, e.g.:

$$GHG\ emissions\ = {}^{gCO2e}/_{liter} \times liters$$

It should also be possible for the vehicle operator to calculate and emission intensity value:

$$Emission\ intensity\ = {}^{gCO2e}/_{tkm}$$

Freight transport buyer

If the buyer knows the transport activity that they purchase in terms of tonne kilometers then combination of this with the emission intensity, either provided by the vehicle operator directly, or using a green freight program, or use of an appropriate default emission intensity value allows them to calculate the emissions.

$$GHG\ emissions\ = {}^{gCO2e}/_{tkm} \times tkm$$

7. Non-combustion emissions

The emission factors that are quoted for both conventional and new fuels that involve combustion of the fuel to generate energy are generally built on the assumption of full or very close to full combustion. Small amounts of gases other than CO_2, which comprise a very small proportion of the total emission output, are converted into their CO_2 equivalent and included in the overall emission factor. However, the use of natural gas (methane) as a transport fuel introduces an additional problem. The highly volatile nature of methane makes it very difficult to contain; unless the combustion chamber of the engine is designed to cope with this, or an effective catalyst is used in the exhaust system, then there is a risk that a significant proportion of the exhaust gas is comprised of unburned methane – so called 'methane slip'. This is particularly important because methane is a highly potent greenhouse gas, with a 100 year global warming potential that is 28 times that of CO_2.

When it comes to calculating the emissions, what makes this difficult to quantify is that the amount of methane that slips through the combustion chamber is related to the design of the engine, and can be high even for some engines that are supposedly designed to be gas engines. Hence using an average emission factor for natural gas fuels such as CNG or LNG can be misleading as it can overestimate the emissions for well-designed engines and underestimate the emissions for poorly designed engines. Furthermore, the understanding of the scale of this issue is only now becoming fully understood, and some older emission factors do not (fully) take the effect into account, again underestimating the emissions from the engine.

4. Overview of the current situation

4.1 Policy landscape

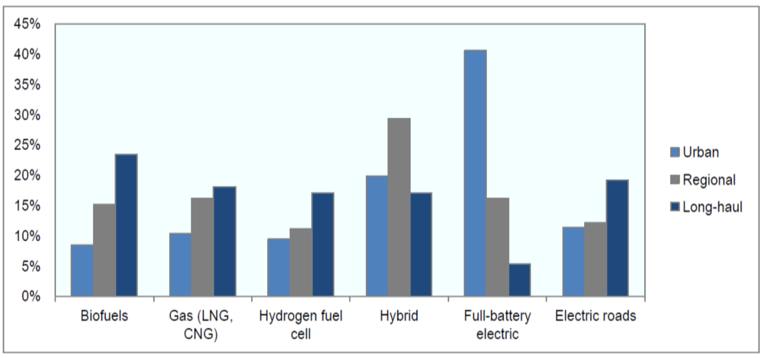
Reports addressing policy issues such as ***Towards Road Freight Decarbonization – Trends, Measures and Policies*** have been written and published by the International Transport Forum (ITF) among others. The main points from the highlighted ITF report are:

- Broaden access to relevant data to be able to assess the impact of measures taken and help inform policy.
- Scale up tested and easy to implement measures such as aerodynamics, low rolling resistance tyres, light weighting and hybridization. Along with ambitious fuel economy standards that include heavy duty vehicles.
- The implementation of policy that drives the adoption of alternative fuels and related infrastructure.
- Finding ways to overcome regulatory barriers to collaboration within the logistics sector and making ways to demonstrate the business case for decarbonization.
- Promoting alternative fuels in the mid to long term is needed with electric batteries, hydrogen and advanced biofuels with strategic policy and significant funding allocated for infrastructure developments. A call for further research and pilot trials is suggested.
- Tailoring decarbonization to regions or country groups as not all countries and regions are at the same point in their decarbonization plans or the ability to implement advanced solutions and infrastructure.

The ITF Decarbonizing Transport Initiative project has been set up with the following goals
Source: ITF Expert Opinion Survey (2018)

- To gather evidence and best practice for decarbonizing transport through continuous engagement with countries and partners
- Help countries design robust transport and climate policies by **developing and disseminating a catalogue of mitigation measures** with **quantitative evidence of their effectiveness** including **assessment of confidence in the results**
- Increase understanding and build capacity in countries and partner organisations regarding ways to mitigate carbon emissions from transport activity

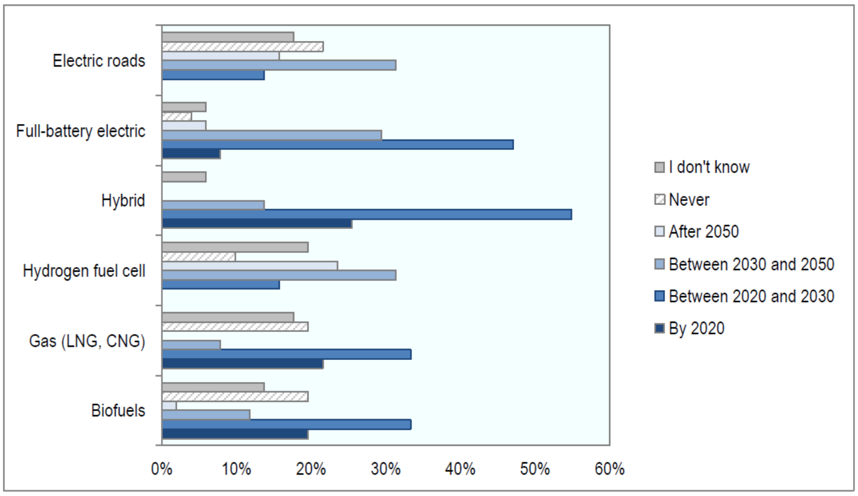
In conclusion there is no single solution that covers all operational aspects (urban, regional and long haul) according to the experts surveyed. Full battery electric is considered the viable option for urban due to smaller vehicles back to base operations and air pollution concerns.



Source: ITF expert opinion survey (2018)

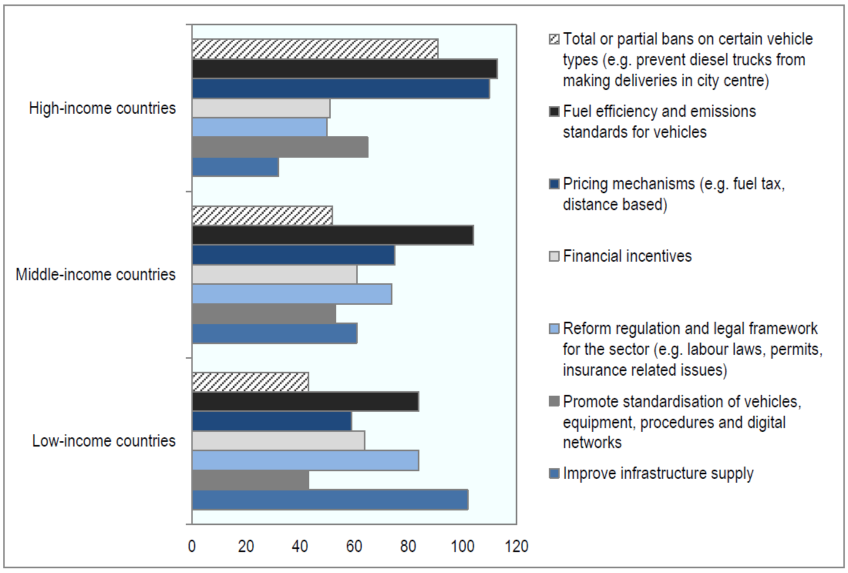
The story is the similar in that the experts surveyed gave differing opinions on the alternative fuels and energy when it comes to long haul operations.

"*Overall there is still a great deal of uncertainty in the widespread use of alternative fuels at a global scale. Exact pathways and alternatives will vary for different regions".*



Source: ITF expert opinion survey (2018)

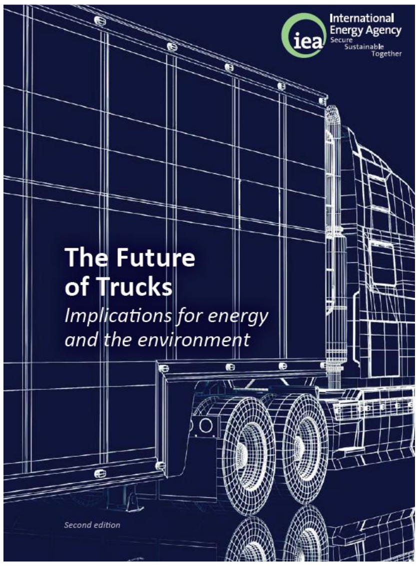
The policy priorities that were picked out by the ITF Expert survey demonstrated the following with respect to high, middle and low income countries, with fuel efficiency and emissions standards being a priority across all countries.



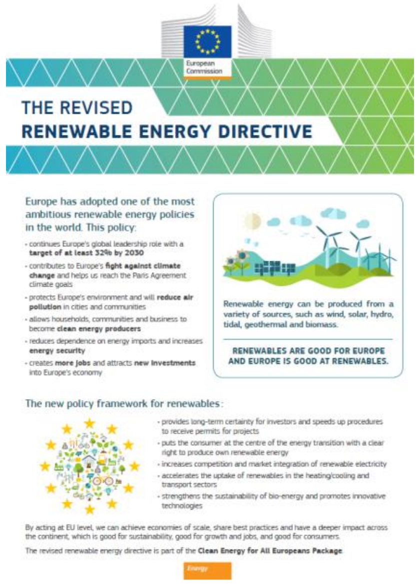
Source: ITF expert opinion survey (2018).

The international Energy Agency published The Future of Trucks report in 2017 and made the following comments on the support needed for low or zero emission fuels in the following areas:

- Research and development
- Market uptake of alternative fuel vehicles
- Adequate access to charging and re-fueling infrastructure
- Availability of alternative energy carriers



In Europe the overriding regulation that involves alternative fuels and its promotion Member States is the EU Renewable Energy Directive (RED). The original renewable energy directive (2009/28/EC) established an overall policy for the production and promotion of energy from renewable sources in the EU. It requires the EU to fulfil at least 20% of its total energy needs with renewables by 2020 – to be achieved through the attainment of individual national targets. All EU countries must also ensure that at least 10% of their transport fuels come from renewable sources by 2020.



In December 2018, the revised renewable energy directive 2018/2001/EU (also termed RED II) entered into force, as part of the Clean energy for all Europeans package, aimed at keeping the EU a global leader in renewables and, more broadly, helping the EU to meet its emissions reduction commitments under the Paris Agreement. The new directive establishes a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible upwards revision by 2023.

Under the new Governance regulation, which is also part of the ‘Clean energy for all Europeans’ package, EU countries are required to draft 10-year National Energy & Climate Plans (NECPs) for 2021-2030, outlining how they will meet the new 2030 targets for renewable energy and for energy efficiency. Member States needed to submit a draft NECP by 31 December 2018 and were required to be ready to submit the final plans to the European Commission by 31 December 2019. Most of the other new elements in the new directive need to be transposed into national law by Member States by 30 June 2021.

The other relevant EU directive is the Fuel Quality Directive (FQD). The Fuel Quality Directive applies to petrol, diesel and biofuels used in road transport and gasoil used in non-road-mobile machinery. The Fuel Quality Directive requires a reduction of the greenhouse gas intensity of transport fuels by a minimum of 6% by 2020. Together with the Renewable Energy Directive, it also regulates the sustainability of biofuels. The greenhouse gas intensity of fuels is calculated on a **life-cycle basis**, covering emissions from extraction, processing and distribution. Emissions reductions are calculated against a 2010 baseline of 94.1 gCO_2e/MJ.

The 6% reduction target is likely to be achieved primarily through:
- the use of biofuels either as blends or B100 in some applications , electricity, less carbon intense fossil fuels, and renewable fuels of non-biological origin (such as e-fuels).
- a reduction of upstream emissions (such as flaring and venting) at the extraction stage of fossil feedstocks.

Council Directive (EU) 2015/652 defines the method to calculate, and the details to report, the greenhouse gas intensity of regulated fuels.

For biofuels to count towards the greenhouse gas emission reduction targets, they must meet certain sustainability criteria to minimize negative impacts in their production phase. Until 31 December 2020, the Fuel Quality Directive and the Renewable Energy Directive set out the following requirements:
- Greenhouse gas emissions from biofuels must be lower than from the fossil fuel they replace – at least 50% (for installations in operation before 5 October 2015) and 60% for installations starting operation after that date.

- The feedstocks for biofuels cannot be sourced from land with high biodiversity or high carbon stock.

The issue of land use change is addressed within the directives as the rising demand for biofuels can displace the production of food and animal feed crops, and induce the conversion of land, such as forests and wetlands, into agricultural land, thus indirectly leading to increased greenhouse gas emissions. These emissions from indirect land use change (ILUC) can significantly reduce or even completely negate the greenhouse gas savings from biofuels.

To account for this, the amount of biofuels produced from cereal and other starch-rich crops, sugars and oil crops and from energy crops grown on agricultural land that can be counted as a sustainable source of renewable energy is limited to 7% of the energy in transport in the Member States in 2020.

4.2 Established fuel emission factor datasets

The production of fuel emission factors is a detailed process that is dependent on the development of comprehensive methodologies that capture the entire process chain from extraction of the fossil fuel, or the agriculture for biofuels through all intermediate processing and distribution stages to the final delivery to the customer.

This section provides an overview of the main fuel emission factor datasets currently available worldwide that are relevant to road freight. It is worth distinguishing between the production of comprehensive databases of emission factors covering the most common production pathways representative of the fuels on or close to market, which is generally done by teams of specialist scientists, and the production of an emission factor for a specific (batch of) fuel which is often under the control of the fuel producer or a third party acting on their behalf, which is clearly a highly targeted effort.

The GLEC Framework contains a short overview of fuel emission factors comprised of the values in the existing EN16258 standard (2011), which are in turn sourced from a JEC 2011 report, and the 2018 GREET emission factors database published by Argonne National Laboratory. (For information on these sources see later the following paragraphs.)

4.2.1 GREET

In the USA the Argonne National Laboratory has for many years been responsible for developing and updating (annually) the GREET emission factor database https://greet.es.anl.gov/, with funding from the US Department of Energy (DOE) Department of Energy Efficiency and Renewable Energy which is used within official US emission calculations. Outputs of the GREET model are used by the USEPA's green freight program (SmartWay), and related legislation e.g. by California Air Resources Board among others. GREET covers not only fuel emission factors, but links through to a consideration of vehicle types and related duty cycles so that the full lifecycle emissions of operations can be assessed in a flexible and complete manner.

The GREET Models provide estimates of "Well to pump" carbon emissions for fuels (GREET Series 1 – Fuel cycle model) and emissions for vehicle life cycle taking into account raw material mining through to vehicle disposal, a "cradle to grave" approach (GREET Series 2 – Vehicle cycle model).

4.2.2 Renewable Energy Directive

Within the EU Renewable Energy Directive (2018) there are published default values for biofuels used within the transport sector that can be used for Member State reporting in response to renewable energy target obligations. The values published for the renewable fuels show variation between the various feedstocks and production processes. The EU RED 2018 includes a mechanism to account for land use change.

4.2.3 National Databases

There are several datasets of fuel emission factors usually compiled and published at a national level. Examples include:

- The UK government (Department for Business Energy and Industrial Strategy [BEIS] and Department for Environment, Farming and Rural Affairs [Defra]) has for many years published a database of TTW and WTT fuel emission factors and associated default emission intensity factors for various means of transportation intended for calculation of emissions in the UK or by UK companies. This dataset has evolved over the years to include developments in alternative fuels including biofuels and CNG/LNG as new data becomes available and methodology develops. As yet there are no values for hydrogen included.
- In France ADEME, the French Ministry for Energy compile a similar dataset to support company emission inventory reporting with a particular focus on GHG emissions from transport services; again alternative fuel emission values are in the development phase.

4.2.4 International Mode-Specific Databases

The global approaches to organization and regulation of maritime shipping and aviation create opportunities for the use of recognized fuel emission factors in these modes (in contrast to modes such as road and rail which are organized and regulated on a more local, often national, level). International bodies such as IMO or ICAO have published fuel emission factors to be used across their global area of responsibility for the small number of fuels that have until now been in common use in these modes: (i.e. HFO, MDO and MGO for international shipping and aviation gasoline and jet kerosene for aviation).

On the plus side international legislation makes it much easier to use a single figure for each of the fuels used in that mode. However, the approach to GHG calculations is not consistent in that the primary emission factors quoted by both ICAO and IMO have been for emissions at point of use only i.e. ignoring upstream emissions.

ICAO is having to address this due to the importance of sustainable aviation fuel as a primary emission reduction mechanism in its future strategy, alongside more efficient aircraft. Its thoroughly researched and peer-reviewed 2019 guidance document into fuel lifecycles eligible for inclusion in the CORSIA program covers the full lifecycle emissions of the possible feedstock and production route combinations and provides a very important reference document as a starting point for the use of fuel emission factors in the aviation sector.

The situation in maritime shipping appears to be very different in that:

- The common denominator for fuel emission factors in IMO documents still appears to be only CO_2 and only at point of use.
- The range of fuels being discussed by maritime industry stakeholders as sustainable alternatives in the medium to long term is highly sector-specific, meaning that the quick fix solution of transferring fuel emission factors from other modes to maritime application is likely to be only partially successful.

4.2.5 JEC

For some time the most notable source of fuel emission factors for use across Europe has been the JEC consortium. The JEC brought together the Joint Research Centre of the European Commission (JRC), the European Council for Automotive R&D of the major European passenger car and commercial vehicle manufacturers (EUCAR) and the R&D division of the European Petroleum Refiners Association (CONCAWE) to produce collectively what were considered to be the definitive set of pan-European fuel emission factors for the most relevant transport fuels from a wide range of feedstocks and processes. They were seen as the definitive source of such information, drawing strength from the broad base of the consortium, depth of the publicly available methodology, and backing from the European Commission. The fuel emission factors included in the EN16258 standard that was accepted as applying to the whole of Europe were sourced from the 2011 report 'JEC Well-to-Wheels Analysis' and have remained unchanged in EN16258 ever since.

As we go to press with this report the JEC has just published its 2020 study, which emphasizies the point that the information available to companies in this area is changing all the time. The previous publication of the JEC dated from 2014 and in the meantime a wide range of new, potential fuels and alternative feedstocks and processes had come to market. This created a problem at the pan-European level because the JEC values were now perceived to be out of date in comparison to other sources that had been produced more recently and which included fuels not covered by the available JEC reports. The result was potential fragmentation and inconsistency through reliance on values that lacked the guarantee of consistent methodology and rigor in the production process.

There was also a vacuum when it came to the newest, potentially disruptive fuels, for which potentially incomplete or false claims could be made, with no official information available that could easily be used to confirm or refute them, or place reasonable bounds on claims according to possible production pathways. Hopefully the new release will allow a more coherent picture to emerge that helps companies progress more easily with beneficial emission reduction projects.

4.2.6 Other sources of emission factors

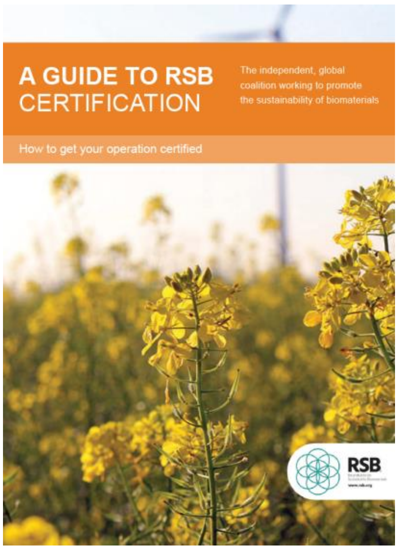
Linked to this last point, liberalization of the wider research market has contributed to a broadening of the number of entities that provide such information, which leads to further market uncertainty and paralysis among the wide range of organizations that are presented with such information when making investment decisions linked to decarbonization. Consultation with a selection of institutes that provide emission factors about their treatment of low emission fuels such as biofuels, electricity and hydrogen resulted in a very limited response, with little information that would help inform a potential end user about how transition fuels are being accommodated within their emission factor datasets. This is not ideal given that trust in the datasets based on transparency and rigor is a key requirement for their subsequent use.

4.3 Emission intensity values

The UK and French databases of fuel emission factors for transport applications are linked to tables of emission intensity values, expressed as CO_2e / tonne-km or CO_2e / passenger-km for different vehicle classes. Other, similar datasets have been developed for use within emission calculation tools such as EcoTransIT, where INFRAS and IFEU combine information from the Handbook of Emission Factors Automotive (HBEFA) to develop default emission intensity factors for road vehicles and other modes of transport. Again development to take into account transition fuels and energy, other than electricity for rail transport is occurring, but still at a relatively early stage.

4.4 Fuel and fuel pathway certification schemes

4.4.1 Roundtable of Sustainable Biomaterials (RSB)

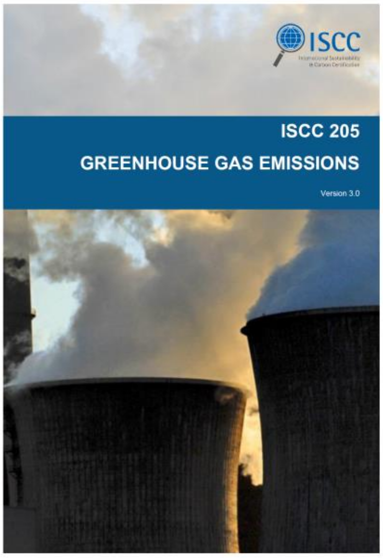


A global voluntary certification scheme that covers the production of any bio-based feedstock, biomass-derived material and any advanced fuel and material, as well as complete supply-chains and novel technologies. Certification can cover biomass or recycled carbon and the production of biofuels such as biodiesel, ethanol, advanced fuels and drop in biofuels.

Fuel suppliers apply to RSB and are audited by an approved auditor before certification is awarded and applications are made available for public comment for 14 days. Biofuels are required to reduce GHG emissions by a minimum of 50% from a fossil fuel baseline. Two standards criteria are offered, namely "Global" and "EU RED" (European Union Renewable Energy Directive); the two differ in the way the critical land use change aspect is addressed. A framework of principles covers not only the GHG emissions aspect but wider resource related and social and economic issues.

The certification revolves more around documented procedures and processes that fuel suppliers have in place rather than published carbon intensity values.

4.4.2 International Sustainability and Carbon Certification (ISCC)



ISCC offer a "globally applicable sustainability certification system and covers all sustainable feedstocks, including agricultural and forestry biomass, circular and bio-based materials and renewables". This scheme has issued over 4000 valid certificates in over 100 countries around the world and covers biofuels, recycled carbon fuels and renewable fuels of non-biological origin (RFNBO), biogas/biomethane and bioliquids and solid biomass.

The scheme complies with the requirements of the EU Renewable Energy Directive (RED) and Fuel Quality Directive (FQD) with standards being developed by consultation. ISCC have recognised certification bodies conducting certification activity and within the GHG emissions calculation methodology there is the ability to use default RED values, disaggregated values or actual values determined using the EU RED methodology. The elements that must be covered are raw material production, processing units and transport and distribution. In order to gain the certification standard for ISCC then the GHG emissions savings need to be 60% and this value has steadily increased from 35% when the scheme first started.

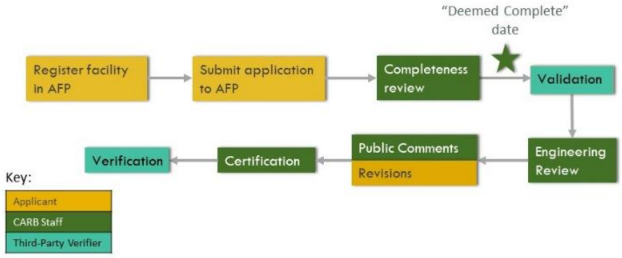
4.4.3 Californian Air Resources Board (CARB) – Low Carbon Fuel Standard (LCFS) Pathway Certified Carbon Intensities

The CARB runs a certification programme for the carbon intensity (CI) of low carbon, alternative fuels. A fuel pathway CI consists of the sum of the greenhouse gases emitted throughout each stage of a fuel's production and use. Carbon intensities of each fuel are listed and are searchable by feedstock, fuel type, classification and facility. The CI is expressed as the amount of life cycle greenhouse gas emissions per unit of fuel energy in grams of carbon dioxide equivalent per megajoule (gCO_2e/MJ). CIs include the direct effects of producing and using this fuel, as well as indirect effects that may be associated with how the fuel affects other products and markets.

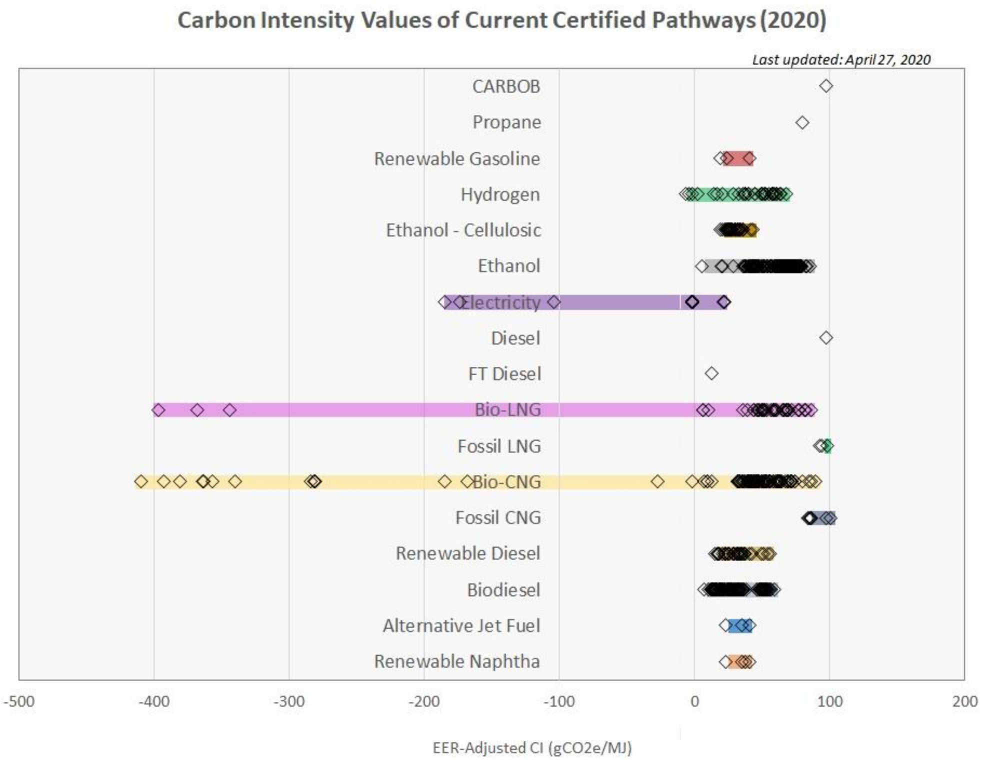
The carbon intensities are derived using the California Greenhouse gases, Regulated Emissions and Energy use in Transportation (CA GREET), a derivative of the Argonne National Laboratory GREET Model.

Within the CARB LCFS, CI values are compared with two baseline fuels namely gasoline and diesel and take into account an Energy Economy Ratio (EER) where low carbon fuels and engines are less energy efficient. There are three levels of certification split as follows:

1. Look up table pathways where there is no need to make an application to the Alternative Fuels Portal but fuel and energy suppliers directly. This approval is limited to diesel, CNG, Propane and California average grid electricity and Smart Charging/Smart Electrolysis.
2. Tier 1 requires an application with supporting evidence to CARB and stipulates the amount of verification data required and involves verification by CARB accredited verifiers.
3. Tier 2 involves added "checks and balances" within the approval process, with engineering review and the inclusion of public comments that need to be assessed by CARB.



The range emission factor values for fuels certified through the CARB LCFS is very wide and shows the importance of truly knowing what fuel you are actually using.



4.5 Research institutions and independent NGOs

There are many reports, studies and articles that cover the benefits and disadvantages of transition fuels within road freight transport. This report is not meant to be a comprehensive review of all studies and reports on low emission fuels used in road freight transport but a selection of examples have been taken to highlight the issues that need to be addressed. Every report adds to the detailed understanding of potential solutions, but at the same time the lack of coordination and often conflicting results leads to a feeling of confusion among users. A lack of consensus about which way is the most appropriate makes the decision making harder and results in a slow uptake of low emission fuels.

One such view has been expressed in Professor David Cebon's blog on whether heavy duty vehicles should be electric or hydrogen. The informative piece can be found here http://www.csrf.ac.uk/2020/02/blog-long-haul-lorries-powered-by-hydrogen-or-electricity/

Other respected NGOs such as Transport and Environment (TE) and the International Council for Clean Transportation (ICCT) regularly issue reports, papers and articles that inform and sometimes counter the current policy direction, particularly focusing on the life cycle impacts of fuels such as natural gas and electricity to ensure a full system approach is taken.

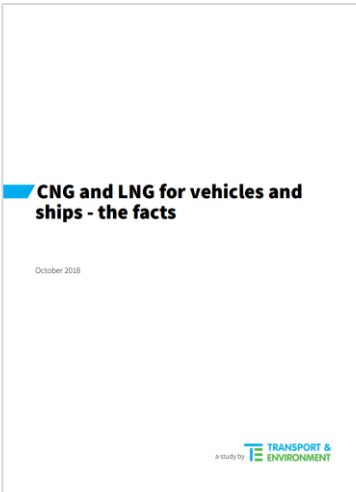
Examples of Transport and Environment publications

- LNG in Trucks and Ships
- Freight Roadmap

Examples of ICCT publications in the scope of this project include

- Beyond Biomass
- Decarbonization of on-road freight transport and the role of LNG from a German perspective
- LNG trucks: A bridge to nowhere
- Renewable gas is a distraction for Europe

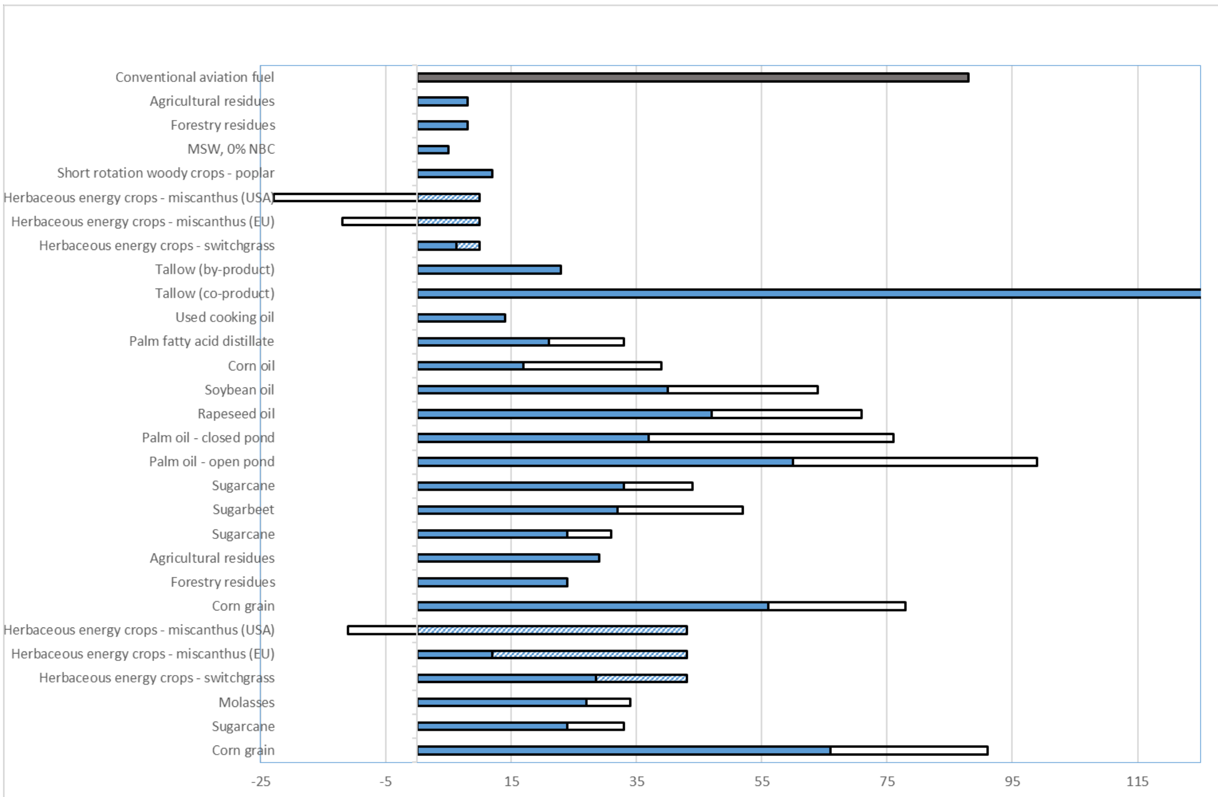
The Energy Transitions Commission (ETC) recently released the report Making Mission Possible – Delivering a Net-Zero Economy, to show clean electrification as the primary route to decarbonisation, complemented by hydrogen, sustainable biomass and fossil fuels combined with carbon capture. Road freight, an in particular heavy trucking, is covered.



4.6 CORSIA for aviation fuels

An example of a transport sector addressing the need to evaluate and publish GHG emissions intensity values from alternative fuels is the aviation sector's International Civil Aviation Organisation (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The purpose is to determine the GHG reductions achieved by deploying Sustainable Aviation Fuel (SAF) as part of an aircraft operators offsetting obligations. The framework recognizes low emissions fuel pathways, a methodology to account for various fuel pathway elements including setting system boundaries, feedstocks, production processes and induced land use change (ILUC)[4]. Where this approach is in some respects exemplary is that the industry has agreed the approach to SAF with peer review and industry "buy-in". The aviation sector benefits from the global nature of the mode and the level of regulation applied to aircraft operators meaning regional and national level differences have less affect when compared to the road sector with far fewer operators and in some case national operators.

The following represents the fuel pathways and GHG impact with data extracted from the CORSIA documentation.



Source: Alan Lewis, Smart Freight Centre, based on CORSIA Eligible Fuels – Life Cycle Assessment Methodology

This approach would potentially be very useful for low emission fuels within the road freight sector, although regional coordination and priorities would present a challenge to a consistent outcome. Such a project, or programme of connected projects, would need to include transport providers, buyers, fuel and vehicle providers, governments and industry associations.

[4] It should be noted that CORSIA is geared towards the offsetting principle where offsetting is used to negate the unavoidable GHG emissions from operations. Offsetting should be the last resort after exploring all other options of energy efficiency improvements and use of lower carbon fuels. Also the offsetting schemes need to have robust and verifiable outcomes to fully account for the offset cost.

5. Industry experience and perspectives

This section of the report covers current road freight industry experiences, the challenges faced with emission factor inconsistency and some examples of low emission road freight trials. GLEC partners were interviewed to obtain their perspectives on the issues faced and some proposed actions to help overcome the barriers that limit the adoption of low emission fuels and vehicles.

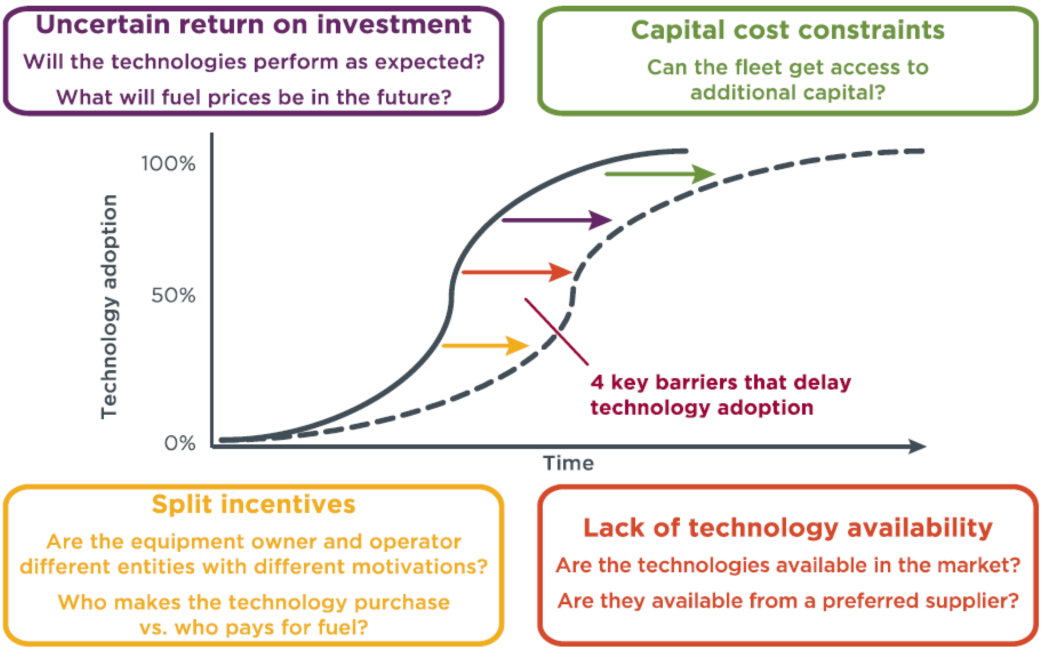
5.1 End user experiences and operational evaluation projects

The diagram below taken from the ITF Report ***Towards Road Freight Decarbonization – Trends, Measures and Policies*** illustrates the barriers encountered in the adoption of fuel saving technology in the trucking sector.

The business case is key in getting fuel and GHG reduction measures implemented, with fuel costs making up a third of an operator's costs it would seem that implementing low emissions fuels and fuel reduction technology would be logical and incentivized. However, many truck operators are small medium enterprises (SMEs) and can struggle to afford the upfront costs even if there is a total cost of ownership saving. A number of factors also contribute the slow uptake of technology:

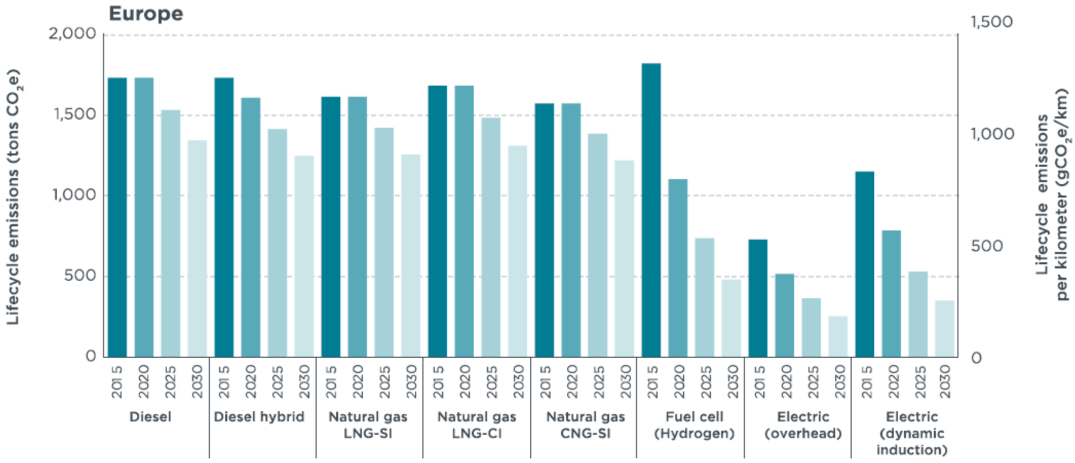
- Uncertainty on whether the benefits of an alternative fuel or technology will be realized
- Access to the capital to cover the upfront costs
- Split incentives where equipment owner and operator are different entities and who pays for the fuel, infrastructure or additional technology
- Availability of the low emission fuel or technology.

All these factors play a part in the rate of adoption and are illustrated in the graph below.



Source: Sharpe (2017).

The graph below collated by the ITF projects a view on the anticipated progress of low emission technologies from 2015 through to 2030 with 5 year intervals in terms of life cycle GHG emissions and GHG emissions per kilometer.



Source: Moultak, Lutsey, Beijing, Berlin, and Brussels (2017).

This suggests that diesel, diesel hybrid, LNG (SI), LNG (CI) and CNG (SI) will each show a progress reduction in emissions but all at fairly similar levels. Hydrogen fuel cell starts with very high emissions but decreases rapidly, electric (overhead) has the lowest starting point and progressively reduces to the lowest life cycle and GHG intensity of all options studied.

5.2 Emission factor challenges

Because transition fuels come in a much wider range of forms, with a range of conventional and biogenic feedstocks and a much wider range of production processes, there is a much greater challenge associated with applying the appropriate emission factor to the fuel being used. This is further complicated by the potentially higher proportion of life cycle emissions that originate in the fuel processing phase compared to conventional fuels, as these are heavily influenced by the source of the energy (particularly the electricity) used, which can itself vary enormously.

This presents a challenge in terms of which emission factor to use from the range that can legitimately apply to the fuel being used, and places a clear requirement for fuel tracking and certification schemes to be introduced as soon as possible if the potential emission savings are to be realized and accurately quantified.

5.3 Low emissions fuel trials

There are a number of alternative fuel vehicle trials taking place within operational situations. One example is the UK **Low Emission Freight Trials (LEFT) Programme** funded by the UK Department for Transport (via Innovate UK)**.** This programme of projects covered a number of low emission fuels within various operations from general road haulage to parcel delivery services. Project details are outlined below. The summary reports, made available in September 2020 with stakeholder dissemination webinars, will give an overview of GHG emissions impact on a well to wheel basis for each technology, the benefits realized and issues encountered. The hope is that these outcomes can be included before final publication of this report.

- A number of consortia were formed between technology providers and operators to trial technology in real world operations.
- Transport Research Laboratory (TRL) and the Low Carbon Vehicle Partnership were chosen to assess the data from the trials.
- There are two parts to each trial, a laboratory and track based emissions testing programme for each technology and the real world operations assessment.
- The following projects have been funded
  - Natural Gas Trucks
    - CNG Fuels
    - Air Liquide Groupe
    - G-volution PLC
    - Kuehne+Nagel – Dedicated and dual fuel
  - Electric vehicles
    - Gnewt Cargo – Electric vans in courier delivery services
    - Tevva Motors – Series Hybrid
    - UPS – package and parcel delivery services
    - Kuehne+Nagel – Magtec, Tevva and Dearman trialing full electric and range extended electric refrigerated trucks and also trialing zero emission liquid nitrogen refrigeration units.
    - Magnomatics Limited – Plug in hybrid electric truck
  - Hydrogen
    - ULEMCo – hydrogen dual fuel trucks
  - Other technologies
    - Lawrence David Limited – Lightweight trailers
    - Howden’s Joinery Group – Kinetic energy recovery systems

The LEFT programme described above is just one example of the many such projects taking place across Europe and worldwide; other examples include the Swiss Energy (BFE) collaborative hydrogen fuel cell vehicles in freight transport and battery electric trucks project.

5.4 GLEC partner interviews

The following GLEC Partners took part in interviews to gauge the take up and experiences with low emission fuels: IKEA, Heineken, Deutsche Post DHL, VW, PepsiCo and BDP
For each low emission fuel or energy carrier the GLEC partner gave their experience and some of the challenges faced; some referred to their own fleet experiences or the related challenges faced by their carriers.

5.4.1 Common themes across all fuels

General issues

- Operators and shippers would benefit from a more structured and robust certification of low emission fuels as understanding and trusting the claims of fuel suppliers and providers is difficult and time consuming to verify. Standards are not currently implemented on GHG intensity of low emission fuels.
- An understanding of whether a specific technology is a transition fuel or the end goal can lead to a "wait and see" situation.
- There are no set processes in place within companies that assess the alternative technologies and their associated business cases that then link to company strategies and sustainability policy.
- Lack of a transparent pricing basis when compared to diesel - the crude oil price is a uniform basis for assessing costs which is not currently the case for alternative fuels.
- Companies can sometimes have a lack of consensus internally due to either lack of information or too much conflicting information on which to base decisions.
- A number of multinational shippers and LSPs deploy a hierarchy of modal shift, then sustainable biofuel, then natural gas and then fossil diesel in their procurement strategies. Fossil based transport service providers are not eliminated from procurement if they can demonstrate a plan to change. This may mean longer term contracts are issued for transport services.

GHG calculation issues

- There is a general perception that emission factors for road freight transition fuels are inconsistent and non-comparable; there can be a lot of information that needs to be assessed in order to come towards a calculation that can be trusted.

Technology, infrastructure and policy issues

- Cost comparisons between the alternative fuel technologies are difficult, with uncertainty about vehicle purchase cost, maintenance costs and vehicle residual values. This is made even harder by the investment needed in re-fueling or charging infrastructure.
- Risks associated with infrastructure investment if implementing at a depot/back to base operation or being able to operate a truck for its anticipated service life, the concept of a stranded asset is a concern.
- The policy, subsidy and taxation landscape for low emission fuels is unclear with regulation and legislation varying between regions and countries making decisions for cross-border operations challenging. A need for pragmatic policymaking that helps the take up of low emission fuels, for example vehicle load regulations to take into account the additional weight associated with alternative technologies where applicable e.g. batteries or (bio)LNG tanks
- The need to involve an extended stakeholder base to include stakeholders such fuel suppliers, infrastructure providers and local authorities is a challenge for low emission fuels compared to a business as usual scenario.

5.4.2 Suggestions to help overcome the barriers

General issues

- Clear approach to biofuel feedstocks and land use change
- Good examples and clear business cases presented in a format that helps understanding, possibly a depository of easily accessible information held by a trusted independent authority.

GHG calculation issues

- Collaboration project in generating consistent and comparable emission factors for low emission fuels with a robust and transparent mechanism for their generation

Technology, infrastructure and policy issues

- Ability to form consortium to trial low emission fuels and create demand for both fuel and vehicles;
- Clear policy consensus across countries and approaches to subsidy to kick start market and improve vehicle availability combined with the ability to inform policymakers but is not considered lobbying;
- Operator and OEM collaborations in order to understand operational constraints, how to assess them and stimulate innovation to bring the vehicles to the market quicker;
- The ability to form collaborations that are not considered a breach of anti-trust laws or seen as cartel forming.

6. Total Emissions of Ownership Models

6.1 Total Emissions of Ownership (TEO) concept

The concept of Total Emissions of Ownership (TEO) is intended to accompany that of Total Cost of Ownership (TCO), which has been developed and applied in recent years to provide a longer-term view of decisions relevant to investment in innovative vehicle technologies. TCO models achieve this by establishing a full, comparative picture of the costs associated with purchasing and operating conventionally and alternatively fueled vehicles over their full lifetime.

Following best practice in GHG emission accounting, the TEO should include both upstream (well to tank) and point of use (tank to wheel) emissions so that full impact of operational decisions ae considered at the system level. As an accompaniment to a TCO calculation, the TEO value provides an assessment of the GHG emissions associated with the full lifetime of the vehicle. The aim is to go beyond using the emission factor values for fuels at the time of purchase of a vehicle, and instead provide a harmonized framework by which the likely trends in emission profiles over the course of a vehicle's lifetime can be considered in advance.

At the current time the TEO only considers the operational phase, and so does not include vehicle production or dismantling, nor any emissions associated with the required transportation infrastructure. This is in line with common practice in operational emission accounting; however, in future it may be possible to incorporate the emissions linked to vehicle production or dismantling as a future development.

At point of inception the primary idea of the TEO was to consider the likely further decarbonization of the electricity sector, following the trend of recent years, so that this could be factored into purchasing decisions at the earliest possible opportunity; however, for a fair comparison the potential to include decarbonization of fuels, and the fuel choices available to users of conventional liquid and gas-fueled vehicles, has also been considered.

Consideration has also been given to how knowledge of the total emissions of ownership could be used to build a link between possible costs of carbon pricing and the costs within a TCO tool. Development of a TCO model was outside the scope of this work, but input from the developers of various TCO models has been sought during the duration of the project.

TCO models work by considering the full range of costs from both the purchase and operation phase for the estimated lifetime of a particular vehicle, taking into account its likely operating cycle. Exact specifications vary, but in general input parameters might include:

- Purchase / lease cost
- Current fuel cost and future fuel cost profile
- Expected fuel use linked to expected operating cycle
- Wage costs
- Maintenance and insurance costs
- In house fueling equipment (if applicable)
- Residual value

Outputs such as total lifetime vehicle cost, and efficiency indicators such as cost per km and cost per tonne-km, could be expected, as well as cost-time profiles that indicate how quickly upfront investment costs may be offset by decreased operating costs. This latter approach requires some form or year-by-year consideration of the expected costs, which lends itself to a similar approach being taken in the accompanying TEO assessment. Inevitably, because this process is considering future events, there is an element of uncertainty in how this can be considered to a reasonable level of accuracy both for the TCO inputs as well as for the emissions. Factors that could influence the absolute costs / emissions and hence any comparative assessment include the speed of technical developments, market factors and the impact of future policies that are currently unknown or unconfirmed. As a result, it is important to ensure a level of flexibility in the approach taken to considering future events. Rather than attempting to model the unknown a scenario-based approach feels more appropriate.

6.2 Proposed TEO approach

The situation regarding possible future development of future emission pathways may be considered as similar to the financial investment sector, where past performance cannot be taken as a guarantee of what the future will look like, but does give a general indication of the likely medium- to long-term trends. In order to address this, many financial regulators have introduced a harmonized approach by which investment companies must project expected returns to potential investors according to conservative, moderate and ambitious scenarios (where conservative < moderate < ambitious in terms of the annual percentage reduction achieved). The return rates for these scenarios are fixed by the regulator to avoid individual companies making over ambitious or unsubstantiated claims and to give the investor both a clear sense of the uncertainty that comes with their investment at point of purchase and a comparable basis for the returns expected from their investment.

Extending this analogy, this approach could also be applied by financial institutions being asked to invest in the decarbonization potential of future projects. We propose to take a similar approach when considering the emissions associated with future electricity generation, i.e. working with conservative, moderate and ambitious scenarios.

6.2.1 What reduction percentages can be achieved?

Over the past years the GHG emissions from electricity generation and distribution have decreased significantly, although the decrease has not been consistent year on year, nor consistent between countries. The UK is an example of a country that has shown a significant reduction in electricity generation emissions; Figure 1 shows the changes between 2010 and 2019.

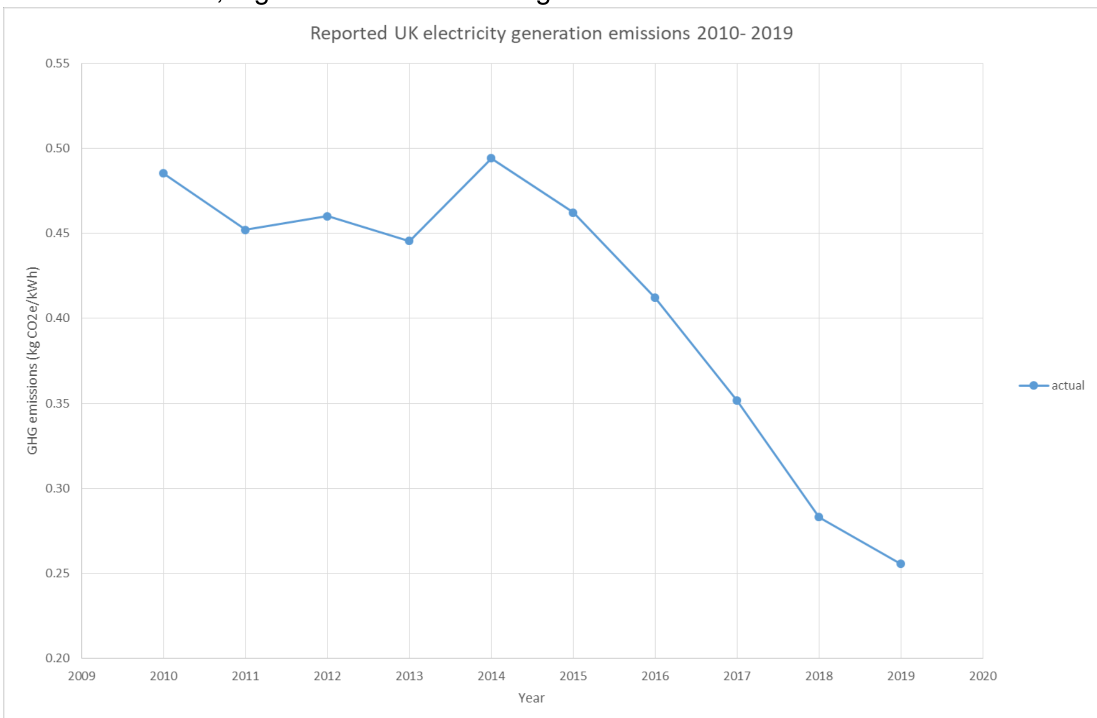


Figure 1. Reported UK electricity generation emissions 2010-2019 (Source: UK Defra / BEIS conversion factors)

Figure 2 shows a range of possible ways in which this specific observed reduction could be represented, based only on the UK data, in terms of an annual percentage reduction, based on conservative, moderate and ambitious scenarios, recognizing that in reality it is not a smooth transition:

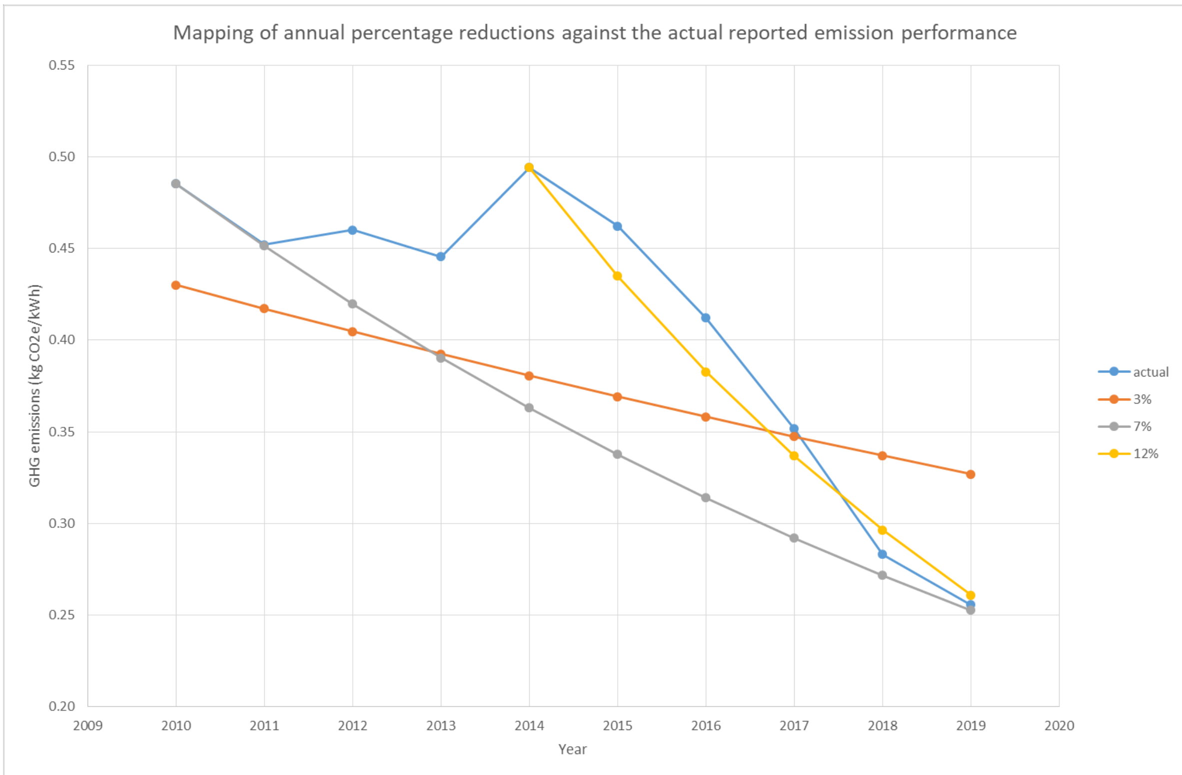


Figure 2. Mapping of annual percentage reductions against actual reported emission performance 2010-2019

- Conservative (3% p.a.): this approaches a mathematical correlation curve for the dataset as a whole, smoothing out the year-on-year variations and underestimating the actual transformation between 2010 and 2019;
- Moderate: this takes the 2010 start point and 2019 end point as fixed and imposes a steady annual percentage reduction;
- Ambitious: effectively this splits the dataset into two, considering the first 5 years as level and then applies a steeper annual reduction percentage for the period 2014 to 2019.

In practice it is likely that none of these scenarios is entirely correct, particularly as there appears to be a step change in the emission intensity value trend in the middle of the timeframe; hence showing the range can give an indication of the extent of variability.
If these trends are projected forward they indicate a widely varying trend, as shown in Figure 3, with the common characteristic that they all tend towards zero in the long term, just at very different rates. Clearly the rate at which (close to) zero emission electricity is reached will significantly influence the TEO and the associated emission benefit of choosing an electric vehicle at an early stage.

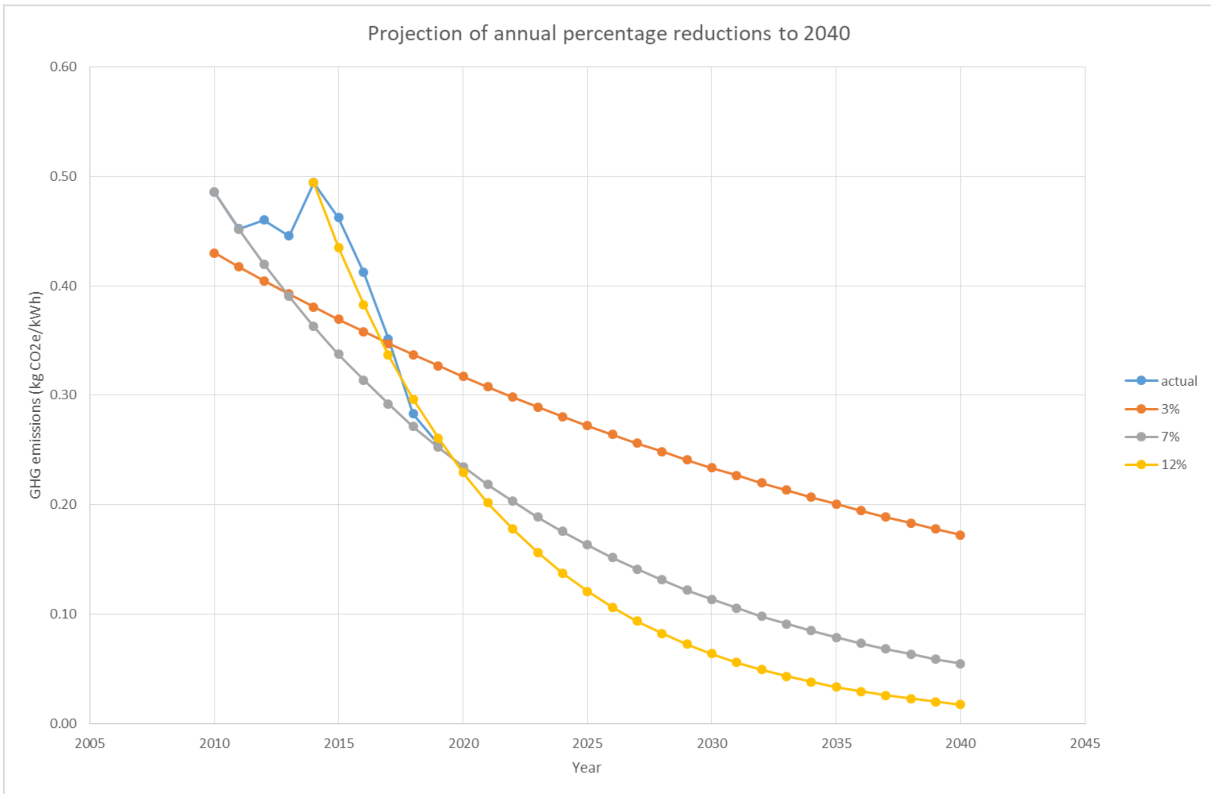


Figure 3. Projection of UK annual percentage reduction scenarios to 2040

Continuing with the UK example, it is not possible for us to state conclusively whether this trend is likely to continue according to any of the individual scenarios, although UK government projections do appear to closely match the 12% annual reduction scenario. In practice the observed progression is likely to continue to show variability due to a convergence of external factors.

What is important in respect of this work is to confirm whether the principle used in this approach is a valid way to think about future development of electricity generation emissions and how that can be reflected in a TEO approach for electric vehicles.

6.2.2 What reduction percentages could be applied?

In practice it seems likely that the development of UK electricity emissions over the past decade is a more positive example than many; hence, we have adopted a more cautious set of scenarios in the following examples, based on annual reduction values of 1.5, 4 and 7% for the conservative, moderate and ambitious scenarios respectively. These could easily be adapted if required and it would be worth having experts in energy policy and electricity generation refine these scenarios to values that are appropriate to each national context while maintaining the principle.

Figure 4 shows the effect of these scenarios from 4 starting points for electricity emission values that have been taken to represent:

- close to full renewable energy (e.g. 30 g CO_2e/kWh)
- a country already well along the low carbon transition (e.g. 200 g CO_2e/kWh)
- a typical European country (e.g. 320 g CO_2e/kWh), and
- a country that is lagging in the low carbon transition (e.g. 500 g CO_2e/kWh)

For the higher starting points figure 4 clearly shows that the level of ambition has a significant impact on the short- to medium-term outcome as this is where there is most to gain, as evidenced by the UK's actual data as a concrete example.

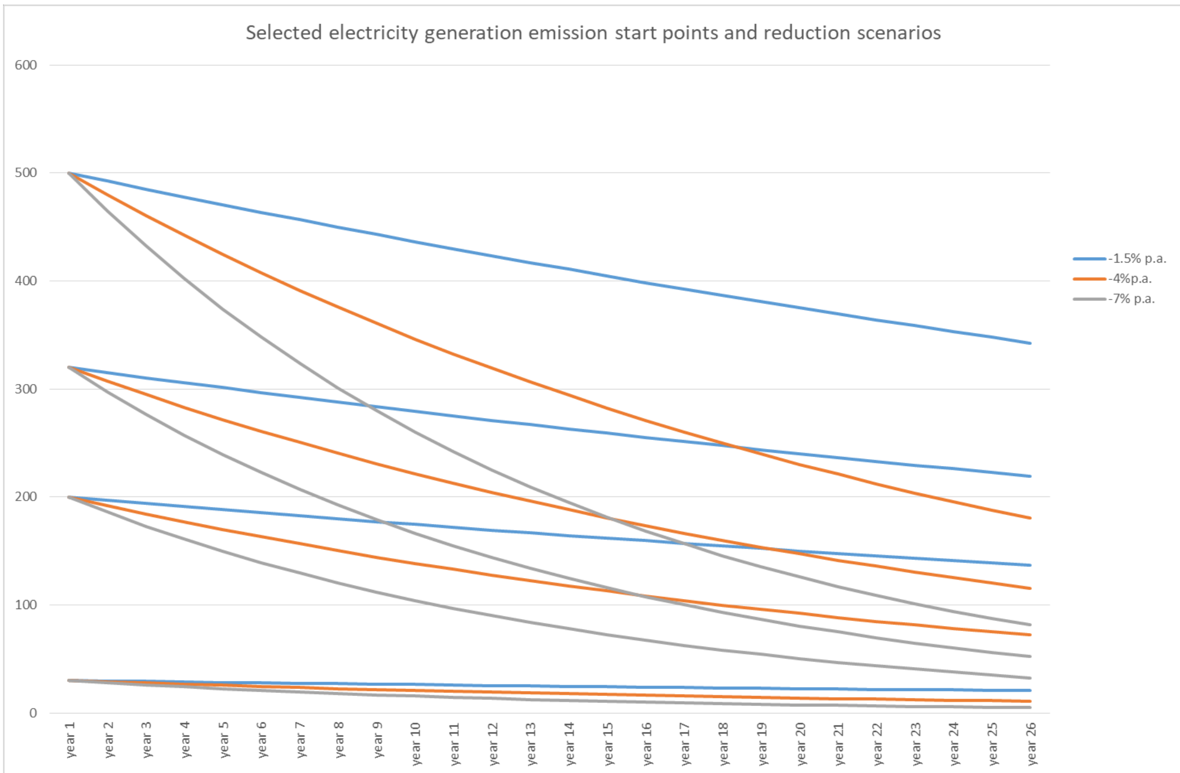


Figure 4. Application of annual percentage reduction scenarios to a selection of possible emission intensity starting points.

Implementation of TEO for electricity use

The way that this is implemented in a TCO model would depend on the way in which the model is structured. Our current research suggests two common approaches:

- use of a constant emission factor alongside constant operational costs for each year in the life of a vehicle
- use of a more disaggregated approach where each parameter, including distance travelled (as newer vehicles join a fleet and are used preferentially) can be varied for each year of a vehicle's life.

In the former case, it would be possible to choose the scenario (conservative, moderate or ambitious) and calculate the average emission factor to apply across the lifetime of the vehicle in each case. In the latter, it would just be a case of tabulating the year on year variation. See Table 1 for an example using 320 gCO_2e / kWh as the starting point and an estimated 10 year vehicle lifetime.

Table 1. Amount of CO_2e per kWh over time under different scenarios

					gCO_2e/kWh							
	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10	Average	
Conservative	320	315.2	310.5	305.8	301.2	296.7	292.3	287.9	283.6	279.3	299.2	-6%
Moderate	320	307.2	294.9	283.1	271.8	260.9	250.5	240.5	230.8	221.6	268.1	-16%
Ambitious	320	297.6	276.8	257.4	239.4	222.6	207.0	192.5	179.1	166.5	235.9	-26%

Whilst either approach to TCO modelling should provide the same answers, there is potential benefit in the additional transparency of setting out the annual data in full. By taking this approach it is easier to see how the total emissions from a vehicle evolve year on year and provides greater flexibility to apply interventions at particular points of a vehicle's lifetime. For example, this would be beneficial if making a link to carbon pricing, particularly if the indicative cost of carbon were set to change periodically during the life of a vehicle.

Both elements are shown in the next tables. In Table 2 shows the estimated emissions from a 7.5T electric vehicle operating 20000 km per year from a starting point of 320 gCO_2e / kWh, (this time over 12 years to show flexibility of the TEO approach). It can be seen that, compared to a constant electricity emission factor, the ambitious scenario gives an average 31% reduction in emissions, whilst in the final year the emissions are less than half those in the initial year (-55%).

Table 2. Full fuel cycle (WTW) CO_2e emissions for an electric truck under different emission reduction scenarios and a starting point of 320 gCO_2e / kWh

								WTW kg CO_2e								
Truck type:	year:	1	2	3	4	5	6	7	8	9	10	11	12	Total		Cumulative Emission Reduction (kg CO_2e)
7.5t truck	No change	4853	4853	4853	4853	4853	4853	4853	4853	4853	4853	4853	4853	58240	0%	0
average load	Conservative	4853	4781	4709	4638	4569	4500	4433	4366	4301	4236	4173	4110	53668	-8%	4572
	Moderate	4853	4659	4473	4294	4122	3957	3799	3647	3501	3361	3227	3098	46991	-19%	11249
	Ambitious	4853	4514	4198	3904	3631	3376	3140	2920	2716	2526	2349	2185	40311	-31%	17929

Table 3 shows that the emission figures from Table 2 are easily converted into a notional carbon price of operation. All values are notional, but this does show the financial benefit that would accrue to an electric vehicle operator through decarbonization of the electricity sector during the course of the vehicle's life, especially in a scenario where the carbon price is increasing as the electricity is decarbonized (as indicated from years 6 and 11 in the example).

Table 3. Carbon price per tonne CO_2e emissions for a 7.5t electric truck under different emission reduction scenarios and a starting point of 320 gCO_2e / kWh

						Carbon price, $/tonne								
	10	10	10	10	10	25	25	25	25	25	40	40	Total	
No change	$49	$49	$49	$49	$49	$121	$121	$121	$121	$121	$194	$194	$1,238	0%
Conservative	$49	$48	$47	$46	$46	$113	$111	$109	$108	$106	$167	$164	$1,113	-10%
Moderate	$49	$47	$45	$43	$41	$99	$95	$91	$88	$84	$129	$124	$934	-25%
Ambitious	$49	$45	$42	$39	$36	$84	$79	$73	$68	$63	$94	$87	$759	-39%

Values for the other emission intensity starting points from Figure 4 are provided in Annex A.

Implementation of TEO concept for other fuels

For a conventionally fueled vehicle it is possible to follow a similar approach of establishing the annual fuel use and then calculating the associated emissions. This allows a year-on-year assessment of the impacts of any emission reduction measures as well as the potential to assess the impact of the same carbon price evolution scenario as for the EV in section 4.

Emission reduction actions for a conventionally fueled can be gradual, for example a general stepped increase in the blend of biofuel in the standard mix, or more interventionist, for example a change to a higher biofuel blend by a specific company or even a change to a completely different fuel.

Table 4 shows examples of these two types of intervention for the case of a 7.5t gross weight vehicle operating 20,000 km per year. The baseline is standard pump biodiesel blend (B5).

The comparative impact of two interventions is then shown: a general increase in pump biodiesel content from 5 to 10% (B5 to B10) at start of year 5 a subsequent switch at start of year 7 for this individual vehicle from B10 to pure biodiesel (B100).

Table 4. Full fuel cycle (WTW) CO_2e emissions for a truck type over time under three scenarios

								WTW kg CO_2e								
Truck type:	year: intervention	1	2	3	4	5	6	7	8	9	10	11	12	Total		Cumulative Emission Reduction (kg CO_2e)
7.5t truck	Stable pump blend (B5)	8715	8715	8715	8715	8715	8715	8715	8715	8715	8715	8715	8715	104580	0%	0
average load	Higher blend (B10) from year 5	8715	8715	8715	8715	8559	8559	8559	8559	8559	8559	8559	8559	103330	-1%	1250
	B10 from year 5 and pure biodiesel (B100) from year 7	8715	8715	8715	8715	8559	8559	5745	5745	5745	5745	5745	5745	86448	-17%	18132
								Carbon price, $/tonne								
		10	10	10	10	10	25	25	25	25	25	40	40	Total		
	Stable pump blend (B5)	$87	$87	$87	$87	$87	$218	$218	$218	$218	$218	$349	$349	$2,222	0%	
	Higher blend (B10) from year 5	$87	$87	$87	$87	$86	$214	$214	$214	$214	$214	$342	$342	$2,189	-2%	
	B10 from year 5 and pure biodiesel (B100) from year 7	$87	$87	$87	$87	$86	$214	$144	$144	$144	$144	$230	$230	$1,682	-24%	

The scenarios are easy to model and would follow naturally from modelling the TCO of these possible interventions, as long as the necessary emission factors for biodiesel blends are available.

Table 4 shows that the implementation of a small increase in biofuel blend has minimal impact on emissions for an individual vehicle, which is not surprising, as this type of intervention is designed to have a large cumulative effect over the whole vehicle parc, where a noticeable emission reduction comes from small impact at maximum scale.

In contrast, shifting to pure biodiesel is shown to have step change reduction in emissions for this vehicle, although well to wheel emissions for the years after the change are only reduced by 34% compared to the starting point and are still higher than the EV with electricity emission factor of 320 gCO_2e / kWh (see Table 2).

Comparison between EV and diesel / biodiesel scenarios

The primary purpose of this task was to examine the development and application of the TEO concept for electric vehicles. However, having applied a comparable approach to a conventionally fueled vehicle it is possible to make some comparisons regarding the relative emissions from these energy sources.

Comparison between the EV and biofuel examples above is instructive in that, at 58,240 kg CO2e, the TEO of the 7.5t electric vehicle, with a stable electricity emission factor of 320 gCO2e / kWh, is 46,340 kg lower, or 56% of, the TEO of a diesel vehicle operating with 5% biodiesel over the same period.

Putting that comparison another way, the electricity emission factor would need to be greater than 575 gCO2e / kWh to favor the diesel vehicle operating with 5% biodiesel on a purely TEO basis.

The maximum emission reduction for this biodiesel, i.e. operating using B100 for the full lifetime, is 34%, which would give a TEO value of 68,942 kg CO2e, which is equivalent to an electricity emission factor of 379 gCO2e / kWh.

For the (arbitrary, notional, and relatively low) carbon price values used in the study, there is a noticeable differential in favor of the EV, particularly for the later years when the carbon price is higher and the electricity emissions have had maximum chance to decrease. For a vehicle of this size it would be expected that this level of differential might amount to around 1-2% of TCO and could be enough to shift the balance from purchase of a conventional vehicle to an EV. Repeating for a 12t vehicle gave very similar results, with the carbon price benefit being marginally higher at 2-3%.

7. Recommendations

The following is an initial set of proposals for further areas of research and implementation that can be considered as part of phase 2 of the GLEC project and work by others.

7.1 Improving emission calculations

Companies find it challenging to calculate emissions from low emission (transition) fuels and electric vehicles that take into account the full fuel life cycle, also called 'well-to-wheel'. Reasons vary but it all comes down to the need for a common approach and support systems for emission calculations.

7.1.1 General Areas for further research and guidance development

Key recommendations for further research and guidance development to improve reliability and trust in reported emissions are:

- Develop reporting standards for low emission fuel/energy suppliers to enable fair comparisons between conventional fuels and low emission alternatives
- Compare existing emission certification schemes and develop common, consistent protocols
  - Investigate the low emission fuel certification protocols that will help fuel pathways to be compared in a consistent manner, covering all fuels and energy carriers and understand the requirements needed for industry acceptance. The principle of endorsed by industry and accepted by operators.
  - A project to assess the differences between low carbon fuel pathway certification schemes and programs would help benefit comparability and understand the standards and verification processes involved.
- Establish a mechanism for regular/ongoing updates of emission factors for transition fuels that consider the full fuel life cycle. This consistent set of emission factors should be freely available, easy to use and updated within an appropriate timeframe.
- Develop a protocol and guidance for trials/pilots of transition fuels and electric vehicles to capture data and emission calculations in a consistent manner, to be fed back into emission intensity datasets that are kept by established research and other organizations and used for policy and other 'official' purposes.

7.1.2 Application of TEO concept to emission calculations

A key recommendations is to apply the 'Total Emissions of Ownership' (TEO) concept to emission calculations associated with vehicle purchase decisions. Main considerations are explained below.

Links to TCO modelling

Feedback from a small number of Total Cost of Ownership (TCO) model developers has been received that the approach presented in the report does fit with the approach taken in their TCO models, both in terms of the electricity scenarios and also incorporation of flexible approach to the use of drop-in fuels in internal combustion engines. However, as yet there is no indication from the TCO developers consulted that they are actively considering inclusion of carbon pricing to their TCO calculation, but this enhancement would facilitate this additional step.

It would be worth checking these points with a wider range of TCO model developers to ensure consistency and to promote uptake of the Total Emissions of Ownership (TEO) approach in general and incorporation of the link to carbon pricing, or shadow carbon pricing as a first step.

Feedback from a wider group of experts in energy policy and electricity generation would be useful to refine these scenarios to values that are appropriate to cover the common range of national contexts.

Supporting company emission calculations
The TEO concept has been framed in the context of TCO because costs are a key determinant of the decisions to progress or not with the decision to purchase an innovative fuel or vehicle.

However, the TEO calculation can also be carried out on its own in order to assess the potential benefits that can be expected from switching. The required dataset consists of information about transport activity and the related vehicle operations, preferably to a good level of detail and with primary data available as the starting point for the current vehicle, fuel, and transport activity. Although primarily aimed at the vehicle operator, the TEO calculation can also be beneficial for transport buyers, particularly those who work in close partnership with specific transport operators on FTL or long-term contracts.

Full technology life cycle
Further research is recommended into emissions from both vehicle production and dismantling as well as the required transportation infrastructure, to give a full technology life cycle picture.

At the current time the TEO only considers the operational phase, including upstream fuel cycle emissions, and so does not include vehicle production or dismantling, nor any emissions associated with the required transportation infrastructure. This is in line with common practice in operational emission accounting; however, the emissions linked to the operational phase form part of and contribute substantially to the fuller product lifecycle emissions. Interest is growing to link the operational emissions with those from vehicle production or dismantling so that LCA analyses can assess the full lifecycle impact in a single analysis and subsequently be linked to promotion of circular economy scenarios. This would also necessitate the development and inclusion of feedback loops in the LCA calculations, as improvements in the embedded emissions of the vehicles would reduce the impact of the transportation that is hidden within the supply chain. Although only a secondary effect it should not be ignored, especially as the supply chain impacts of investing in the infrastructure needed for a low carbon future are expected to be significant and easily neglected.

7.1 Uptake of low emission fuels or electric vehicles

Companies find it challenging to start using low emission fuels or electric vehicles in practice. Cited reasons are lack of coordination and collaboration, vested interests and hidden agendas, and inconsistent policies. Other concerns include the availability of feedstocks for biofuels, the energy efficiency or losses around hydrogen supply, practicality of battery electric vehicles, upfront costs of battery or hydrogen fuel cell vehicles, and re-fueling infrastructure.

Key recommendations to accelerate uptake are:

- Collate trials and pilots that are taking place, starting with those across Europe, and summarize the costs and benefits realized by operators and shippers
- Develop mechanisms that can help consortium building of different stakeholders for collaborative projects on low emission fuels and electric vehicles
- Develop mechanisms for cross-border collaboration that removes the barriers due to differing policy and lack of consensus. This can cover mechanisms to deploy infrastructure and aim to eliminate the risk of “stranded assets.
- Consult with a wide range of TCO model developers to promote incorporation of the TEO approach and the link to carbon pricing, or shadow carbon.

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Annexes

Annex A - TEO Full data for the range of EV scenarios

The following tables provide the full range of TEO scenario outputs for the EVs used in the analysis.

								WTW kg CO_2e								
Truck type:	year:	1	2	3	4	5	6	7	8	9	10	11	12	Total		Cumulative Emission Reduction (kg CO_2e)
7.5t truck	No change	455	455	455	455	455	455	455	455	455	455	455	455	5460	0%	0
average load	Conservative	455	448	441	435	428	422	416	409	403	397	391	385	5031	-8%	429
	Moderate	455	437	419	403	386	371	356	342	328	315	302	290	4405	-19%	1055
	Ambitious	455	423	394	366	340	317	294	274	255	237	220	205	3779	-31%	1681

Table 5. Full fuel cycle (WTW) CO_2e emissions for an electric truck under different emission reduction scenarios and a starting point of 30 gCO_2e / kWh

								WTW kg CO_2e								
Truck type:	year:	1	2	3	4	5	6	7	8	9	10	11	12	Total		Cumulative Emission Reduction (kg CO_2e)
7.5t truck	No change	3033	3033	3033	3033	3033	3033	3033	3033	3033	3033	3033	3033	36400	0%	0
average load	Conservative	3033	2988	2943	2899	2855	2813	2770	2729	2688	2648	2608	2569	33542	-8%	2858
	Moderate	3033	2912	2796	2684	2576	2473	2374	2279	2188	2101	2017	1936	29370	-19%	7030
	Ambitious	3033	2821	2624	2440	2269	2110	1963	1825	1697	1579	1468	1365	25194	-31%	11206

Table 6. Full fuel cycle (WTW) CO_2e emissions for an electric truck under different emission reduction scenarios and a starting point of 200 gCO_2e / kWh

								WTW kg CO_2e								
Truck type:	year:	1	2	3	4	5	6	7	8	9	10	11	12	Total		Cumulative Emission Reduction (kg CO_2e)
7.5t truck	No change	4853	4853	4853	4853	4853	4853	4853	4853	4853	4853	4853	4853	58240	0%	0
average load	Conservative	4853	4781	4709	4638	4569	4500	4433	4366	4301	4236	4173	4110	53668	-8%	4572
	Moderate	4853	4659	4473	4294	4122	3957	3799	3647	3501	3361	3227	3098	46991	-19%	11249
	Ambitious	4853	4514	4198	3904	3631	3376	3140	2920	2716	2526	2349	2185	40311	-31%	17929

Table 7. Full fuel cycle (WTW) CO_2e emissions for an electric truck under different emission reduction scenarios and a starting point of 320 gCO_2e / kWh

								WTW kg CO_2e								
Truck type:	year:	1	2	3	4	5	6	7	8	9	10	11	12	Total		Cumulative Emission Reduction (kg CO_2e)
7.5t truck	No change	7583	7583	7583	7583	7583	7583	7583	7583	7583	7583	7583	7583	91000	0%	0
average load	Conservative	7583	7470	7358	7247	7138	7031	6926	6822	6720	6619	6520	6422	83856	-8%	7144
	Moderate	7583	7280	6989	6709	6441	6183	5936	5698	5471	5252	5042	4840	73424	-19%	17576
	Ambitious	7583	7053	6559	6100	5673	5276	4906	4563	4243	3946	3670	3413	62985	-31%	28015

Table 8. Full fuel cycle (WTW) CO_2e emissions for an electric truck under different emission reduction scenarios and a starting point of 500 gCO_2e / kWh

						Carbon price, $/tonne								
	10	10	10	10	10	25	25	25	25	25	40	40	Total	
No change	$5	$5	$5	$5	$5	$11	$11	$11	$11	$11	$18	$18	$116	0%
Conservative	$5	$4	$4	$4	$4	$11	$10	$10	$10	$10	$16	$15	$104	-10%
Moderate	$5	$4	$4	$4	$4	$9	$9	$9	$8	$8	$12	$12	$88	-25%
Ambitious	$5	$4	$4	$4	$3	$8	$7	$7	$6	$6	$9	$8	$71	-39%

Table 9. Carbon price per tonne CO_2e emissions for a 7.5t electric truck under different emission reduction scenarios and a starting point of 320 gCO_2e / kWh

						Carbon price, $/tonne								
	10	10	10	10	10	25	25	25	25	25	40	40	Total	
No change	$30	$30	$30	$30	$30	$76	$76	$76	$76	$76	$121	$121	$774	0%
Conservative	$30	$30	$29	$29	$29	$70	$69	$68	$67	$66	$104	$103	$695	-10%
Moderate	$30	$29	$28	$27	$26	$62	$59	$57	$55	$53	$81	$77	$584	-25%
Ambitious	$30	$28	$26	$24	$23	$53	$49	$46	$42	$39	$59	$55	$475	-39%

Table 10. Carbon price per tonne CO_2e emissions for a 7.5t electric truck under different emission reduction scenarios and a starting point of 320 gCO_2e / kWh

						Carbon price, $/tonne								
	10	10	10	10	10	25	25	25	25	25	40	40	Total	
No change	$49	$49	$49	$49	$49	$121	$121	$121	$121	$121	$194	$194	$1,238	0%
Conservative	$49	$48	$47	$46	$46	$113	$111	$109	$108	$106	$167	$164	$1,113	-10%
Moderate	$49	$47	$45	$43	$41	$99	$95	$91	$88	$84	$129	$124	$934	-25%
Ambitious	$49	$45	$42	$39	$36	$84	$79	$73	$68	$63	$94	$87	$759	-39%

Table 11. Carbon price per tonne CO_2e emissions for a 7.5t electric truck under different emission reduction scenarios and a starting point of 320 gCO_2e / kWh

						Carbon price, $/tonne								
	10	10	10	10	10	25	25	25	25	25	40	40	Total	
No change	$76	$76	$76	$76	$76	$190	$190	$190	$190	$190	$303	$303	$1,934	0%
Conservative	$76	$75	$74	$72	$71	$176	$173	$171	$168	$165	$261	$257	$1,739	-10%
Moderate	$76	$73	$70	$67	$64	$155	$148	$142	$137	$131	$202	$194	$1,459	-25%
Ambitious	$76	$71	$66	$61	$57	$132	$123	$114	$106	$99	$147	$137	$1,186	-39%

Table 12. Carbon price per tonne CO_2e emissions for a 7.5t electric truck under different emission reduction scenarios and a starting point of 320 gCO_2e / kWh

Annex B - GLEC Partner Interview responses

Natural Gas (CNG/LNG)

Aspect	Comments
General experience	▪ There is some support for natural gas but only if there is a plan to move to biomethane in the future. ▪ There's a belief that there is still a GHG saving compared to diesel, however it can be hard to fully trust claims. ▪ Natural gas truck technology is available but the refueling infrastructure is still developing. ▪ Easier to introduce natural gas or biomethane when there is a back to base depot operation with bunkered refueling set-up ▪ CNG trucks are more established, but ramping up LNG with a focus to move to LNG and a further move to bioLNG. ▪ Generally seen as a way to reduce air pollution particularly in urban areas. There is also a benefit of being quieter compared to a diesel truck. ▪ Approach can be country specific or area based where policy emphasis, subsidy and infrastructure exist
Issues encountered	▪ There were initial concerns with truck performance in terms of power under load, however these have largely been addressed. ▪ Methane slip and leakage remain concerns however with newer dedicated NG gas trucks the methane slip issue appears to have been resolved. ▪ Investment is needed in infrastructure that will be in place for a long period and will need to be used in order to generate payback, A worry exists that if other technologies advance and become mainstream then CNG/LNG infrastructure could become redundant before a return on investment is seen. This deters investment. ▪ Disappointment is encountered when WTW savings do not match suppliers' claims, this is more an issue with transport service buyers than with the operators. Conflicting opinions can arise either within ▪ Restrictions on CNG and LNG truck use in tunnels e.g. CNG/LNG cannot use the Channel Tunnel.
GHG Calculation issues	▪ Some are self-calculating using EU Renewable Fuel Directive values as a check against fuel providers claims ▪ Extra effort is needed to conduct due diligence checks against fuel providers claims. ▪ Difficulties are encountered with emissions values for CNG and LNG; values can be inconsistent across the various sources available; finding the most credible source can take effort. ▪ A good baseline is needed to be able to recognize GHG reductions. ▪ Companies with more mature GHG calculation systems and set ups can incorporate CNG and LNG into their reporting.

Biofuels (Biodiesel and biomethane)

Aspect	Comments
General experience	▪ There is interest in using biofuels as a drop in fuel with an aim for 100% (i.e. B100) and as blends (e.g. B20) but the emphasis from GLEC Partners is a move towards 2nd generation biofuels as concerns over sustainability exist with 1st generation food crop based feedstocks.
Issues encountered	▪ Some concerns over increased vehicle maintenance that may increase total cost of ownership. ▪ There is a reputational risk if evidence raises questions over food crops and land use change including biodiversity and social or ethical implications. In particular the palm oil derived biofuels, some companies have policies in place that forbid use of palm oil in fuels and it can be very hard to assess what you are actually buying. ▪ Concerns over availability of the 2nd generation biofuel feedstocks and fuel. ▪ Legislation changes from country to country which creates extra effort in determining which biofuels are available. Some multinational companies require a global approach to biofuels which is currently very difficult to achieve ▪ A lack of trust regarding fuel providers' claims on GHG emissions and cost structure basis; is biofuel more expensive due to technical (process costs) or commercial (trading profit margins) reasons? ▪ A lack of robust certification of biofuels that adequately accounts for feedstock issues and carbon intensity claims. ▪ Differing policy on renewable fuel obligations (e.g. linked to EU Renewable Energy Directive) and tax regime associated with biofuels makes for a complex situation.
GHG Calculation issues	▪ Obtaining GHG fuel emission factors, either generic or fuel specific, can be difficult and a lack of consistency in values means extra effort is needed to calculate emissions from biofuels ▪ Initially GHG intensity values sourced from biofuel suppliers' marketing were used in calculations; however now there need to be official values to support calculation and company reporting. As an example, biomethane values can generating between 50% and 80% GHG reduction but this range makes it uncertain as to the actual saving that results from the investment.

Electricity

Aspect	Comments
General experience	▪ Generally experience within GLEC Partners is in the pilot phase of electric trucks. ▪ Existing trucks retrofitted with electric drivetrains have been trialed and these projects are heavily subsidized. ▪ Electric trucks seen as a solution to the air pollution problem in major cities across Europe and the rest of the world. They also ensure business continuity (or the ability to trade) where low, ultra-low or even zero emission zones are being implemented or considered with truck restrictions put in place. ▪ Some use electric vehicles as a marketing strategy. ▪ Generally within city logistics and with back to depot operations and less emphasis on long haul operations
Issues encountered	▪ The lack of availability of fully battery electric vehicles in the desired size range suitable for the required operation is a key issue ▪ Upfront costs are still considered too high; however consideration of whole life costs or total cost of ownership (TCO) is vital to assess the technology. ▪ The variation of carbon intensity of the electricity used to charge vehicles will determine the scale of GHG savings. ▪ Charging infrastructure, electricity suppliers and grid operators need to be involved in projects, meaning greater coordination of projects is required. ▪ The technology is still at an early stage and truck OEMs will move at different rates of introduction depending on the baseline of their truck fleet performance to meet the 2025 and 2030 EU targets. ▪ The introduction of electric vehicles requires an integrated energy system approach and needs to be a smart integration.
GHG Calculation issues	▪ Generally GHG calculations for electric vehicles is straightforward as long as the emission factor for the electricity used to charge the vehicle is available. ▪ The main issue reported is a lack of easily accessible emissions factors and the consistency of these between countries. Also the published factors may be based on data that is out of date when considering the recent improvements in electricity grid decarbonization.

Hydrogen

Aspect	Comments
General experience	▪ Very little experience with hydrogen fuel cell vehicles within the GLEC partners consulted. ▪ A wide range of opinion is present, with some believing that that hydrogen is the solution for long haul heavy duty trucks in the future and others questioning whether the trucks will be available and affordable in the timeframes needed for GHG reduction targets. ▪ Some believe that hydrogen is currently around 10 years behind electric vehicles i.e. where electric vehicle technology, availability and acceptance were 10 years ago.
Issues encountered	▪ Currently very limited data for GLEC Partners to base decisions on whether to trial hydrogen technology vehicles ▪ Some companies are assessing how to test hydrogen vehicles in operation. ▪ Availability of the vehicles and the fuel is unknown and questions raised on the WTW GHG savings with current hydrogen production processes. If hydrogen is produced from fossil methane then very little benefit in GHG reduction ▪ Current cost of ownership models predicts very high costs for FCEV.
GHG Calculation issues	▪ A distinct lack of WTW GHG emission factors for the hydrogen production pathways even in the more comprehensive datasets there are no values for hydrogen.

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