WORKING GROUP ON MONITORING METHODOLOGIES OF CO_2 NEUTRAL FUELS

2024

MONITORING THE USE OF CO_2 NEUTRAL FUELS IN ROAD TRANSPORT A CROSS-SECTORAL INDUSTRY ASSESSMENT

AECC Aurobay BDBe bft BIOAGRA

Bioéthanol FRANCE BMW BOSCH bp Bundesverband Behälterschutz e.V.

cecod CLEPA European Association of Automotive Suppliers DAF DENSO Crafting the Core

DOVER FUELING SOLUTIONS Drivkraft Sverige EBB eFuel alliance

ELAFLEX en2x Wirtschaftsverband Fuels und Energie e.V. eni ePURE european renewable ethanol

ETANOLI AUTOILIJAT eurogas ewaba

FuelsEurope GILBARCO VEEDER-ROOT Haltermann Carless HELLENiQ ENERGY

HEXAGON HIF HUTH HYUNDAI Liquid Gas Europe

IVECO • GROUP jama LKQ LOTHER GRUPPE

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VDA vitesco TECHNOLOGIES

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STATEMENT OF COMPLIANCE GUIDELINES & ANTITRUST LAW

The comprehensive work undertaken by the Working Group on Monitoring Methodologies was conducted under the strictest adherence to antitrust guidelines, ensuring the highest standards of legal compliance throughout the project's duration. Professional Compliance Lawyers were present at every meeting of the Working Group, serving as vigilant guardians of antitrust regulations and ensuring that compliance was meticulously maintained at all stages of the project's development. These legal experts consistently emphasized the critical importance of adhering to the predetermined agenda of the meetings and avoiding any discussions or comments that could be construed as inappropriate or potentially anticompetitive.

Given the collaborative nature of the project, which involved competitors active at different levels of the automotive value chain working together, the Antitrust lawyers implemented and enforced a rigorous prohibition on the disclosure of any commercially sensitive information. This included, but was not limited to, individual company data on prices, profit margins, costs, market forecasts, production figures, capacity details, investment plans, business strategies, bidding information, and/or contract specifics. The lawyers also ensured that discussions steered clear of matters relating to individual suppliers or customers, maintaining a neutral and competition-friendly environment.

Throughout the course of the project, great care was taken to avoid making any recommendations regarding future market behaviour, including pricing strategies, output levels, or investment decisions. This precautionary measure was crucial in maintaining the integrity of the competitive landscape and preventing any potential collusion or market manipulation. To further safeguard against antitrust violations, all members of the Working Group were consistently encouraged to voice their concerns promptly if they perceived any comment or statement as potentially inappropriate or in violation of antitrust guidelines.

The approach of the Working Group while elaborating on the different methodology options has been purely objective and science-based to provide a neutral overview without predetermining any choices nor standpoints.

The meticulous approach to compliance extended beyond the meetings themselves. The secretariat, tasked with documenting the proceedings, produced precise minutes for each meeting. These draft minutes were subsequently reviewed by the antitrust lawyers, providing an additional layer of scrutiny to ensure not only direct adherence to antitrust guidelines during the meetings but also to detect any possible critical situations that might have arisen in the aftermath of the discussions.

In the collaborative work phases, the output of individual members was consistently anonymised by the secretariat before being presented for further discussion within the group. This anonymisation process served as an additional safeguard, ensuring that sensitive information remained protected and that compliance guidelines were rigorously followed. By implementing these comprehensive precautions, the Working Group successfully achieved its dual objectives: producing a high-quality report on Monitoring Methodologies for CO_2 neutral fuels while simultaneously maintaining unwavering compliance with antitrust laws and regulations. This report has been legally reviewed by the external antitrust counsel.

ABSTRACT

This report[1] was prepared to respond to the European Commission's request to industry, OEMs and fuel companies, to present technological options that can prove and monitor the use of CO_2 neutral fuels in new vehicles, and contribute to the European Commission's commitment to present a methodology for registering vehicles running on CO_2 neutral fuels.

Monitoring CO_2 neutral fuels implies the tracking and tracing of the fuel from the production or entry point, in case of imports, all the way down to the final use in a given vehicle. The Working Group on Monitoring Methodologies (WGMM) therefore features a broad sectorial representation including OEMs and their suppliers, fuel producers and fuels suppliers, fuel retailers and their equipment suppliers, in order to ensure that the TCMV's proposed methodology fits the requirements of all sectors of the automotive and fuels value chain for a robust and reliable proofing and reporting methodology.

A Technology Neutral, Inclusive and Consistent Definition for CO_2 Neutral Fuels is Needed to Avoid Over-Complexity of the EU Regulation

The work of the WGMM started with an assessment of the compromise agreed between Germany and the Executive Vice-President Timmermans in March 2023, and the Commission's briefing to the member state experts in the TCMV, the proposed fuels definition and the pre-suggested methodologies identified by the Commission services.

The Commission proposal of September 2023 only included eFuels, also labelled RFNBOs, in its definition of CO_2 neutral fuels and required these fuels to have a 100% GHG emission savings based on the "lifecycle analysis" of the fuel. This approach is evaluated by the experts in the WGMM as technically very difficult to achieve currently and inconsistent with the overall EU Green Deal goals defined as "net-zero", recognizing GHG emissions and also absorption/storage by either biogenic or industrial means. The Working Group's proposal aims to correct this inconsistency, and proposes an alternative definition

"CO_2 neutral fuel' means all fuels defined by the Renewable Energy Directive (EU) 2018/2001, provided that they meet the sustainability criteria of that Directive and associated delegated acts, where the same amount of CO_2 from biomass, ambient air or recycled carbon sources is bound in the fuel production as is released during combustion in the use phase. Those fuels shall include renewable and/or synthetic fuels, such as biofuel, biogas, biomass fuel, renewable liquid and gaseous transport fuel of non-biological origin (RFNBO) or a recycled carbon fuel (RCF)[2]."

There should be one unique definition of CO_2 neutral fuels for all EU legislative acts.

CO_2 Neutral Fuels Complementary to Electrification in Road Transport

The report furthermore shows that the inclusion of CO_2 neutral fuels in road transport does not weaken the new vehicle CO_2 reduction targets, but instead, would be a complement to battery-electric and hydrogen-powered vehicles with the potential of accelerating

1. This report is the result of a collective contribution, on some aspects it might not reflect the views and opinions of all participating companies
2. This definition could be adapted to reflect the availability of new options such as "Low-Carbon Fuels" as defined in the revised Hydrogen and Gas Package adopted in Aug. 2024

the decarbonisation of road transport.

Road Transport the Lead Market to Create a Long-Term Investment Case for CO_2 Neutral Fuels for the Benefit of all Transport Sectors.

Thanks to the size of the market and investment resources, the potential economies of scale, the significant taxation share of fuels, and the need for a market access for the co-products stemming for instance from Sustainable Aviation Fuels (SAF), road transport can be the ideal market for scaling up the uptake of CO_2 neutral fuels, enabling industrial scale production and cost reduction for businesses and citizens.

The Role of Biofuels?

Biofuels represent today 90% of renewables in road transport and they can continue to meet a large part of future increased energy demand. Biofuels are currently commercially available and delivered in sufficient amounts and thus available to accelerate the decarbonisation of the transport sector significantly.

Fuelling Technologies for Vehicles & Retail

The report's main objective is to provide the Commission, TCMV experts and their administration in Member States with a comprehensive, objective, neutral and technical assessment of all identified fuel monitoring options.

The members of the WGMM, and the experts who contributed to the work have no intention to recommend any of the proposed methodologies, the final decision remaining the sole responsibility of the legislator.

Two Potential Approaches, and 11 Technology Options to Monitor CO_2 Neutral Fuels

The assessment performed by the experts of the WGMM concluded that, in the current stage of technology development, 2 main approaches can be considered for the use and monitoring of CO_2 neutral fuels in a new vehicle class after 2035:

- **Direct and exclusive CO_2 neutral fuel supply** to the vehicle where the fuels is delivered through a dedicated and isolated infrastructure end-to-end, in an exclusive manner, through fuel pumps that only supply 100% CO_2 Neutral Fuel.
  - **Fuel Marking:** well-established fuel identifier technology that uses a distinct physical marker additive, which can now be used to prove CNF throughout the supply chain.
  - **Digital Fuel Tracking System (DFTS):** already used in industrial safety systems, this technology enables secure digital tracking and ledger accounting of CNF across fuel supply system and vehicle operation.
  - **On-board Detection:** vehicle-based group of technologies that can immediately detect presence or absence of CNF during fuelling by chemical or physical tests, and enable/disable vehicle operation.
  - **Physical security of fuel connections** to enable CNF but prevent fossil-based fuel throughput
- **CO_2 neutral fuel supply for specific vehicle via the overall fuel supply system**, where the CO_2 neutral fuel is delivered via the current fuel infrastructure currently shared with petroleum fuels. This approach is particularly adapted for gaseous fuels. The fuel requirements of the vehicle are exactly matched with the same quantity of CNF supplied into the overall fuel supply system and securely monitored and matched with the vehicle through a digital tracking system.

The table below summarises the type of methodology, its detection method, poten-

APPROACH	**Direct Exclusive CNF Supply to Vehicle**				**Mass Balanced CNF Supply for Specific Vehicle via Common System.**	
DESCRIPTION	The CNF is delivered directly to the vehicle. The fuel pump and supply are exclusively CNF, and the vehicle consumption is exclusively CNF. The vehicle does not and cannot receive or use any fossil-based fuel. The physical movement of carbon-neutral fuel through a dedicated supply chain is too restrictive during the transition phase primarily due to the significant infrastructure investments and logistical complexities involved. Establishing an independent supply chain to avoid contamination requires substantial capital expenditure and time, which can be prohibitive for early-stage implementation. Additionally, the limited availability of dedicated fuelling stations can create inconveniences for consumers, leading to range anxiety and hesitancy in adopting carbon-neutral fuel vehicles. This approach also poses challenges for fuel suppliers and retailers in predicting demand and ensuring consistent supply, further complicating the transition.				This mimics the operation of the electricity grid, where there are both renewable and non-renewable suppliers, and customers for 100% renewable, or non-renewable electricity. All of the electricity is carried on a common grid but renewable off-take contracts are exactly matched to certain 100% renewable supply. Similar to renewable electricity supply contracts, indirect but precisely matched supply of CNF into existing fuel supply infrastructure, equivalent to consumption of identified vehicles, the CNF sustainability and quantity certification must be reported to account for the fuel consumed by the CNF vehicles. Digitised transactions and ledger accounts can provide high accuracy and rigour. Nonetheless, this approach is not supported by the proposed inducement system for CNF vehicles by the European Commission.	
CONCEPT	Regional Exclusivity	Fuel Property Measurement	Fuel Additivation		Digital Supply Chain Tracking with Mass Balancing	Mass Balance
POTENTIAL TECHNOLOGIES	8. EU Market exclusively supplied with CNF 1. Mechanical adaptation of Tank Filler	5. Vehicle on-board fuel detection function 6. On-board Fuel Molecular Sensor	2. Fuel marker along upstream and downstream 4. Hybrid approach: Fuel Marker and DFTS	3. 100% digital fuel tracking from upstream to downstream 4. Hybrid approach: Fuel Marker and DFTS 7. Bidirectional communication between vehicle and gas station	11. Combined Mass Balancing DFTS w/ digital handshake 10. Fuel Usage	2. Mass Balancing

Rigorous → Flexible

tial inducement systems and the compatibility with the fuel type. They are presented in no particular order, can be used in combination which could have various advantages.

#	METHODOLOGY	TRACKING METHOD	DETECTION METHOD	INDUCEMENT SYSTEM	FUEL COMPATIBILITY
1	Mechanical adaption of tank filler / nozzle	Physical	Mechanical	Not required	Gaseous and Liquid fuels
2	Fuel marker along upstream and downstream (sensor in vehicle)	Physical	Sensor	YES	Liquid fuels
3	100% digital tracking from upstream to downstream (DFTS w/ digital handshake)	Physical	Electronic by re-using existing data	YES	Gaseous and Liquid fuels
4	Hybrid approach - upstream: fuel marker & sensor until EU border - downstream: DFTS w/ digital handshake	Physical	Sensor & Electronic	YES	Liquid fuels
5	Vehicle On-Board Fuel Detection Function	Physical	Sensor	YES	Liquid fuels
6	Vehicle Onboard Fuel Molecular Sensor	Physical	Existing Engine Sensor	YES	Liquid fuels
7	Bidirectional Communication between vehicle and gas station	Physical	Electronic	YES	Gaseous and Liquid fuels
8	EU market exclusively supplied with CNF	Physical	NR	Not required	Gaseous and Liquid fuels
9	Mass-Balanced CNF supply to each CNF vehicle	Virtual	None	NO	Gaseous and Liquid fuels
10	Fuels Usage Balancing - FUB	Virtual	Electronic	YES	Gaseous and Liquid fuels
11	Combined mass balancing - DFTS w/ digital handshake	Virtual	Electronic	YES	Gaseous and Liquid fuels

Outcome of the Evaluation Matrix

Option 1 - Mechanical Adaption of Tank Filler / Nozzle: Mechanical adaption of the filler neck and the nozzle would physically prevent that the wrong fuel is filled but in practice, it is prone to tampering and might not be considered as robust enough when used alone. Additionally, it will incorporate high efforts for the development of new standards and hardware at both filling station and vehicle, including additional integration efforts.

Option 2 - Fuel Marker along Upstream and Downstream: A fuel marker and sensor in the vehicle physically tracks the CNF. This methodology is already used for heating oil, but there is currently no off-the-shelf automotive sensor available. New developments for automotive requirements (e.g. robustness, selectivity, sensitivity) are expected. With regards to tampering robustness, marking the fossil fuel may be a more robust solution.

Option 3 - 100% Digital Tracking from Upstream to Downstream DFTS w/ Digital Handshake): The DFTS (digital fuel tracking system) is a 100 % digital solution along the entire delivery chain, completely based on the existing data and infrastructure of the different stakeholders. Via a digital handshake, the reliable pairing of vehicle and nozzle is enabled and allows flexible inducement reaction. Manipulation robustness is assured by reliability checks within a multi-trust centre approach (stakeholder – cloud - vehicle). The solution needs technical adaptations in the vehicle, logistics and fuelling stations.

Option 4 - Hybrid Approach – Upstream Fuel Marker & Sensor Until EU Border – Downstream - DFTS w/ Digital Handshake: A potential means to improve the sensor & marker approach could be a hybrid approach in combination with the DFTS. Within this solution, the lack of automotive ready sensors could be bypassed by performing a digital handshake with filling station, based on a sensor signal which measures the fuel marker in the filling station itself. Less stringent requirements for such a sensor could therefore apply, which leads to lower integration efforts at the OEM side and faster time to market.

Option 5 - Vehicle On-Board Fuel Detection Function: On board fuel detection by processing the existing Engine Control Unit (ECU) signals is a pragmatic software solution which is based on data already available in the vehicle. The solution may work for CNFs with properties which are different to conventional ones such as HVO and Diesel. However, currently no solution for gaseous fuels is known.

It might require calibration to include possible future fuels, since the actual measurement value (correlating with property) may change from one fuel source to another, resulting in additional deployment efforts in-field.

Option 6 – Vehicle On-Board Fuel Molecular Sensor: A molecular structure sensor is another option which directly tracks the fuel type in the vehicle. It is not a marker as proposed in Option 2. The on-board sensor is available in series production and fulfils the standards outlined in EN590 and EN228.

It is capable of providing the on-board, real-time final verification required by the EU, as it already does in bus and truck applications to detect fossil fuels. CNF detection has been successfully implemented for standards such as EN14214 and EN15940, and new databases are currently being developed for eFuel molecules like MtG and FT.

Option 7 - Bidirectional Communication Between Vehicle and Filling Station: Bidirectional communication between the vehicle and the filling station provides a tamper-proof approach which could be used as a 1-to-1 pairing solution between nozzle and vehicle.

Next to the secure authentication process, the solution provides a filling monitoring and a blockage device in the filler neck, which can inhibit filling with conventional fuel. However, to fulfil tampering requirements, the solution needs technical adaptations.

Option 8 - CNF Exclusively Available in EU market: While this scenario is unrealistic to be considered for 2035, it is one that is certainly possible in the longer-term and so is worthy of considering as part of the overall transition strategy for transport in the EU. This assumes that CNF is exclusively available, likely some years away, and would be the result of substantial scale-up of CNFs for road transport alongside the needs of other sectors, and also the reduction of overall liquid and gaseous fuels demand, achieved by efficiency and electrification.

Option 9 - Mass-Balanced CNF Supply to Each CNF Vehicle: Mass-balancing is an indirect solution which focuses on an input-output approach, controlled by booking and claiming of certificates. Trading markets such as electricity and gaseous fuels in pipelines are efficiently controlled by such an approach. This means for a potential CNF application, that the fuel may not be physically consumed in the claiming CNF vehicle. But the fuel supply system reliably assures that the CNF amount is introduced in average elsewhere into the market. Such a solution would benefit from high system efficiency, fast ramp-up of fuel production and fuel supply chain whilst enabling that in the introduction phase filling stations do not need to have a dedicated CNF pump.

Option 10 - Fuel Usage Balancing: Fuel Usage Balancing solution uses a mass-balancing approach based on tracking of fuel energy in the vehicle tank without a handshake between filling station and vehicle. Instead of the filling station, the responsibility of certificate handling is transferred to the motorist, who is directly connected with a certificate marketplace, which may be an efficient solution for fleet customers in commercial vehicle segment.

However, for average end-customer in passenger car segment, the solution might be a burden by transferring too much responsibility to the motorist for certificate handling.

Option 11– Digital Tracking with Mass Balancing: Since mass-balancing (Option 9) is based on a certificate handling mechanism which incorporates average reporting of the stakeholders to an authority, a hybrid solution in combination with a DFTS (see option 3) is proposed. This system benefits from a fast accumulation of certificates on single vehicle level since it can include the DFTS as monitoring platform and performer of the digital handshake between the vehicle and the filling station. So, accurate and in-time certificate handling could be assured per individual vehicle. In addition, the vehicle has an inducement system mechanism to monitor the usage of CO_2 neutral fuels.

Methodology Assessment from Customer and Retailer Perspective

The report also focuses on the requirements and considerations for customers and retail sectors to ensure the successful integration and acceptance of CNF powered vehicles, and the enabling technologies (Chapter 6). It addresses the technology requirements for a successful CNF roll-out and monitoring. To this end, it evaluates the identified technology options from various angles including availability, costs implications, ease of use, security of monitoring and inducement technologies.

These technologies also have potential applications beyond the European Union, thereby laying a robust foundation for the widespread adoption of CNF. It is important to ensure that CNF dedicated vehicles can operate beyond EU boundaries and to establish control mechanisms that prevent the use of non-CNFs. Options for this issue are also addressed.

The report furthermore provides an analysis of the effective inducement system required for supporting the EU's CO_2 Neutral Fuel (CNF) requirements. The experts recommend the incorporation a fuelling monitoring system to track CNF use to ensure the vehicle is exclusively fuelled with CNF, an inducement system in the form of a mechanism that reacts if non-CNF is detected, enforcing compliance through various responses.

Finally, the report explores the issue of regulatory geofencing which is a direct consequence from the inducement systems chosen to ensure compliance with CNF requirements. Regulatory geofencing influences how vehicles function outside EU borders and affects the resale value of used vehicles in non-EU regions. The analysis describes the implications for vehicle usability, enforcement, and potential misuse outside the EU, and the impact on customers.

Regulatory Evaluation

The report is completed by a detailed analysis of all regulations to identify adaptations that may be required to recognise individual CNF monitoring methodologies (Chapter 7).

The report describes the advantages, disadvantages and impacts from a regulatory perspective, which includes an assessment of the prospect and time duration for potential implementations, and formulates brief amendments where possible.

The report *"Monitoring the use of CO_2 Neutral Fuels in Road Transport – a Cross-Sectoral Industry Assessment"* is available in digital version and will complemented with factsheet type information for all monitoring methodologies described.

03

ORIGIN & PURPOSE OF WORKING GROUP

3.1. Origin & Political Background

Timeline

- **March 2023** – Compromise on CO_2 Emission Standards for Cars and Light-Duty Vehicles, which include a new class for vehicles which are exclusively supplied by CO_2 neutral fuels.
- **July 2023** – First proposal from the Commission on the new vehicles class
- **20th September 2023** – Establishment of the Working Group on Monitoring Methodologies in Stuttgart, Germany
- **25th October 2023** – First meeting of the Steering Group
- **Nov/December 2024** – General Assembly & Publication of the Final Report on all Monitoring Options
- **April 2025** – Deadline for the Commission for the methodology for Heavy-Duty Vehicles

As part of the "Fit for 55" package, on the 28th of March 2023, the Council of the EU adopted an amendment to regulation 2019/631 on CO_2 emissions for new cars and vans. A description of the CO_2 emission standards is available in the appendix of this report (Section 9.2). This decision followed a political discussion on the 2035 CO_2 reduction targets that require 100% tailpipe CO_2 reduction. Hence, Electrification would remain as the only option. Germany, Italy, Poland and other Member States advocated for the inclusion of CO_2 neutral fuels (CNF) to facilitate renewable transportation, thereby offering a solution to meet regulative targets with internal combustion engines (ICEs) fuelled with renewable fuels. Consequently, in this regulation, the Commission has agreed to make a proposal for registering vehicles running exclusively on CO_2 neutral fuels after 2035, in conformity with EU law, outside the scope of fleet standards, and in conformity with the EU's climate neutrality objective. This agreement was shaped in recital 11 of Regulation (EU) 223/851:

> **"Following consultation with stakeholders, the Commission will make a proposal for registering after 2035 vehicles running exclusively on CO_2 neutral fuels in conformity with Union law, outside the scope of the fleet standards, and in conformity with the Union's climate-neutrality objective."**

The TCMV aims to develop a proposal for registering vehicles running permanently on CO_2 neutral fuels (CNF) in conformity with EU law and the RED sustainability criteria. During a TCMV meeting on the 3rd of July 2023, the Commission mentioned in a presentation that the "technology solution [is] left in the hands of the industry (OEM and fuel companies)." This explicit request in combination with the CO_2 fleet regulation agreement in March 2023 has incentivised the industry to take action. A first proposal on CNF definition was seen in July 2023 which suggested that CO_2 neutral fuels should be defined as "renewable fuels of non-biological origin" (RFNBOs), which is laid out in the EU's Renewable Energy Directive (RED). However, the definition of RFNBOs in the RED that aims for at least 70% reduction in GHG emissions compared to fossil fuels was rejected by DG CLIMA, which argued that it is "imperative that the definition only includes renewable transport fuels of non-biological origin which have GHG savings of at least 100%".

In response to the call to action of the TCMV in July 2023, the Working Group on Monitoring Methodologies for CO_2 neutral fuels was established. On September 20th, 2023, in Stuttgart, Germany, stakeholders from both the broad automotive value chain including OEMs, fuels industries, and retailers have agreed to establish the "Working Group on Monitoring Methodologies (WGMM) for CO_2 neutral fuels" to contribute to the work of the TCMV and evaluate existing Technology options to monitor the use of Carbon Neutral Fuels in new vehicles. The WGMM aims to develop a proposal for registering vehicles running permanently on CO_2 neutral fuels in conformity with EU law and the Renewable Energy Directive sustainability criteria. Regarding the fuels and the monitoring methodologies, the members of the WGMM also call on the European Commission and the TCMV to ensure that the principle of technology neutrality prevails.

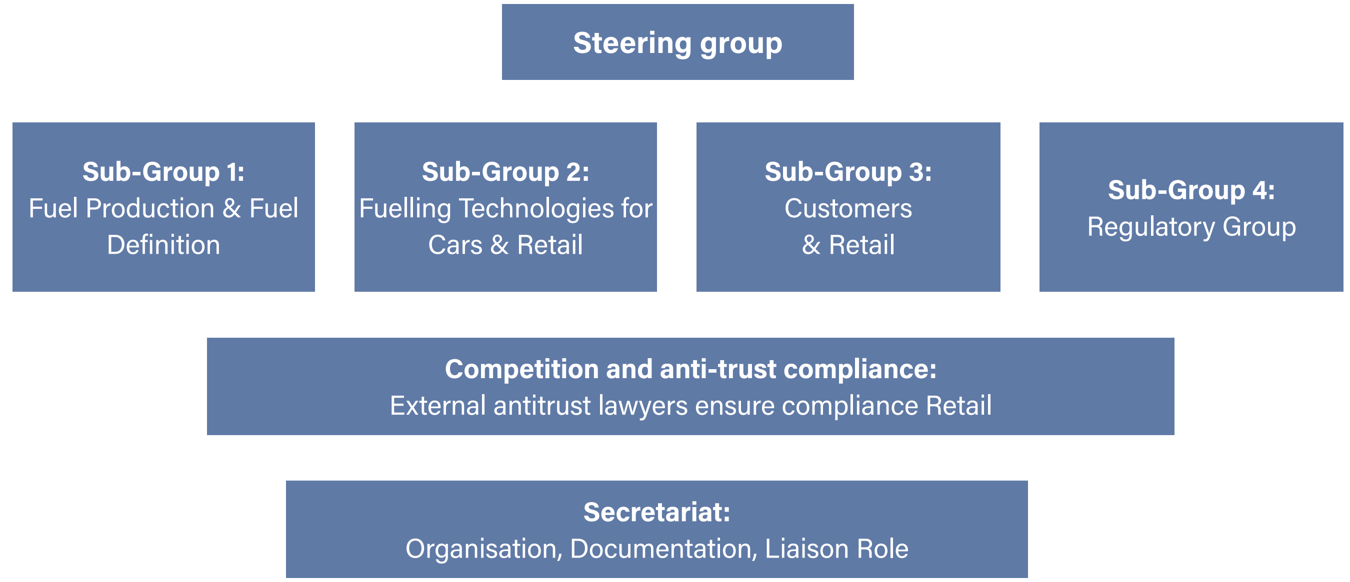
As the new CO_2 standards were initially only applicable to LDVs, COREPER recently validated new CO_2 Emission standards for HDVs as well. The European Parliament also voted in favour of these new CO_2 Emission standards for HDVs. On the 9th of February 2024, COREPER confirmed new CO_2 Standards for Heavy Duty Vehicles. Here, the same tailpipe approach exists as in the CO_2 Emission standards for cars and light-duty. Although the Commission proposed a reduction of 90% in 2040 without the recognition of CNF a large market share for the ICE would be missed out. After Germany and other Member States threatened to abstain the vote, negotiations were held on how to improve the recognition of CO_2 neutral fuels within the regulation. The following wording was included as legally non-binding within recital (17):

> **"Following consultation with stakeholders, the Commission will, within a year from entry into force of this regulation, assess the role of a methodology for registering HDV exclusively running on CO_2 neutral fuels, in conformity with Union law and with Union climate neutrality objective;"**

3.2. Purpose

The purpose of the WGMM can be deduced from the origin of the group. The WGMM aims to include and represent the entire road transport sector and automotive value chain, including stakeholders from the LDV, HDV, and off-road transport industry. The overarching purpose is to deliver and provide the European Commission, European Parliament and Member States, especially directed to the TCMV, with a comprehensive report of all potential solutions for monitoring the use of CO_2 neutral fuels in new vehicles. Therefore, the WGMM describes advantages and disadvantages of all potential monitoring methodologies. As mentioned in the anti-trust guideline, it cannot pick a winning monitoring methodology. The Working Group evaluates all methodologies from a technical and political perspective. The industry's collective expertise is the fundament and is conjointly offered to the European Commission. This bundled expertise targets to ensure the acknowledgement of renewable fuels to be a viable and robust alternative for the decarbonisation of the European Automotive sector.

3.3. Structure & Members



The Working Group consists of a clear structure to ensure an effective work of its members. More than 50 Corporations, Organisations or Unions from the global transport sector have collectively collaborated to establish this group. The WGMM is led by a Steering Group which coordinates the communication and is responsible for important decisions along the process. Subordinated to the Steering Group, there are four different Sub-Groups, all responsible for different key issues. Sub-Group 1, consisting of 83 Members, is responsible for Fuel Production & Fuel Definition. Sub-Group 2 has 82 members and consolidates and evaluates Fuelling Technologies for vehicles. Sub-Group 3 has 41 members and considers Fuelling Technologies from the perspective of the customers and retail. Ultimately, Sub-Group 4, with 84 members, accumulates all relevant regulations regarding the implementation of the monitoring methodologies. The Steering Group and all Sub-Groups are organized by a Chair and Co-Chair that have been decided upon at the beginning of the project. All the Sub-Groups regularly held meetings to discuss the ongoing process.

Aside from the content-intensive part of the Working Group, external antitrust lawyers thoroughly accompany the whole work of the WGMM to ensure absolute compliance with competition law. Additionally, there is the Secretariat, which is responsible for coordinating all activities of the WGMM. The Secretariat is managed by the von Beust & Coll. Consultancy based in Hamburg, Germany.

The following report will entail in detail the outcome of the four Sub-Groups starting with Chapter 4 on Fuel production & Fuel Definition. Fuel pathways and the availability of feedstock will be the content of the chapter. Chapter 5 follows with a detailed description of advantages and disadvantages of the existing technology options to monitor Carbon Neutral Fuels in the vehicle. Chapter 6 contains a detailed overview of the technology options from the perspective of customers and retail. Lastly, Chapter 7 presents relevant policy regulations for the described technology options which need to be considered when looking ahead for implementation. The report is complemented by a thorough conclusion and exhaustive appendix of references.

04

FUEL PRODUCTION & FUEL DEFINITION

Introduction

This chapter examines the definition of "CO_2 Neutral Fuels" proposed by the European Commission, considers the comparable EU CO_2 regulations and methodologies, and evaluates also the implications and consequences of the Commission's proposal. It then proposes an alternative definition for the purpose of maximizing the potential for CO_2 neutral fuels to contribute to meeting goals for CO_2 emissions reductions in transport.

Also described is how regulatory recognition of CO_2 Neutral Fuels in road transport CO_2 regulation can create a new market which could increase supply, increasing the ability of the EU economy to meet the EU GHG reduction goals, and reducing dependence on fossil fuel imports.

4.1. WGMM proposed Fuel Definition

Context

The European Commission has committed to consider a proposal to enable the certification, via Euro 7 vehicle emissions regulation for "Carbon Neutral Vehicles" running exclusively on "CO_2 Neutral Fuels" to be qualified as "zero emission vehicles" equivalent to an electrified vehicle. Any such regulatory development will require a definition of "CO_2 Neutral Fuels" (CNF).

The Commission's proposal only includes eFuels in its definition of CO_2 neutral fuels and requires these CO_2 neutral fuels to have a **100% GHG emission savings based on a "well-to-wheel" approach which accounts in particular for the emissions of the production and the transportation of the fuel and is therefore currently very difficult to technically achieve.**

The current CO2 standards regulations (LDVs and HDVs) is based on the tailpipe approach thus measuring the use phase of the vehicle. Therefore, the proposed definition by the Commission creates a distortion between CO2 neutral fuels being evaluated on a Well-to Wheel basis while other technologies remain on the tailpipe approach.

It is important to remember that the overall EU Green Deal goals are labelled "net-zero", recognizing GHG emissions and also absorption/storage by either biogenic or industrial means. The Commission's definition appears to be inconsistent with this. The Working Group's proposal aims to correct this inconsistency.

The Working Group proposes the following definition for Carbon Neutral Fuels:

> **"CO_2 neutral fuel" means all fuels defined by the Renewable Energy Directive (EU) 2018/2001, provided that they meet the sustainability criteria of that Directive and associated delegated acts, where the same amount of CO_2 from biomass, ambient air or recycled carbon sources is bound in the fuel production as is released during combustion in the use phase. Those fuels shall include renewable and/or synthetic fuels, such as biofuel, biogas, biomass fuel, renewable liquid and gaseous transport fuel of non-biological origin (RFNBO) or a recycled carbon fuel (RCF)[3].**

The Working Group considers that the definition of CO_2 neutral fuels as presented by the European Commission in the point 9a of Article 2 of the Euro 6 Regulation is not fit for purpose on the following grounds:

1. The Commission's proposal only refers to eFuels (RFNBOs) in its definition of CO_2

3. This definition could be adapted to reflect the availability of new options such as "Low-Carbon Fuels" as defined in the revised Hydrogen and Gas Package adopted in Aug. 2024

neutral fuels, hence **totally excluding other low-carbon renewable fuels with high and immediate decarbonisation potential** such as biofuels and biogases.

2. **As such the Commission proposed definition is inconsistent/significantly misaligned with its own definition of sustainable fuels in several other regulations:** EU ETS, EU ETS II (Road & Buildings), the Renewable Energy Directive (RED), RefuelEU Aviation, and FuelEU Maritime. The scientific basis for such differences is not clear:

- **The EU ETS, which foresees a zero-rating for CO2 emission from biomass as well as for RFNBOs (hydrogen and eFuels): zero CO2 emissions**
- **The EU ETS II for road transport fuels and buildings, where CO2 emissions from biofuels & eFuels are considered to be: zero CO2 emissions**
- **The Renewable Energy Directive (RED), emissions from biofuels & synthetic fuels are compensated (credits arising respectively from photosynthesis and CO2 capture): zero CO2 emissions**
- **IPCC guidelines for National Energy & Climate Plans: emissions from biomass-derived fuels: zero CO2 emissions in transport**

3. This very narrow definition denies citizens the choose to choose their preferred technology option, excludes an important CO_2 compliance route for vehicle manufacturers, and ignores an important route for technology and industrial competitiveness for European Industries.

Supporting facts for the proposed definition of CO_2 neutral fuels:

1. **The actual EU climate targets are ambitious and all sustainable options (not just eFuels / RFNBOs) will be required to contribute to meeting them.** There is no silver bullet to decarbonise the transport sector. **Acknowledging the role of CO_2 neutral fuels for the general road transport fleet** does not weaken the new vehicle CO_2 reduction targets. Instead, it would be a **complement to battery-electric and hydrogen-powered vehicles with the potential of accelerating the phase-out of fossil fuels.**

2. **An internal combustion engine (ICE) vehicle using renewable fuels has a similar – or even lower – carbon footprint than a battery electric vehicle (BEV).** An ICE car fuelled exclusively by CO_2 neutral fuels, in line with the sustainability criteria and greenhouse gas reduction thresholds of the RED, is a CO_2 neutral vehicle at point of use, and should be considered as such in the CO_2 standards Regulations for LDV and HDVs as is the case for EVs.

- **The current methodology for Regulations on CO_2 emissions standards considers only emissions at the tailpipe and provides a distortion in comparing ICEVs and EVs.**
- **But in reality, emissions from the production of fuels or electricity need to be accounted for.**

A lifecycle analysis of the carbon footprint of a vehicle should be applied to all technology options and would enable to consider the emissions from the production of the energy used, hence enabling scientifically sound comparison of the overall emissions.

A study conducted by IFPEN 2022 showed that hybrid cars running on biofuels have CO_2 emissions in Life-cycle Analysis (LCA) as low as BEV with the French low-carbon electricity mix. With the European electricity mix, hybrid cars running on such biofuels have lower CO_2 emissions in LCA.

3. **Circular CO_2 (from both biofuels and eFuels) does not increase CO_2 concentration in the atmosphere.** Therefore, both biofuels and synthetic fuels should be accounted CO_2 neutral fuels.

4. As for the GHG savings comparison - according to a study by Studio Gear Up (2022) on Greenhouse gas abatement costs for passenger cars, no technology today can achieve 100% emission reduction (on a Well-to-Wheel or LCA basis) as is requested by the Commission with its ambition to reach a minimum 100% GHG intensity reduction in CO_2 neutral fuels.

5. All forecasts show that long-term, when the whole value chain becomes fully renewable, **CO_2 neutral fuels would deliver 100% GHG reduction on a well-to-wheel basis.** This requires time and investments, and, all available capturing technologies (renewable energy consumption, carbon capture, etc.) will be needed.

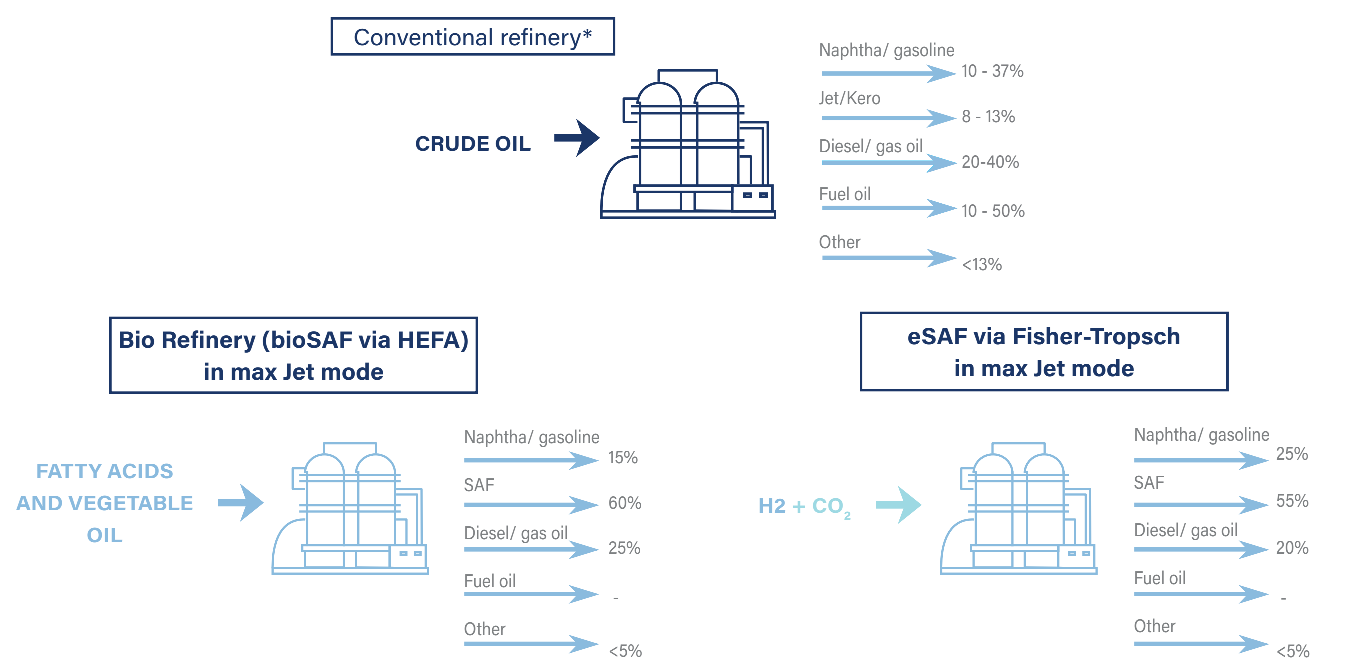
6. RED has a clear reference to GHG thresholds and sustainability criteria as well as a clear reference to sustainable feedstocks. **The definition of CO_2 neutral fuels should rely fully on the existing definition and sustainability criteria of the RED as a single and transparent source of requirements. All sustainable fuels fulfilling these criteria should be considered.** The European sustainability criteria set in the RED are among the strictest in the world and the proposed definition ensures a minimum reduction of CO_2 emissions as per RED requirements.

7. To avoid over-complexity of the EU regulation, there should be **one unique definition of CO_2 neutral fuels for all EU legislative acts and this definition should be aligned with RED.**

8. Enabling the use of CO_2 neutral fuels in road transport is viewed by the fuels and automotive industry as supportive and synergistic for the uptake of sustainable fuels in **aviation and maritime** for the following reasons:

Market size and investments resourc-

Graph 4.5: Conventional Jet Fuel/ SAF yields



Illustrative Refinery Yields (processing medium crude basket and depending on the complexity of the production scheme
Source: cleanfuelsforall.com

es: multi-billion investments will be needed to cover European needs of aviation and marine fuels. The bigger the market size, the bigger the investors' interest will be. Heavy-duty transport makes up 24% of final energy consumption in transport, while air and maritime transport each account for only 2%[4]. Reliable **revenues generated from the sale of renewable fuels to road transport will enable fuel suppliers to reinvest in SAFs and marine bunker fuels.**

Lead market: Road transport can be the ideal lead market we need to scale up the uptake of CO_2 neutral fuels, enabling industrial scale production and cost reduction for businesses and citizens. Fuels for road transport have already a significant taxation share, which can be a strong lever to incentivise renewable fuels production and use, by adapting the taxation to the carbon content alike electricity.

Co-products: It is technically not possible to produce only sustainable kerosene (SAF) in biorefineries and via Fischer-Tropsch route. During the production and refining process, **co-products such as renewable diesel, gasoline/naphta**, renewable LPG, and other products are also made, some of which can be used in road transport. Road transport demand for these products strengthens the business case to invest.

Economies of scale: The larger the capacity of the production plant, the lower are the CAPEX and OPEX per product/unit produced. Other associated costs, such as logistics and infrastructure, are also optimised. Airlines, shipping companies and transport operators could benefit from falling prices for renewable fuels, which would ultimately benefit end consumers.

In addition, a share of RED-compliant biofuel feedstocks – which are not listed in Annex IX – are not covered by the scope of the relevant sector regulations (ReFuelEU Aviation and FuelEU Maritime) and will therefore not be diverted to these sectors anyway.

Today, biofuels account for up to 90% of renewables in road transport and they can continue to meet a large part of future increased energy demand. **Biofuels are currently commercially available and delivered in sufficient amounts and thus available to accelerate the decarbonisation of the transport sector significantly.**

4.2. Fuel Production

i. Description of Fuel Production Pathways

Depending on the combustion principle, engines are developed and optimized for different types of fuels. The CO_2 neutral biofuel or eFuel based components given in the table below are used as drop-in fuels in existing engines - on its own or as a mixture. In petrol engines, a mixture of renewable gasoline components listed below at various ratios is needed so that the final blended products comply with their respective fuel standards. Additionally, the option for use of non-drop-in fuels exist if engines are adapted to them. A list of widely known drop-in and non-drop-in fuels is given in Annex 9.c.

Table 4.1

Diesel Engine (Compression Ignition)	Petrol Engine (Spark Ignition)	LPG Engine (Spark Ignition)	NGV Engine (Spark Ignition)
HDV & LDV	LDV	LDV	HDV & LDV
Diesel type HVO, Biodiesel, Diesel type eFuel (eDiesel)	Petrol type HVO (bionaptha), Bioethanol, Petrol type eFuel (eGasoline), Ethanol-to-Gasoline (ETG), Methanol-to-Gasoline (MTG), bioETBE	LPG type HVO (bioLPG), LPG type efuel (eLPG), renewable DiMethylEther (DME), eDimethylesther (eDME) (from eMethanol)	Biomethane (bioCNG, bioLNG), eMethane

4. Source: EEA - Annual European Union greenhouse gas inventory 1990–2021 and inventory report 2023

1. Diesel Engine Vehicles

Diesel engines are typically used to equip both light and heavy-duty vehicles. In 2022, 40.8% of cars circulating in the EU ran on diesel, whereas the share of newly registered cars running on diesel was 13.6% in 2023. However, it is in the commercial vehicle and bus sectors that the diesel engine is truly dominant: in 2022, 90.7% of vans, 96% of trucks and 90.5% of buses in the EU ran on diesel, and the share of newly registered vehicles running on diesel in 2023 was still 82.6%, 95.7% and 62.3% respectively for the three categories.

a) Diesel Fuel of Renewable Biogenic Origin: FAME and HVO

Biodiesel (FAME; Fatty Acid Methyl Ester) and renewable diesel (HVO; Hydro-treated Vegetable Oil) are renewable alternatives of biogenic origin to fossil-derived diesel fuel. They are produced from an array of renewable feedstocks including vegetable oils, animal fats and Used Cooking Oils (UCOs). Although often made from identical feedstocks, the processes used to make FAME and HVO are different, with different end uses.

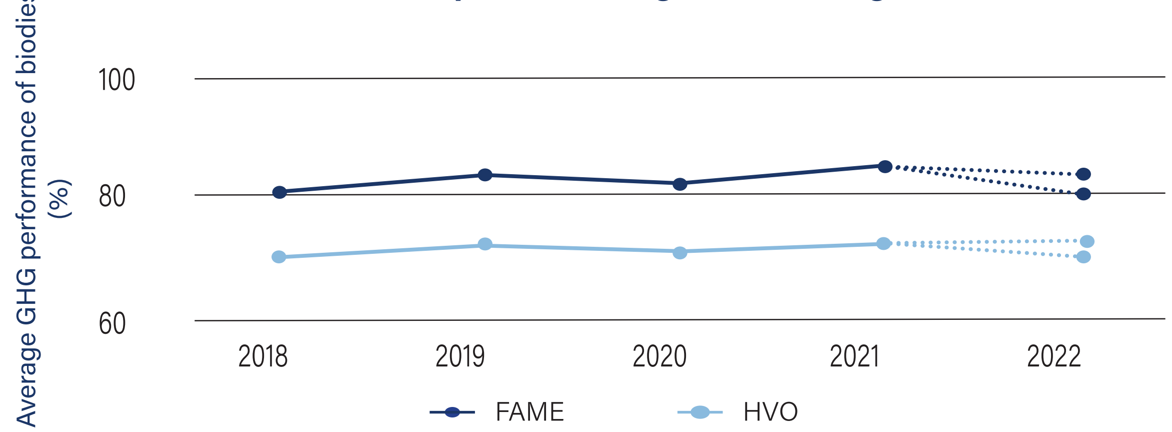
FAME is produced via biomass esterification, where fats are broken down then reacted with methanol to produce a final product similar to fossil diesel, but with a higher oxygen content. Like conventional diesel, biodiesel must comply with CEN standards.

Blends are designated "B", followed by a number indicating the percentage of biodiesel; B100 would be pure biodiesel. B10 is currently the maximum blend permitted by the Fuel Quality Directive (Annex 9.3) for sale at publicly accessible pumps across the EU. Higher biodiesel blends are also widely used around the world – B20 in the US, B35 in Indonesia, B10 in Malaysia, B12,5 in Brazil and B12,5 in Argentina.

HVO is produced via the hydro-processing of oils and fat, which gives a final drop-in fuel product, usable in a Diesel engine with no or minor modifications.

Overall, between 2018 and 2022, average emission intensity of diesel fuel of renewable biogenic origin for road transport has decreased by 8.6%[5]. Correspondingly, the average

Graph 4.6: Average GHG Savings



Source: Stratas Advisor, European Environment Agency, and national statistics
*Conservative estimate for 2022

5. These are average values. To be noted that the difference between FAME and HVO should not be interpreted as one technology is inherently more performant (in terms of GHG emission reduction) than the other. The difference is simply due to the fact that, traditionally and on average, HVO production is much more based on waste and residues, whereas for FAME production the agricultural crop component, while declining over the last years, is still important. It should be expected that said difference between FAME and HVO will be reduced over the coming years, as FAME is more and more produced from waste and residues, too.

6. For biofuels, biogas consumed in the transport sector, and bioliquids produced in installations starting operation from 1 January 2021.

GHG savings remain well above the threshold[6] set by the Renewable Energy Directive.

b) Diesel Fuel of Renewable Non-Biogenic Origin: eDiesel

Diesel can also be produced synthetically with electricity, water and air. Electricity is required to split water in hydrogen and oxygen. In addition, carbon dioxide is added. It can be captured from ambient air, industrial processes or biogenic sources. Two synthesis routes exist to produce eDiesel: Firstly the Fischer-Tropsch (FT) process, and secondly, methanol synthesis and further conversion of methanol to middle distillates (MtD) – typically ranging from C10 to C22 like diesel or kerosene. Both routes are chemically well-known and have a high technology readiness level although no large-scale MtD plant is in operation now. The difference is that via FT process several by-products like naphtha or kerosene exist and a refinery process is always required. These by-products can be used as blending components for CO_2 neutral fuels for petrol engines in road transport (see eGasoline, below), but also in the chemical industry, maritime, or aviation. This leads to synergies with other sectors but reduces production volumes for a dedicated product. Following the methanol route more eDiesel per energy input can be produced and no traditional refinery process is required. Many eFuel production plants are planned to follow the FT route e.g. Nordic electrofuel or Arcadia eFuel but also to follow the methanol route e.g. Hif global or Liquid Wind. Several vehicle tests have shown that eDiesel can be used in blends with fossil or biodiesel or as a pure product – also in existing vehicles.

According to the Renewable Energy Directive (RED) all RFNBOs and biofuels have to meet a defined CO_2 reduction threshold. However, a lifecycle analysis has shown that this reduction could be higher, potentially up to 95%. Further production and sustainability criteria are defined like the use of renewable electricity and sustainable carbon sources: In the Delegated Regulation 2023/1184 derived from the RED, it is defined that grid-connected eFuel plants are only allowed to use additional renewable electricity (from installations not older than 36 months) and need to prove a monthly temporal correlation (hourly from 2030 on) between the electricity generation and consumption in the same price bidding zone. CO_2 has to come from ambient, biogenic or from Industrial point sources, which are only allowed until 2041 and are required to be established in the EU Emission Trading system (ETS). These criteria are increasing production costs.

2. Petrol engine vehicles

As shown in the latest ACEA reports, 54.7% of existing passenger cars in 2022 ran on petrol – either with a full petrol engine or in a hybrid petrol engine. Regarding new EU passenger cars registrations in 2023 **(2024 Data to be added in future Drafts)** included a 35.3% share of petrol cars, a 25.8% share of hybrid cars and a 7.7% share of plug-in hybrids.

A variety of CO_2 neutral fuel pathways may be used in new CO_2 neutral petrol type vehicles, and may also effectively allow decarbonisation of pre-existing vehicles. Some of these CO_2 neutral pathways – such as bioethanol and bionaphtha, co-product of kerosene HVO (Hydro-treated Vegetable Oil) the most produced type of SAF (Sustainable Aviation Fuel) today - are readily available and already blended in petrol fuels sold in Europe.

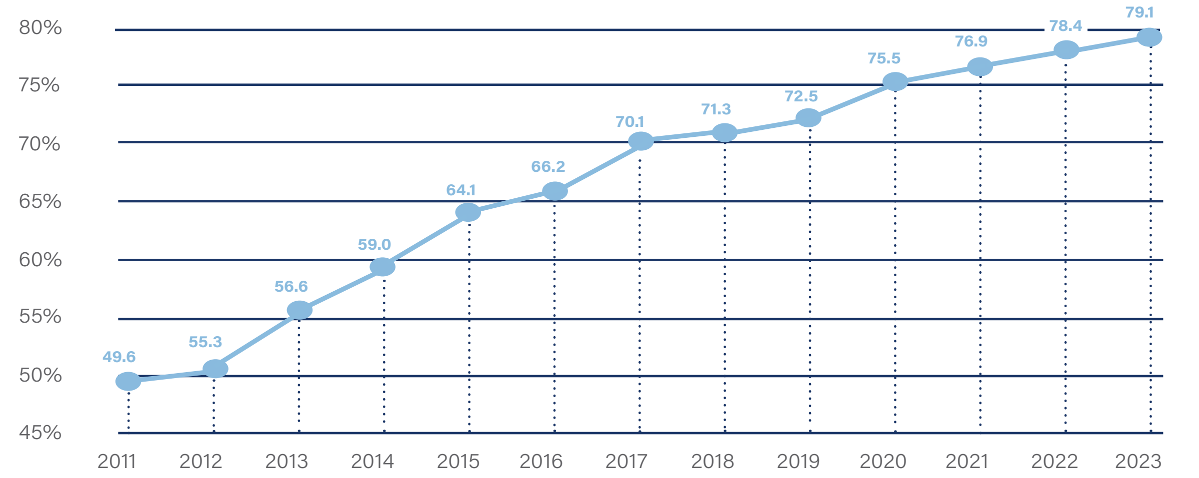
Bioethanol, bionaphtha and eNaphtha have different chemical properties and may be blended together to combine the best of each product: bioethanol has high neat octane number (109) and low volatility; bionaphtha has low octane (around 40) but high volatility.

a) Bioethanol

Bioethanol is the most produced biofuel in the world, with a global output of 125 billion litres (63 Mtoe) in 2023 (48% US, 28% Brazil, 8% China, 6% EU, 5% India, 5% rest of

Graph 4.7: Average Certified GHG Emission Savings in %

Since 2011 the average certified greenhouse gas emission savings of renewable ethanol against fossil fuel have increased continuously, reaching 79.1% in 2023



Source: Aggregated and audited data of ePURE members and other European producers for volumes certified under RED I or RED II methodology

the world) according to S&P Global. It is obtained by fermentation of sugars and starch contained in biomass.

100% renewable E85 has already proven its viability in the retail market in California, where it is used by about one million flex-fuel vehicles. It represented one-third of E85 Californian sales in 2022. French lab IFPen tested in 2024 three types of renewable gasoline to replace fossil gasoline in E85: bionaphtha, eNaphtha (co-product of eSAF) and Ethanol-to-gasoline (ETG). In all 3 cases, the pollutants emissions were very low compared to Euro 7 limits.

In 2023, European producers of renewable ethanol achieved an average certified GHG intensity reduction rate of 79% compared to the EU fossil fuel comparator. In 2023, 1,5 million tonnes of CO_2 were captured in bioethanol plants in Europe. By decarbonising boilers, by capturing fermentation CO_2 from ethanol production, and by replacing fossil CO_2 in other sectors, European bioethanol producers keep improving the GHG reduction of bioethanol made in Europe. Biogenic CO_2 can be used in eFuels production.

b) Gasoline Fuel of Renewable Biogenic Origin: Bionaphtha

Bionaphtha is a co-product of the production of HEFA (Hydro-processed Esters and Fatty Acids) a Sustainable Aviation Fuel. A HEFA plant never produces 100% HEFA. According to FuelsEurope (graph 4.5) when in maxi Jet Mode, the plant produces 15% of bionaphtha co-product. SAF plants do not only produce SAF, but also a variety of co-products. Bionaphtha is ideal as a component to blend with high % blends of ethanol or methanol such as for E85 or M85 grades, or with other renewable gasoline fuels, and this opportunity would likely assist the business case for SAF production.

c) Gasoline Fuel of Renewable Non-Biogenic Origin: eGasoline

Like the production of eDiesel, synthetic gasoline requires the same ingredients and follows identical production routes. Again, FT and methanol synthesis is possible to produce eGasoline. The only difference is that methanol to gasoline is follow different further conversion, which is a technology as mature as the MtD process. Methanol-to-Gasoline (MtG) technology was first developed by Mobil in 1980. It has proven commercial operation in large-scale projects e.g. in New Zealand. However, due to previous economic reasons MtG has not been adopted so far. The Haru Oni project by Hif Global in Chile plans to use a MtG process. Aramco and ENOWA have announced the installation of MtG utilising ExxonMobil technology in an eFuel plant in Neom in Saudi Arabia by 2025. MtG technology involves a multi-stage process to convert methanol into gasoline, with operating temperatures of 300-400°C and pressures of 15-20 bar. Production and sustainability criteria as well as blending shares can be similar to the eDiesel pathway.

3. LPG Engine Vehicles

a) LPG fuel of Renewable Biogenic Origin:

Liquid gas, commonly referred to as **Autogas** or **LPG (Liquefied Petroleum Gas)**, primarily comprises **propane (C_3H_8)** and **butane (C_4H_{10})**. Under relatively low pressure (6-8 bar at 20°C), it remains in liquid form but converts to a flammable gas when released at atmospheric pressure.

Dimethyl Ether (DME), an emerging renewable alternative, shares similar properties with LPG and can be used directly or blended with it.

Chemically akin to propane and butane, DME remains in liquid form under moderate pressure and is compatible with existing LPG infrastructure. When blended up to 12% by mass, DME can be used in LPG engines without requiring modifications.

Renewable Liquid Gases (rLG) include renewable propane, butane, BioLPG (bioPropane) and eLPG, known collectively as rLPG and renewable dimethyl ether, referred to as renewable DME.

Renewable LPG (also known as "bioLPG") - is from non-fossil and/or renewable/recycled sources, composed of propane and/or butane or mixtures with other light hydrocarbons.

Renewable and Recycled Carbon DME - from biogenic material, non-organic municipal waste, captured CO_2. Chemically similar to propane and butane, can be used directly or blended.

Renewable LPG (also known as "bioLPG") can be produced from biological sources and potentially from renewable electricity and CO_2. Currently, it is mainly sourced from HVO plants, where it is a by-product, of the production of renewable diesel or SAF

b) eLPG – CO_2 and H2 to Fuel: LPG Fuel of Renewable Non-Biogenic Origin:

eLPG (electro-LPG) is a renewable, non-biogenic fuel synthesized from CO_2 and hydrogen produced via renewable electricity-powered electrolysis. It can be produced as a co-product of hydrocarbon synthesis processes, such as Fischer-Tropsch (FT), or Methanol-to-Gasoline (MtG), or as a primary product from processes that directly synthesize LPG by combining CO_2 and hydrogen. eLPG relies on renewable electricity to generate hydrogen and can utilize captured CO_2 from industrial emissions or direct air capture, ensuring a closed carbon cycle.

4. NGV Engine Vehicles

Biogases are forms of biomethane (as bioCNG, bioLNG), or eMethane.

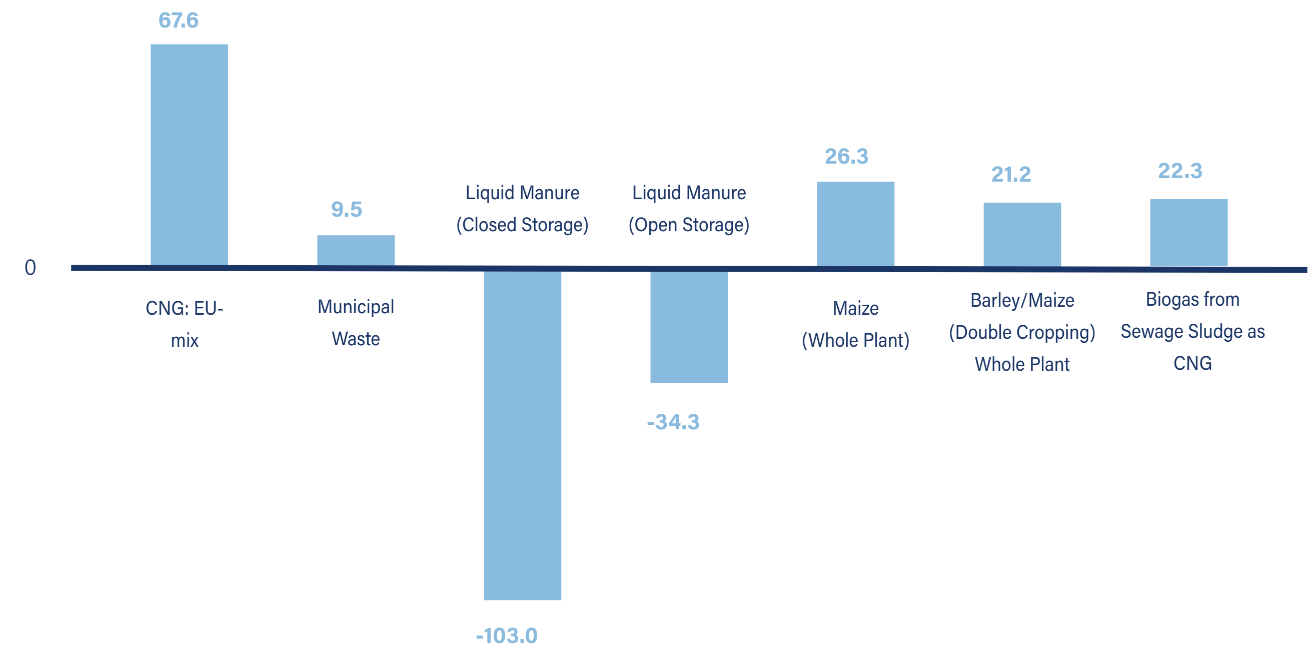
BioMethane ("renewable natural gas") is a near-pure source of methane produced either by "upgrading" biogas (a process that removes any biogenic CO_2 and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation. Most biomethane is from waste sources via anaerobic digestion. Thermal gasification with biomethane synthesis and Hydrothermal gasification are at demonstration stage.

BioCNG is the compressed gaseous form of biomethane, storable at 200 bar.

BioLNG is biomethane in liquid phase, giving higher energy density.

eMethane is an RFNBO from produced combining renewable hydrogen with CO or CO_2.

Graph 4.8: WTT Including Combustion Emissions (gCO_2eq) of CNG and BioCNG



Source: https://publications.jrc.ec.europa.eu/repository/handle/JRC121213

ii. Availability of Feedstock

The authors acknowledge the often-heard concerns that there will be insufficient renewable fuels to supply road transport, with the assertion that all available supply should eventually be routed to so-called hard-to-abate sectors like aviation and maritime in which no alternative to CO_2 neutral fuels exist.

A number of studies[7] however show that feedstock availability for both 1st generation biofuels and advanced biofuels is sufficient to meet the biofuels needs to contribute to the decarbonization of transport. It is important to recognize that assumptions for future use in road transport assume substantial electrification of fleets and the car parc, with CNFs able to play a significant complementary role . It should also be highlighted that 1st generation biofuels are not accounted for aviation and maritime transport targets and have therefore the potential to continue contributing to the decarbonization of road transport.

A full analysis and illustration of the potential available feedstocks, and the corresponding finished biofuels or eFuels is beyond the scope of this report, and so only brief summaries with graphical. A comprehensive study on biomass availability for production of CO_2 neutral fuels will be delivered by the Working Group in 2025.

7. The JRC-EU-TIMES model. Bioenergy potentials for EU and neighbouring countries by Joint Research Centre (European Commission) (2015)
- Research and innovation perspective of the mid-and long-term potential for advanced biofuels in Europe by Directorate for Research and Innovation (European Commission) (2017)
- Sustainable biomass availability in the EU, to 2050 (Concawe IC) by Imperial College commissioned by Concawe (2021)
- Task 2 of the study: Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels (DI Fuels) by Directorate for Research and Innovation (European Commission), Wageningen University & Research (2024)
- The Role of E-Fuels in Decarbonising Transport, by the IEA (January 2024)
- Ram M., Galimova T., Bogdanov D., Fasihi M., Gulagi A., Breyer C., Micheli M., Crone K. (2020). Powerfuels in a Renewable Energy World - Global volumes, costs, and trading 2030 to 2050. LUT University and Deutsche Energie-Agentur GmbH (dena). Lappeenranta, Berlin.

ii. Traceability of CO_2 Neutral Fuels

Road transport fuels regulatory compliance is administered at Member State level in a robust manner. This is typically placed under the scrutiny of national customs and excise duty authorities who can apply penalties in case of infringement. The high taxation rate on road transport fuels across the EU (with approximately €270Billion per annum collected) have given rise to very high security and robust accounting for virtually every litre of fuel sold. In most EU countries, compliance with renewable fuels regulation and blending mandates (the RED) is implemented alongside.

Renewable fuels production must abide by the sustainability criteria and rules set in articles 26 and 28 to 31a of the Renewable Energy Directive and in their associated secondary legislations:

1. Regulation (EU) 2022/996 establishes rules to verify sustainability and greenhouse gas emissions saving criteria and low ILUC-risk criteria

2. Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin.

3. Regulation (EU) 2023/1185 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a minimum threshold for greenhouse gas emissions savings of recycled carbon fuels and by specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels

This set of thorough and complex rules is gathered in 'systems documents' maintained by Voluntary Schemes (valid for international trade) and National Schemes (valid for national trade within one single Member State). These schemes must be accredited (a) by the EC and Member States for Voluntary Scheme and (b) only by Member States for National Schemes.

In 2018, RED II had set an initial ambition to consolidate the practice at EU level and put in place a Union database (UdB). The UdB was officially launched last January 15th 2024 and is operational as of the 21st of November 2024, according to the deadline set by RED III. The European Commission considers the UdB is functional for liquid biofuels. Up-to-date information on the status of its roll-out can be found on: europa.eu

In conclusion, the certification of the production of renewable and low-carbon liquid fuels can rely on a well-seasoned EU framework and continuously improved framework enforced in close coordination between the European Commission, Member State authorities, accredited certification schemes and independent certification bodies. Assuming an overland transportation vehicle can be assimilated to an aircraft or a shipping vessel, the UdB's functionalities under development for aviation and maritime could be extended to provide for a sturdy technical platform to trace the compliance of CO_2 Neutral Fuels from production to their marketing in the European Union.

05

FUELLING TECHNOLOGIES FOR VEHICLES & RETAIL

5.1. Introduction

The European Commission indicated their specific requirements for ensuring that a vehicle labelled as zero-emission, thanks to its exclusive use of CO_2 neutral fuel, does not and cannot use fossil-based fuel.

This Chapter describes how technologies and operational methods available today can be used such that the operation of a vehicle can be secured in a way that it meets this requirement. For this application, some of these technologies will require further detailed design and development to enable the best possible performance. Establishing clarity and acceptance of this overall approach as a viable compliance route will drive the business model to invest further in these innovations.

The authors' work shows that these technologies can enable an operational framework that is highly robust as is required for regulatory purposes. However, it will be essential that the corresponding policy framework is adapted to these developments, in order to deliver the enabling policy signals, compliance routes and create the required guardrails.

5.2. Description of Options for CO_2 Neutral Fuels

There are several possible configurations of an effective scheme, with eleven available separation and detection technologies/options examined by the expert group. The relative attributes of each technology are described in section 5.3. These options are presented in no particular order, and with no relation to their potential or recommendation from the group. These options can be used in combination, with each configuration having different advantages.

Please note that not all options are needed at each stage and that different configurations may be more suitable for certain fuel types or grades (as described in Chapter 4).

The Monitoring technologies/options can be grouped into the following two approaches:

a) **Direct Exclusive CO_2 Neutral Fuel Supply to Vehicle:** The CO_2 neutral fuel is delivered to the vehicle through a dedicated and isolated infrastructure end-to-end, in an exclusive manner, through fuel pumps that only supply 100% CO_2 Neutral Fuel. The technologies to facilitate this approach are described from option 1 to 8 in Section 5.3.

b) **CO_2 Neutral Fuel Supply for Specific Vehicle via Common System:** The CNF requirements of the vehicle are delivered via the current fuel infrastructure currently shared with petroleum fuels. This approach is particularly adapted for gaseous fuels. The fuel requirements of the vehicle are exactly matched with the same quantity of CNF supplied into the overall fuel supply system (e.g. a pipeline, terminal, or retail station) and securely matched with the vehicle through a digital system. It is described in detail in options 9 to 11 in section 5.3.

There are 4 possible concepts for direct exclusive CNF supply to vehicle:

- **Fuel Marking:** well-established fuel identifier technology that uses a distinct physical marker additive, which can now be used to prove CNF throughout the supply chain.
- **Digital Fuel Tracking System (DFTS):** already used in industrial safety systems, this technology enables secure digital tracking and ledger accounting of CNF across fuel supply system and vehicle operation.
- **On-board Detection:** vehicle-based group of technologies that can immediately detect presence or absence of CNF during fuelling by chemical or physical tests, and enable/disable vehicle operation.

- **Physical security of fuel connections** to enable CNF but prevent fossil-based fuel throughput

Table 5.1. summarises the different approaches, as well as the different concepts that were discussed in the WGMM.

Not all the options are applicable to all types of fuels. As specified in table 2 of 5.4, all drop-in fuels, where the chemical composition of renewable and conventional fuels is the same, cannot rely on on-board detection or fuel marking options.

Table 5.1

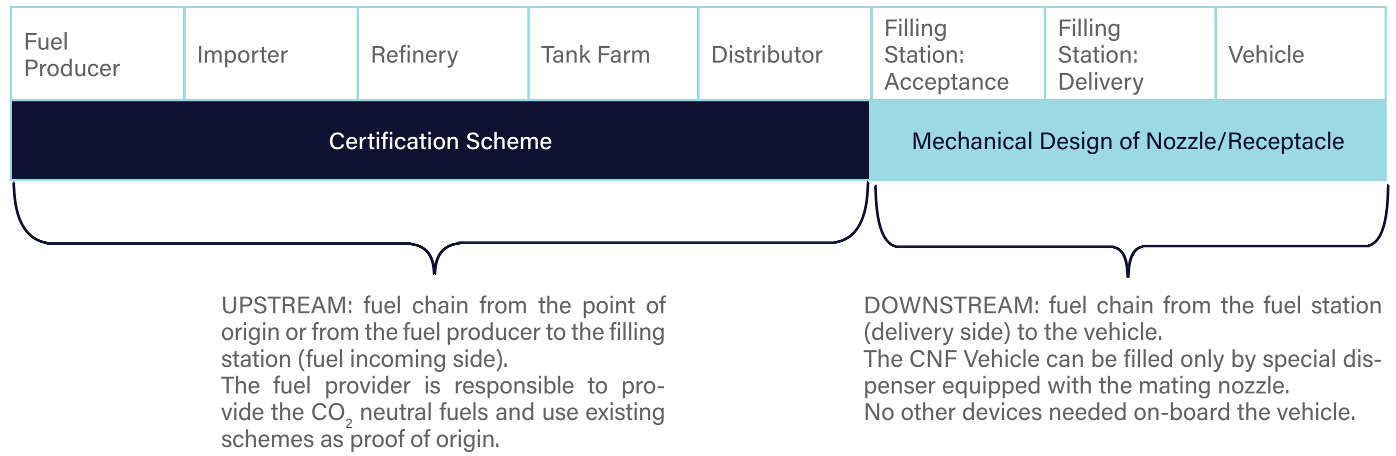
APPROACH	**Direct Exclusive CNF Supply to Vehicle**				**Mass Balanced CNF Supply for Specific Vehicle via Common System**	
DESCRIPTION	The CNF is delivered directly to the vehicle. The fuel pump and supply is exclusively CNF, the vehicle consumption is exclusively CNF. The vehicle does not and cannot receive or use any fossil-based fuel. The physical movement of carbon-neutral fuel through a dedicated supply chain is too restrictive during the transition phase primarily due to the significant infrastructure investments and logistical complexities involved. Establishing an independent supply chain to avoid contamination requires substantial capital expenditure and time, which can be prohibitive for early-stage implementation. Additionally, the limited availability of dedicated fuelling stations can create inconveniences for consumers, leading to range anxiety and hesitancy in adopting carbon-neutral fuel vehicles. This approach also poses challenges for fuel suppliers and retailers in predicting demand and ensuring consistent supply, further complicating the transition.				This mimics the operation of the electricity grid, where there are both renewable and non-renewable suppliers, and customers for 100% renewable, or non-renewable electricity. All of the electricity is carried on a common grid but renewable off-take contracts are exactly matched to certain 100% renewable supply. Similar to renewable electricity supply contracts, indirect but precisely matched supply of CNF into existing fuel supply infrastructure, equivalent to consumption of identified vehicles, the CNF sustainability and quantity certification must be reported to account for the fuel consumed by the CNF vehicles. Digitised transactions and ledger accounts can provide high accuracy and rigour. Nonetheless, this approach is not supported by the proposed inducement system for CNF vehicles by the European Commission.	
CONCEPT	Regional Exclusivity	Fuel Property Measurement	Fuel Additivation		Digital Supply Chain Tracking with Mass Balancing	Mass Balance
POTENTIAL TECHNOLOGIES	8. EU Market exclusively supplied with CNF 1. Mechanical adaptation of Tank Filler	5. Vehicle on-board fuel detection function 6. On-board Fuel Molecular Sensor	2. Fuel marker along upstream and downstream 4. Hybrid approach: Fuel Marker and DFTS	3. 100% digital fuel tracking from upstream to downstream 4. Hybrid approach: Fuel Marker and DFTS 7. Bidirectional communication between vehicle and gas station	11. Combined Mass Balancing DFTS w/ digital handshake 10. Fuel Usage	2. Mass Balancing

Rigorous → **Flexible**

5.3. Description of Technology Options

Option 1 – Mechanical Adaption of Tank Filler / Nozzle

Graph 5.1: Responsible Stakeholders Involved



Description

The mechanical adaptation of the tank filler/nozzle covers the "downstream" part of the fuel chain, with a dedicated connection between the filling station and the vehicle. This method alone is not enough to be accounted as a complete monitoring system, and it would need to be combined with another method covering the "upstream" part of the fuel chain. With such a proper methodology in the upstream part, we assume herein this description that the right fuel arrives at the filling station, it is placed in a dedicated storage, and it would be sold through a dedicated dispenser.

The fuelling station would install a dedicated dispenser equipped with a specific fuel nozzle, which is not able to connect with the receptacle used for the fossil version of the fuel in use.

In this way, the vehicle could only receive the correct (CNF) fuel because the fossil fuel nozzle cannot be connected to the vehicle.

This method is based on a mechanical design of the nozzle and the receptacle, where we can classify the following situations:

- Liquid fuels, such as petrol and diesel: the receptacle is a round-shaped hole, designed to accept the fuel nozzle. The dimension and the shape of the hole are the only parameters that could change to create a dedicated receptacle for renewable fuels, to be used in alternative to petrol or diesel. For this kind of fuel, it is less reliable than a secure connection that prevents unauthorized filling.
- Gaseous fuels, such as natural gas and LPG: the nozzles and the receptacles form a leakproof connection. In this case, the mechanical shape and dimensions of the receptacles can be varied to create a new leakproof connection, able to connect only with the renewable fuel dispenser and not with the fossil one. For example, there is a "B200 standardized connector", which is currently used for light-duty natural gas vehicles (according to ISO 14469)
- Requires the duplication of dispensers, especially in the transition phase.
- The vehicle cannot run if the CO_2 neutral

fuel is not available. But we must take into account that, especially in a transition phase, the number of CO_2 neutral fuel filling station could be limited.

- Outside Europe such a new connector would not be made available.
- Tampering possibilities do need to be considered. In the current mechanical concepts, it cannot be completely excluded.

Option 2 – Fuel Marker along Upstream and Downstream

A CNF Marker additive would enable all market participants (from the fuel industry to vehicle manufacturers) to introduce climate-neutral fuel as a new fuel variant with two safety features with very little effort, maximum speed and flexibility in the introduction by 2035. The physical features are already being tested in the field, for instance during the DeCarTrans project, where physical safety features are:

- Colour achieved with designated additive
- Chemical identifier tag (additive)

Fuel marker products can be used for the marking and colouring of CNF liquid fuel products such as 'methanol to gasoline', BTL, or HVO. They usually are free-flowing liquids and may contain an additional labelling system. The product can be easily pumped, poured or dispensed directly from the container. As synthetic fuels are being developed as drop-in alternatives to conventional fossil fuels, they are very similar in their chemical composition. They are burnt under the same engine conditions and are recognised as having no impact on air quality emissions from the vehicle. Note that this additive technology is not suitable for use in any gaseous fuels.

At a final stage, the concept would need to be combined either with the vehicle-sensor or digital handshake solution to robustly enforce consumer use of CNF.

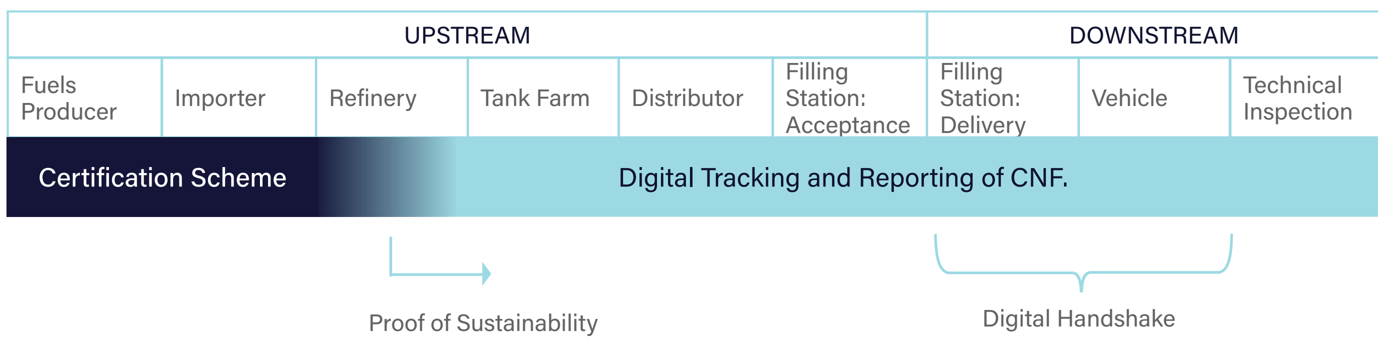
Target Stakeholders

The Fuel Marker is connected to all relevant stakeholders, including the Customs Directorate and the Ministry of Finance. Confirmation of CNF for pure CNF vehicles, plausibility check and tracking of the fuel (incl. CO_2 footprint).

- Visual inspection of only CNF-dedicated vehicles using colour recognition similar to the known procedures for port diesel or heating oil EL.
- The colour of the chemical tag is checked by a marker to prevent fraud. For the Customs Directorate, analysis methods are supplied by the additive supplier and independently supervised by the government regulator.

Option 3 – 100% Digital Fuel Tracking System from Upstream to Downstream (DFTS w/ Digital Handshake)

Graph 5.2



Digital twins are already used in other industrial systems, as application for fuels offer secure and robust digital tracking and ledger accounting of CNF across fuel supply system and in-vehicle operation. DFTS enables all stakeholders a fast on-boarding process, by utilising only data, which is already available (via RED II framework) in fuel supply infrastructure and the vehicle. It can be implemented fast with the potential of starting field introduction immediately with the Commission's approval.

DFTS digitalises the entire fuel supply chain from fuel production to end consumer (all relevant stakeholders) and enables all stakeholders to utilise CO_2 Neutral Fuel (CNF) as a new fuel variant by digital certification.

DFTS includes CO_2 tracking and certification of sustainability reports of CNF along the fuel supply chain from refinery to the filling station (upstream). As main DFTS entry information serves the fuel's proof of sustainability (PoS), which is originated by an already established certification scheme (e.g. ISCC, Nabisy, 2BS) and transferred through DFTS. DFTS performs a digital pairing of vehicle and fuel supply chain (digital handshake) to assign the refilling event to the filling station (downstream) Based on this filling event, the vehicle can check, whether filled fuel was CNF and accordingly can perform an inducement reaction, if check result is negative. It further incorporates digital fuelling monitor as software function in the vehicle.

DFTS provides confirmation of CNF for CNF only vehicles, assures robustness with plausibility checks in a multiple trust centre approach and enables end-to-end tracking of fuels including its CO_2 footprint. DFTS is further capable of including sustainability information of physical fuel blends and mixtures, as well as fuel origin or even fuel properties. Transparent sustainability tracking is possible, enabling the vehicle to incorporate its own climate-consciousness which transparently accounts for a real driving sustainability footprint. DFTS further enables prompt and retrospective inducement of the consumer with flexible transition from soft to hard limiting/inducement. DFTS can provide access for the authorities (quasi-technical review with historical data of consumers). Enables a tolerance phase in emergency situations or canister filling.

Option 4 – Hybrid Approach – Upstream: Fuel Marker & Sensor Until EU Border – Downstream: DFTS w/ Digital Handshake

This "Triple Solution" enables all market participants (from the fuels industry to vehicle manufacturers) to introduce climate-neutral fuel as a new fuel variant by combining two safety features and a digital solution with very little effort, maximum speed and flexibility in the introduction. **The physical features are already active in field tests as part of the DeCarTrans project (funded by the German Federal Ministry of Transport and Digital Infrastructure).** The physical safety features are:

- Colour
- Chemical tag

The marking system includes CO_2 tracking and certification of sustainability reports for CO_2 neutral fuel along the fuel supply chain from the fuel depot to the filling station (upstream), and includes a digital refuelling monitor as a software variant in the vehicle. The vehicle performs a digital handshake with the petrol station in order to assign the refuelling event to the petrol station (downstream). Based on this event, the vehicle checks whether the refuelled fuel is CNF and, if the test result is negative, reacts accordingly. Note that this additive technology is not suitable for use in any gaseous fuels. See section 5.3. Option 2.

Target stakeholders

The Hybrid Approach has the connection to all relevant stakeholders including the customs directorate and the Ministry of Finance. Confirmation of CNF for pure CNF vehicles, plausibility check and tracking of the fuel (including CO_2 footprint).

Option 5 – Vehicle On-Board Fuel Detection Function

Today's existing vehicle and combustion engine technology has a high reliability and is affordable to enable individual mobility, transportation of goods and raw materials and many other purposes. Typical vehicles sold today have a lifetime >10 years and will operate beyond the year 2040.

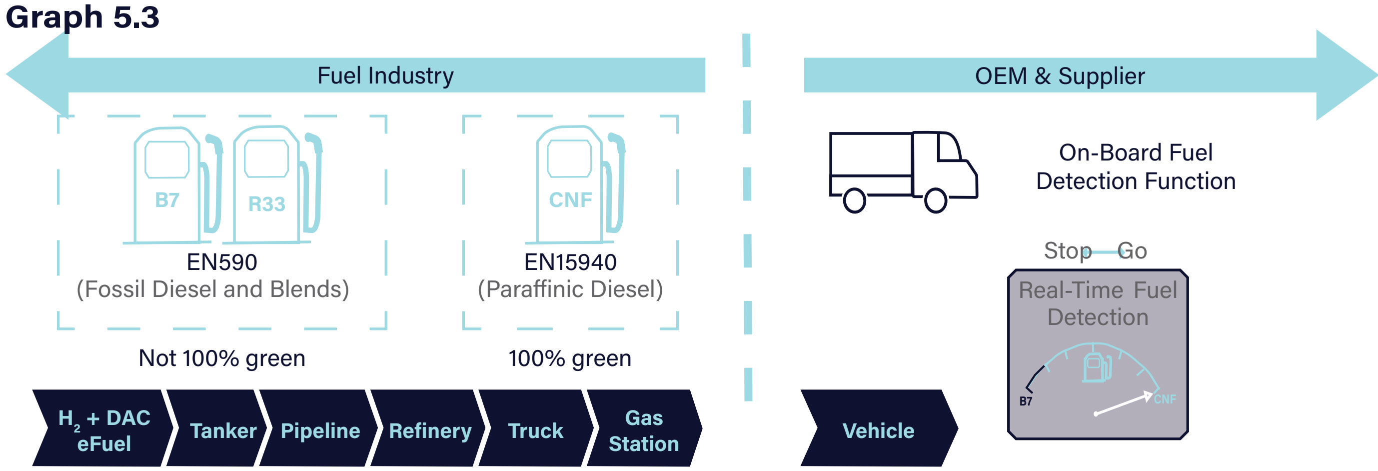
Already most of today's vehicles are suitable for the use of synthetic fuels such as paraffinic fuels (EN15940 labelled as "XTL") and synthetic gasoline fuel (from Methanol-to-Gasoline process denoted as "MTG"). Paraffinic fuels and MTG have a strong potential for emissions reduction due to the absence of aromatic hydrocarbon molecules and produce less soot emissions than fossil fuels. These fuels can be produced carbon-neutrally by using green hydrogen and capturing the CO_2 from renewable, air or using biomass as input feed to the production process.

An audit process is already established to certify that the fuels are carbon-neutrally produced. Thanks to differences in the chemical composition, the fuel properties differ from the fossil fuels and the usage of these new fuels could induce a different system response for CNFs. A fuel detection function could be based on the existing vehicle and engine system technology without new sensors or interfaces to implement. In the case that the CNF is chemically the same as the fossil fuel e.g. gaseous fuels, then such detection technology is limited and other methodologies have to be considered.

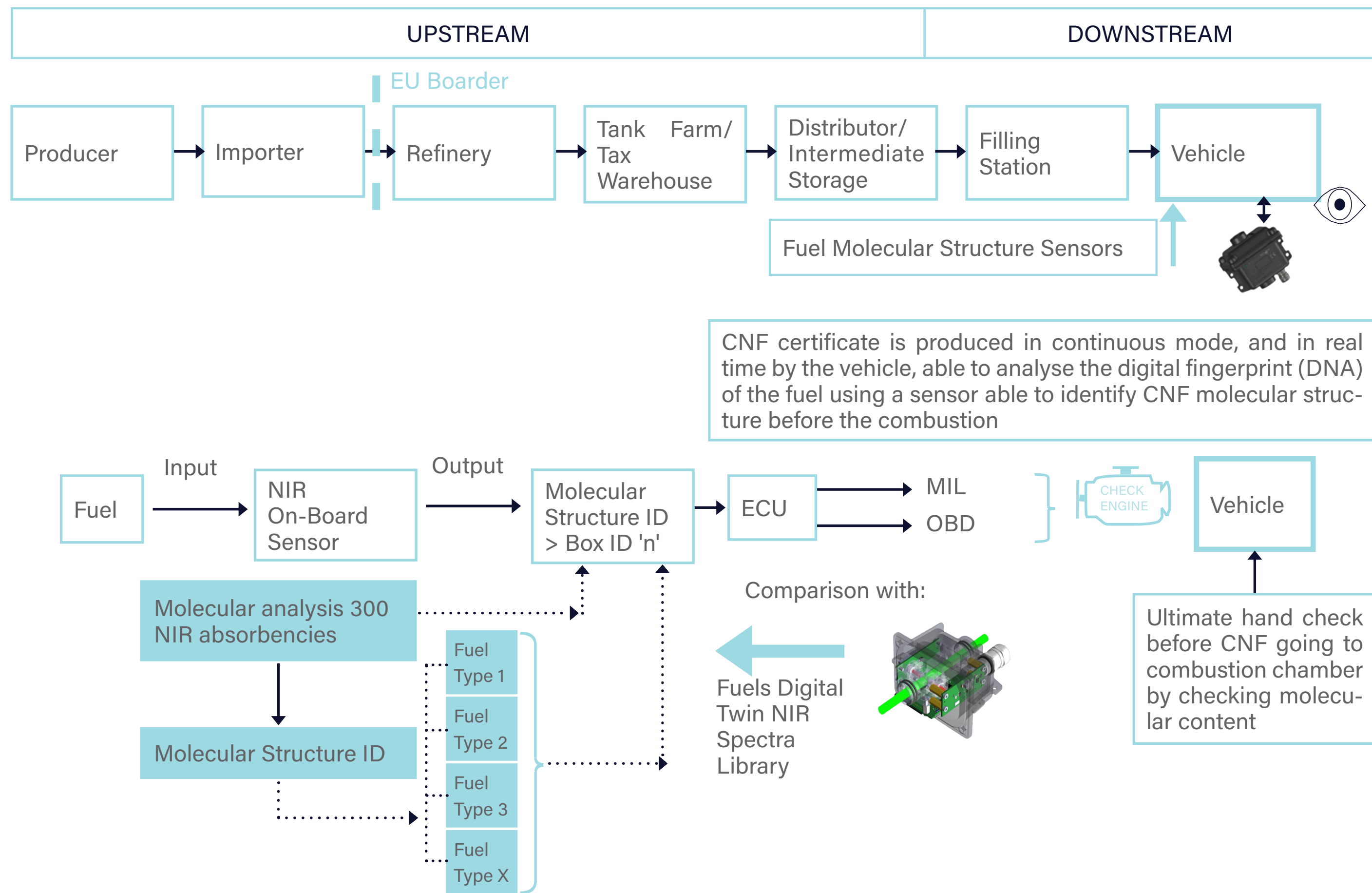
While such functions could be realized in an engine management system, it is also likely to realize functions that alters the engine operation when a non-carbon-neutral fuel would be used, likely to reduce performance and/or operability. Several levels of alteration from initially warning the driver and then limiting or stopping the vehicle operation could be considered, like those applicable to the latest diesel cars/vans/trucks with SCR (Selective Catalytic Reduction) technology to control the NO_x emissions.

The detection function is also retrofittable. The fuel detection function could operate on a vehicle and engine management system level without any further data connection and services in the data cloud. Therefore, in such a configuration this methodology would protect the owner's data privacy and also should be resilient against cyber-attacks and IT fraud or tamper attempts. The comparatively low complexity of detection function and lower demands on additional infrastructure would allow also a fast realisation and effective implementation on a vehicle.

Graph 5.3



Graph 5.3



Option 6 – Vehicle On-Board Fuel Molecular Sensor

In the realm of fuel quality measurement, several sensor technologies could be employed to assess the physical and chemical properties of fuels. However, many of these technologies are limited in their ability to distinguish between different fuel types within the defined European fuel standards (EN590, EN228, EN15940, EN14214, EN15293). This limitation arises because the physio-chemical properties of fossil fuels or CNF within these standards do not significantly differ to allow clear separation between fossil and 100% fossil free fuels.

In contrast, Near Infra-Red (NIR) spectroscopy has been extensively used in various process industries (chemical, refining, pharma…) since the 1970s-80s for quality control of organic products (feedstocks; finished products), including fuels in refineries since the 1990s. The technology is now in series production and has been successfully utilized in the transportation market for several years, following 15 years of development supported by OEMs, engineering teams, and universities. It can be seamlessly integrated with regulatory geofencing systems, enabling the application of constraints based on the vehicle's location, further enhancing its versatility and adaptability.

This technology is not suitable for gaseous fuels.

Option 7 – Bidirectional Communication between Vehicle and Filling Station

The basic principle targets two main aspects using e.g. Near Field Communication (NFC), Bluetooth Low Energy (BLE) or Wi-Fi:

1. How to generate trust in the CO_2 neutral fuel (CNF) delivering partner?
2. How to ensure that no manipulation takes place during the whole fuel transfer duration (anti-tampering)?

Therefore, this solution contains an authentication method of the CNF delivering partner before the start of fuel transfer and a tampering protection during the fuel transfer. The method was developed for the refilling at a filling station, but it could be used wherever CNF is transferred from one area of responsibility to another (e.g. tank farm to tanker truck). In the following description the example of a refilling of a vehicle at a filling station is described:

- Delivering partner = filling station
- Receiving partner = vehicle

Description

Authentication of the delivering partner:

For the authentication of the delivering partner (filling station) at least one partner needs an internet connection to an authentication authority. The authentication authority can be any trustworthy organization or association which provides a digital authentication service accessible via internet. Additionally, a digital communication between the two partners is necessary.

A data communication between filling nozzle and the filler neck in the vehicle is used to initiate the authentication process and to be robust against tampering during the whole refilling process. Depending on the gas stations communication infrastructure, a bidirectional data communication could be used. Alternatively, unidirectional data communication in the filling neck is possible.

Option 8 - EU Market Exclusively Supplied With CNF

This scenario is described and examined for a future year, certainly after 2035. This is more realistically an exercise in exploring the potential that this could be possible in a time-scale after 2035 to help achieve the policy of the EU for climate neutrality.

Petroleum-based liquid and gaseous road transport fuels would be banned and therefore unavailable in the EU (or in certain Member States), and for some or all vehicle categories (e.g. diesel or gasoline or methane). Accordingly, all affected vehicles would have to use CNF. When crossing the borders (entry) into the EU (or into affected Member States), suitable measures may still have to be defined. The responsible stakeholder would likely be the Member State legislator to ensure that no fossil-based fuels would be put on the market.

This option assumes that CNF availability would be sufficient to meet demand. Today the CNF availability is low, relative to the total demand. However, if the political framework is changed it could stimulate investments into CNF production. Additionally, it is expected that total liquid and gaseous fuel demand will decline as petroleum-based fuels are discouraged through policies, and through fleet and park electrification, thus at some point allowing CNF supply to match demand.

Option 9 - Mass-Balanced CNF Supply to Each CNF Vehicle.

Here, the CNF requirements of the vehicle are delivered via the current fuel infrastructure currently shared with fossil fuels. The fuel requirements of the vehicle are exactly matched with the same quantity of CNF supplied into the overall fuel supply system (e.g. a pipeline, terminal, or retail station) and matched with the vehicle securely with a digital system. This is often described as "Mass Balancing".

It is fully recognised that the Commission currently foresees that the necessary security is achieved by physical separation/dedication means. This option could be applied during a transitional period throughout the fuel supply chain until the availability of CNF is secured everywhere in the EU. This will work in a similar way to green electricity, for which Mass Balancing represents the mainstream methodology for distributing and certifying "green" electricity to end users (including vehicles).

When the technologies and methodologies are fully established and successful in delivering this solution, to the satisfaction of governments, customers, automotive and fuel industries, it is worth considering if the supply of CNF to vehicles can be achieved robustly by mass-balancing means. This report aims at proposing a comprehensive overview of all available options. It illustrates the necessary technologies and methodologies could be evolved further in future to enable such an approach.

Each CNF vehicle uses fuel from the conventional fuel distribution system using existing retail fuel stations. However, use of all fuel by the vehicle is exactly matched in quantity by supply of the exact amount CNF upstream of the retail site. This approach has major advantages in using mostly existing physical infrastructure. These advantages would enable a wider, more rapid and lower cost roll-out. Finally, this approach is specifically adapted for the distribution of gaseous fuels. Robust and secure accounting will ensure that the use of the vehicle does not create any demand for any fossil fuel, only for CNF. This will deliver the exact same climate benefits as a system requiring direct physical supply.

This approach could also use a digital fuel tracking system, digital handshake and two-way communication between vehicle and petrol station as enabling technologies, as described in Option 11. It would also draw on the experience of mass balancing in electricity markets, aviation fuel supply and other commercial and regulatory compliance operations. The expert authors believe that a similar level of rigour and security can be achieved as with Direct Physical Supply. Accordingly, the authors believe it is important to not exclude the Mass-Balance option alongside the Direct Physical supply model.

Option 10 – Fuel Usage Balancing - FUB

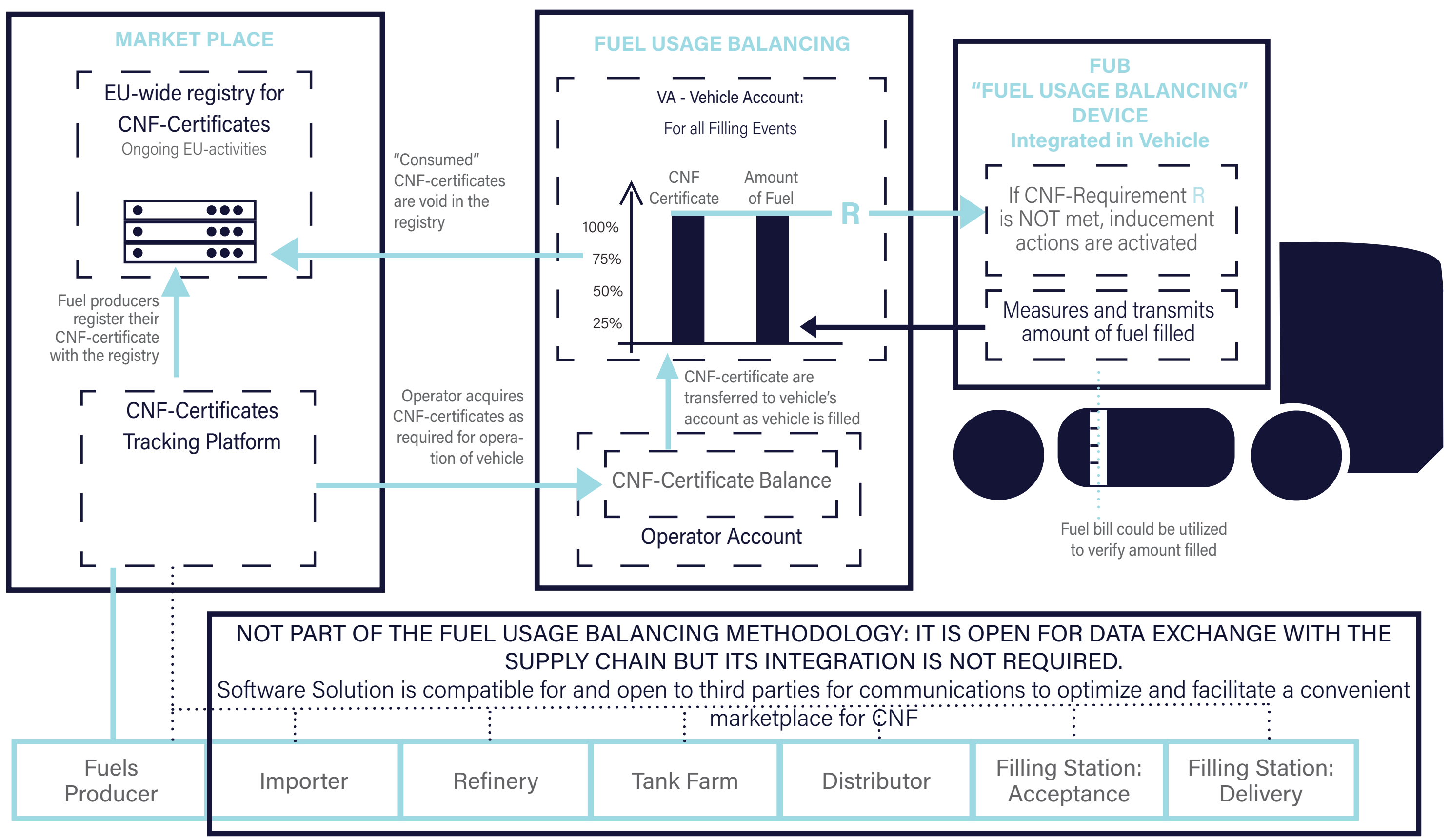
This is a technology that can enable an accurate implementation of a mass-balance operational methodology on an individual vehicle level, i.e. combined with Option 9. The Fuel Usage method (FUB) is a software solution that tracks each vehicle's fuel usage. One feature of the FUB-device in the vehicle is detecting filling of the vehicle and connecting to the vehicle's individual account in the software. The amount of fuel filled is taken from the financial transaction data to pay for the fuel, an integrated process in the software, and stored in the vehicle's software account.

The motorist is responsible for purchasing CNF certificates matching the fuel used. The software platform facilitates the acquisition of these certificates and directly communicates with the CNF registry to void used certificates.

Based on certificate compliance, the system signals the vehicle to activate or not activate a wide range of inducement actions up to denial of operation. As the software platform is open to all market players, it seems likely that motorists will be able to purchase a service that continuously acquires and provides the required CNF-certificates automatically without any further input or action of the motorist of the vehicle.

The FUB method works for all types of fuels, i.e. gaseous, liquid or electricity. It does not detect the origin of the fuel, i.e. whether it is fossil or renewable e.g. methane (=biomethane or synthetic methane).

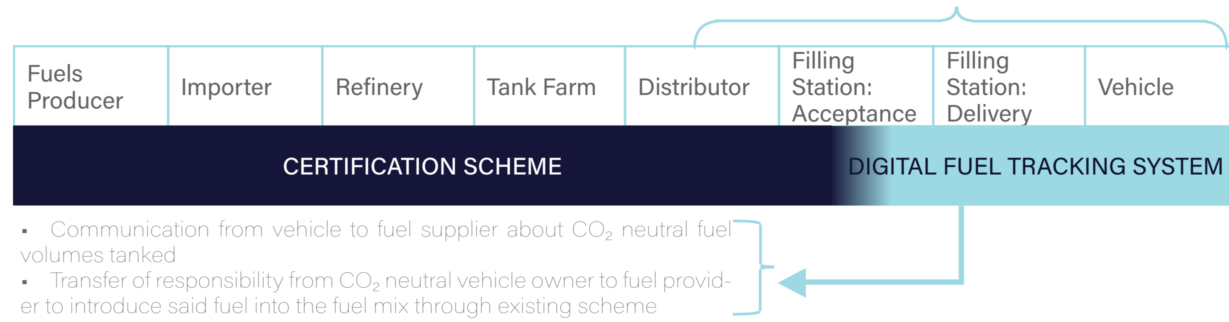
Graph 5.4



Option 11 – Combined Mass Balancing - DFTS w/ Digital Handshake)

Graph 5.5

- Digital Software solution that enables transparency and auditability of CNFl volumes.
- Provides critical digital handshake to the vehicle to continue to operate
- If CNF vehicle tanks without a confirmation through a "digital handshake", the vehicle will not be able to operate and inducement system will be activated.



Description

This is designed to enhance Mass-Balancing methodology Option 9 by combining it with a digital fuel tracking system.

Mass Balancing

See Option 9.

Digital Fuel Tracking System (Digital solution)

See Option 3.

Under this system, customers who opt for CO_2 neutral fuels are not guaranteed to receive the physical renewable product. Instead, the approach ensures that an equivalent amount of CO_2 neutral fuel is supplied to the market and consumed elsewhere, aligning with the principles of sustainability and environmental responsibility based on the renewable energy directive approved certification schemes. This method emphasizes the importance of digital tracking to maintain the integrity of the CO_2 neutral fuel claims.

This monitoring solution leverages both principles to ensure that the vehicle has an inducement system mechanism to monitor the usage of CO_2 neutral fuels.

This software solution will have to be transparent and auditable (similar to existing European certification scheme) to enable a correct and clear accounting of the CO_2 neutral fuel volumes that the fuel supplier has sold to CNF vehicles. The resulting volume would have to be introduced to the fuel mix accompanied with the respective European certificate applicable for the CO_2 neutral fuel.

The filling station (publicly available or for captive fleets) is connected to this digital platform and 'consumes' the certificates according to the amount of delivered fuel. The platform will offer the possibility to define different compensation criteria, such as the full compensation between fuel delivered and acquired certificates at the end of a predefined period (for example once a month).

This solution leverages the existing fuel supply infrastructure and certification scheme for RFNBOs and biofuels of the European Union (REDII/III) to provide a solution that enforces the use of CO_2 neutral fuel vehicles in the market, as long as they tank CO_2 neutral fuel.

5.4. Evaluation Matrix & Outcomes

Table 5.2: Tracking; Detection and Inducement Overview by Technology:

#	METHODOLOGY	TRACKING METHOD	DETECTION METHOD	INDUCEMENT SYSTEM	FUEL COMPATIBILITY
1	Mechanical adaption of tank filler / nozzle	Physical	Mechanical	Not required	Gaseous and Liquid fuels
2	Fuel marker along upstream and downstream (sensor in vehicle)	Physical	Sensor	YES	Liquid fuels
3	100% digital tracking from upstream to downstream (DFTS w/ digital handshake)	Physical	Electronic by re-using existing data	YES	Gaseous and Liquid fuels
4	Hybrid approach - upstream: fuel marker & sensor until EU border - downstream: DFTS w/ digital handshake	Physical	Sensor & Electronic	YES	Liquid fuels
5	Vehicle On-board Fuel Detection Function	Physical	Sensor	YES	Liquid fuels
6	Vehicle On-board Fuel Molecular Sensor	Physical	Existing Engine Sensor	YES	Liquid fuels
7	Bidirectional Communication between vehicle and gas station	Physical	Electronic	YES	Gaseous and Liquid fuels
8	EU market exclusively supplied with CNF	Physical	NR	Not required	Gaseous and Liquid fuels
9	Mass-balanced CNF supply to each CNF vehicle	Virtual	None	NO	Gaseous and Liquid fuels
10	Fuels Usage Balancing - FUB	Virtual	Electronic	YES	Gaseous and Liquid fuels
11	Combined mass balancing - DFTS w/ digital handshake	Virtual	Electronic	YES	Gaseous and Liquid fuels

Outcome of the Evaluation Matrix

Option 1 - Mechanical adaption of tank filler / nozzle: Mechanical adaption of the filler neck and the nozzle would physically prevent that the wrong fuel is filled but in practice it is prone to tampering and might not be considered as robust enough when used alone. Additionally, it will incorporate high efforts for the development of new standards and hardware at both filling station and vehicle, including additional integration efforts.. This option requires the physical product to be moved in a dedicated supply chain.

Option 2 - Fuel Marker along upstream and downstream: Fuel marker and sensor in the vehicle physically track the CNF based on already known system such as heating oil, but currently no off-the-shelf automotive sensor is available. New developments for automotive requirements (e.g. robustness, selectivity, sensitivity) with high efforts as well as handling vehicle hardware variants are expected. Further, the tracer system needs calibration and high selectivity to fuel blends and mixtures. With regards to tampering robustness, marking the fossil fuel may be a more robust solution.. Possible improvement in a hybrid approach described as Option 4. This option requires the physical product to be moved in a dedicated supply chain.

Option 3 - 100% digital tracking from upstream to downstream (DFTS w/ digital handshake): DFTS (Digital Fuelling Tracking System) as a 100 % digital solution along the entire delivery chain, completely based on the existing data and infrastructure of the different stakeholders, can be implemented fast with the potential of starting field introduction immediately with EC's approval. Via digital handshake reliable pairing of vehicle and nozzle is realized and allows flexible inducement reaction. Manipulation robustness is assured by plausibility checks within a multi trust centre approach (stakeholder – cloud - vehicle). Today available data points in high precision and based on existing standards and legal framework (taxation, delivery bills) at the stakeholders are combined in an intelligent way on a cloud platform providing maximum end-to-end robustness. DFTS is further capable to include sustainability information of physical fuel blends and mixtures (as other solutions cannot), as well as fuel origin or even fuel properties. Transparent sustainability tracking is possible, enabling the vehicle to incorporate its own climate-consciousness which transparently accounts for a real driving sustainability footprint. In this way helping to stimulate a faster switch from fossil to non-fossil fuel usage. The solution needs technical adaptations in the vehicle, logistics and the fuelling stations

Option 4 - Hybrid approach – upstream: fuel marker & sensor until EU border – downstream: DFTS w/ digital handshake: A possible improvement of the sensor & marker approach could be a hybrid approach in combination with DFTS. Within this solution, the lack of automotive ready sensors could be bypassed by performing a digital handshake with filling station, based on a sensor signal which measures the fuel marker in the filling station itself. So less stringent requirements for such a sensor would apply, which leads to lower integration efforts at OEM side and faster time to market. However, sensitivity and selectivity challenges of a marker-based system still exist (c.f. Option 2). This option requires the physical product to be moved in a dedicated supply chain.

Option 5 - Vehicle On-board Fuel Detection Function: On board fuel detection by processing the existing Engine Control Unit (ECU) signals is a pragmatic software solution which is based on data already available in the vehicle. The solution may work for CNFs with properties which are different to conventional ones such as HVO and Diesel. However, currently no solution for gaseous fuels is known.

It might require calibration to include possible future fuels, since the actual measurement value (correlating with property) may change from one fuel source to another, resulting in additional deployment efforts in field. This option requires the physical product to be moved in a dedicated supply chain.

Option 6 – Vehicle On-board Fuel Molecular Sensor: Molecular structure sensor is another option, which directly tracks the fuel type in the vehicle and not a marker as proposed in Option 2. The on-board sensor is available in series production and fulfils the standards outlined in EN590 and EN228.

It is capable of providing the on-board, real-time final verification required by the EU, as it already does in bus and truck applications to detect fossil fuels. CNF detection has been successfully implemented for standards such as EN14214 and EN15940 (using a fingerprint database), and new databases are currently being developed for eFuel molecules like MtG and FT.

This solution is perfectly compatible with and can enhance the implementation of Option 3. This option requires the physical product to be moved in a dedicated supply chain.

Option 7 - Bidirectional Communication between vehicle and filling station: Bidirectional communication between the vehicle and the filling station provides a tamper-proof approach which could be used as a 1-to-1 pairing solution between nozzle and vehicle.

Next to the secure authentication process, the solution provides a filling monitoring and blockage device in the filler neck, which can inhibit filling with conventional fuel. However, to fulfil tampering requirements, the solution needs technical adaptations (e.g. vehicle hardware and software, filling station software (front-end, back-end) and hardware). This option requires the physical product to be moved in a dedicated supply chain.

Option 8 - EU market exclusively supplied with CNF: This assumes that CNF is exclusively available, likely some years away, and would be the result of substantial scale-up of CNFs for road transport alongside the needs of other sectors, and also the reduction of overall liquid and gaseous fuels demand, achieved by efficiency and electrification. While this scenario is unrealistic to be considered for 2035 or earlier, it is one that is certainly possible in the future and so is worthy of considering as part of the overall transition strategy for transport in the EU.

With this in mind, it is worthwhile considering further what transition mechanisms, regulatory reform and business model support can be effective to ramp up of the fuel production and supply chain developments, to meet this desirable objective.

Option 9 - Mass-Balanced CNF supply to each CNF vehicle: Mass-balancing is an indirect solution which focuses on an input-output approach, controlled by booking and claiming of certificates, i.e. not a monitoring technology on vehicle level. Experienced energy trading markets such as electricity and gaseous fuels in pipelines are efficiently controlled by such an approach. This means for a potential CNF application, that the fuel may not be physically consumed in the claiming CNF vehicle. But the fuel supply system reliably assures that the CNF amount is introduced in average elsewhere into the market. Such a technical solution would benefit from high system efficiency, fast ramp-up possibility of fuel production and fuel supply chain incorporating, that in the introduction phase each filling station does not need to have a separate CNF pump. If the European Commission would allow, a proposal could be to have a transitional approach (already before 2035) and later in time switch over to an approach with tracking per individual vehicle including tracking of fuel origin, possibly by e.g. Option 11. However, physical real-time tracking of the CO_2 footprint of an individual vehicle is not possible with mass-balancing instead an overall system footprint could be calculated.

Option 10 - Fuel Usage Balancing: Fuel Usage Balancing solution uses a mass-balancing approach based on tracking of fuel energy in the vehicle tank without a handshake between filling station and vehicle. Instead of the filling station, the responsibility of the certificate handling is transferred to the motorist, who is directly connected with a certificate marketplace, which may be an efficient solution for fleet customers in the commercial vehicle segment. Separating out the filling station and corresponding handshake shows the simplicity and a potential fast introduction of the approach. However, still a hardware device (incl. additional integration efforts and costs) in the vehicle is necessary. In addition, the solution lacks a calibrated fuel amount sensor in automotive usage, unless financial transaction data is used, or it is combined with a digital fuelling tracking system.

Option 11 – Combined mass balancing – DFTS w/ digital handshake: Since mass-balancing (Opion 9) is based on a certificate handling mechanism which incorporates average reporting of the stakeholders to an authority, a hybrid solution in combination with DFTS is proposed. This system benefits from a fast accumulation of certificates on single vehicle level since it can include the DFTS as monitoring platform and performer of the digital handshake between the vehicle and the filling station. So, accurate and in-time certificate handling could be assured per individual vehicle. However, only a virtual real time tracking of the CO_2 footprint is possible based on the in-time certificate handling and robust digital platform enabling this process.

06

CUSTOMERS & RETAIL

6.1. Executive Summary

The adoption of CO_2 neutral fuels (CNF) technologies can be crucial enabler for sustainable energy transition within the transport sector. This chapter focuses on the requirements and considerations for customers and retail sectors to ensure the successful integration and acceptance of CNF powered vehicles, and the enabling technologies. It addresses the technology requirements for a successful CNF roll-out and monitoring. To this end, it evaluates the technology options presented in the previous chapter, including availability, potential costs, ease of use, security of monitoring and inducement technologies. These technologies also have potential applications beyond the European Union, thereby laying a robust foundation for the widespread adoption of CNF. It is important to ensure that CNF dedicated vehicles can operate beyond EU boundaries and to establish control mechanisms that prevent the use of non-CNFs. Options for this issue are also addressed.

6.2. Requirements for the Technologies for CNF Powered Vehicles for Customers and Retail

When evaluating alternative technologies for monitoring CNF powered vehicles, it is crucial to examine several factors that directly impact both customers and retail. Here is an expanded look at each requirement:

Availability Across EU Member States: A consistent and reliable CNF supply chain across the EU is vital for the successful implementation of CNF-powered vehicles. The technology supporting CNF usage must be adaptable and scalable to ensure fuel availability meets demand growth. This consistency would provide consumers confidence that CNF refuelling options are widely accessible, helping to reduce range anxiety and make CNF-powered vehicles a practical choice.

Leverage of Existing Infrastructure: One major advantage of CNF is the potential to utilise existing infrastructure with no modifications. This is particularly beneficial for retailers and customers alike, as it reduces the need for costly new investments in fuelling infrastructure. If technological barriers arise that demand significant infrastructure upgrades, this advantage may be compromised, reducing CNFs appeal and cost-effectiveness.

Cost Evaluation: The estimated cost of implementing CNF-related infrastructure, essential for both customers and retailers, should include installation, operation, and maintenance expenses in order to enable stakeholders to more accurately gauge and compare CNF infrastructure costs. This comparison helps in estimating the economic viability of CNF in relation to other low-carbon options, enabling informed decisions about where and how to invest in this technology.

Ease of Use: Consumer adoption depends heavily on user-friendly technology that simplifies the transition to CNF-powered vehicles. Systems for CNF refuelling and monitoring should integrate seamlessly with existing vehicle and station technology, allowing users to experience minimal disruption. For example, intuitive fuelling stations and simplified payment systems would contribute to a smooth experience, helping to drive customer acceptance and increase usage.

Safety for Users: Options must offer users confidence in fuel quality and compatibility. With clear labelling, fuel markers, or on-board detection systems, CNF ensures that users know exactly what they are putting in their tanks, reducing the risk of misfuelling and potential damage to the vehicle.

Security for Retail Stations: Retailers also need assurance that the CNF supply and distribution channels are secure. This includes safeguarding the physical stations and ensuring fuel quality and authenticity. By implementing reliable monitoring and verification systems, retailers can avoid fuel adulteration and other security risks, thus ensuring the trustworthiness of the CNF supply chain.

Global Applicability: As CNF technology expands, the capability to use these technologies outside the EU could present strategic advantages. Vehicles powered by CNF should ideally be compatible with infrastructures and regulations globally, allowing users to rely on CNF both within the EU and abroad. This feature is especially relevant for fleet operators and frequent travellers, ensuring fuel accessibility regardless of location.

Tamper-Proof Solutions: Security extends beyond just access; it also involves protecting against tampering with the fuel or the monitoring technology. Tamper-proof solutions ensure that neither the CNF nor the associated technology can be manipulated, safeguarding the integrity of fuel transactions and protecting customers from fraud. For example, tamper-resistant seals and digital monitoring systems can help verify the authenticity and quality of the fuel, further enhancing trust in CNF-powered vehicles.

By addressing these key requirements, CNF monitoring technology can become a viable, competitive, and sustainable alternative fuel option for consumers and retail stations alike, helping to foster a smoother transition toward carbon-neutral transportation in the EU and potentially beyond.

1. Taxation

To achieve the EU's climate goals, it's essential to move towards a unified approach in energy taxation that takes into account the entire lifecycle of energy sources rather than merely their energy density. Current taxation methods, which often depend on the energy density of fuels (i.e., the amount of energy per unit volume or mass), can disadvantage low-carbon or renewable energy sources that might be less dense but are more climate-friendly. This structure not only fails to incentivise greener options adequately but can also create market imbalances across the EU, where individual countries may prioritize or discourage certain fuels in ways that don't align with EU-wide climate objectives.

Harmonizing energy taxation across the EU, as for the Commission's proposal 2021/563, would establish a consistent tax floor for all CO_2 neutral energy sources. This would mean that minimum taxes would apply uniformly to 100 % CNF, renewable, and low-carbon fuels, reducing discrepancies in how countries tax such energies domestically. It would also ensure that the full environmental impact of energy sources is considered, encouraging both producers and consumers to shift towards cleaner alternatives by reflecting the true cost of emissions in their pricing structures.

The adoption by the Council of the Commission's proposal would require member states to integrate these principles into their national excise duties on energy and mineral oil would help build a cohesive, market-driven transition to clean energy across the EU. This would make it more economically viable to adopt CO_2 neutral solutions, further incentivising innovation and the adoption of clean energy technologies. In this way, a lifecycle-based approach to energy taxation would provide a more accurate reflection of environmental costs, ultimately driving a faster and fairer transition toward the EU's climate goals.

6.3. Assessment of Monitoring Options Based on the Customer & Retail Perspective

All options for Direct Fuel Supply will require the physical product to be moved in a dedicated supply chain. In the introductory phase, given the limited number of filling stations, this could potentially increase costs for customers.

Option 1: Mechanical Adaption of Tank Filler/Nozzle

Advantages:

1. **Ease of Implementation and High Acceptance:** Modifying the nozzle and filler size is a simple, cost-effective solution that can be rolled out without extensive changes to existing infrastructure or vehicle design. This option builds on established practices in the industry, particularly with gaseous fuels (e.g., CNG, LPG), where differing nozzle sizes have been used successfully. This familiarity can increase acceptance among users and stakeholders, as minimal training or adjustments are needed.

3. **Experience with Gaseous Fuels:** The auto and fuel industries already have significant experience with different nozzle sizes for fuels like compressed natural gas (CNG) and LPG. Leveraging this expertise reduces the risk of deployment, as safety and operational guidelines are already well-understood and could be adapted to CNF.

4. **Introduction of New Standards:** While new standards for nozzle and receptacle sizes would need to be introduced, the effort is likely to be manageable. By establishing consistent standards for CNF, the industry can ensure compatibility across all new CNF vehicles and stations, simplifying operations for both retailers and customers.

5. **Elimination of Inducement Systems:** Since CNF-specific nozzles will not connect with standard fossil fuel nozzles, there is no risk of misfuelling, and no additional inducement system is required to prevent accidental fossil fuel usage. This also simplifies the vehicle design, reducing manufacturing costs and potential points of failure.

6. **Adaptability of Legacy Fleet:** Legacy vehicles could be retrofitted with a compatible fuelling connector, enabling existing fleets to transition to CNF without significant modifications. This enhances the appeal of CNF as it allows for gradual adoption and extension to older vehicles.

7. **Globally Recognized Standards for Liquid and Gas Refuelling:** The international standards for refuelling (e.g., gasoline, diesel, CNG, LNG, H2, LPG) address several important factors that could apply to CNF:

- **Simplicity and Accessibility:** Filling CNF vehicles would be as straightforward as refuelling conventional vehicles, encouraging widespread adoption.
- **Low Total Cost of Ownership:** Vehicle modifications, dispenser equipment, and other necessary hardware for CNF are expected to have a low total cost, which is crucial for consumer affordability and widespread infrastructure adoption.
- **Global Reliability and Interchangeability:** Components such as dispensers and vehicle fittings would be standardised, ensuring compatibility across regions and reducing the need for localised adaptations.
- **Environmental Benefits:** The adaptation would involve systems, like vapour recovery,

to prevent the release of hydrocarbons, reducing environmental impact during refuelling.

- **Simplicity for All Regions:** The system design would be straightforward, making it suitable for deployment in both developed and less-developed areas, where complex technology might be difficult to maintain.
- **Minimal Investment for Petrol Stations:** Since existing stations would only need minor upgrades, CNF would be accessible at a lower cost than other energy sources requiring major infrastructure overhauls.

Disadvantages:

1. **Adapter Requirement for Non-EU Regions:** Vehicles may require an adapter to use the new nozzle configuration outside the EU. This requirement could increase the burden on travellers or fleet operators working across regions, as they would need to carry adapters.

2. **Potential for Tampering with Adapters:** The presence of adapters may also allow for tampering within the EU, posing a risk of unauthorized or improper refuelling. Strict standards and control mechanisms would need to be in place to mitigate this risk.

3. **Dependence on Nozzle and Receptacle Availability:** The success of this solution depends on the availability of compatible nozzles and vehicle receptacles, particularly in the years leading up to the EU's target of 2035. A coordinated roll-out would be necessary to ensure widespread availability, preventing potential logistical bottlenecks as adoption increases.

4. **Nozzle and Receptacle Functionality:** For CNF Systems and Fuel station infrastructure a functional validation is necessary. New nozzle outlet leads a different fuel flow behaviour in filler pipe and have deep impact to the liquid seal of ORVR Fuel Systems. Therefore all OEMs must develop, validate and homologate new CNF systems based on common systems to meet all market-specific legislations. Also, customer suitability and safety must be guaranteed by the car manufacturer.

Requirements for Successful Implementation

To ensure this adaptation solution is successful, a few key elements are essential:

- **European Agreement on Nozzle requirements, Diameter and Shape:** The EU must establish a unified standard for CNF nozzles, ensuring that all CNF fuelling points and vehicles are compatible. Ideally, this standard should extend internationally to facilitate global CNF adoption and allow for seamless cross-border travel without adapters.
- **Standardization and Global Compatibility:** Harmonization with international standards would simplify vehicle and infrastructure design, fostering wider CNF adoption. It would also allow manufacturers to produce vehicles compatible with CNF across global markets, boosting economies of scale and reducing per-unit costs.

Option 2: Fuel Marker along Upstream and Downstream

Advantages:

1. **Established and Familiar System:** Fuel markers are already a well-established technology in the fuel market, and customers are accustomed to their use. This familiarity can streamline acceptance and reduce resistance to implementation.

2. **Inducement Potential:** With swift adoption, fuel markers can effectively support inducement systems, providing a method to enforce fuel compliance and deter non-CNF use.

3. **No Major Behavioural Changes for Consumers:** For end users, no changes to the fuelling process are required, as the marker system operates seamlessly within the existing fuel infrastructure. This ease of use encourages consumer adoption.

4. **Minimal Infrastructure Changes Needed:** Existing fuel storage, pump capacities, and other infrastructure remain largely unchanged, with minimal costs for additional hardware, such as sensors to detect markers. This compatibility reduces implementation costs and simplifies the transition for fuel providers.

5. **Enhanced Safety and Fraud Prevention:** Fuel markers add a layer of security by enabling visual inspection for colour-coded tags and sensor checks along the supply chain. This dual approach helps prevent fuel fraud and ensures that the correct fuel is used.

6. **Low Implementation Costs:** Compared to more complex digital systems, fuel markers require relatively low-cost hardware additions and straightforward integration with existing fuel systems, making it a cost-effective compliance solution.

7. **Flexible Monitoring Capabilities:** Markers allow for visual inspection, sensor verification along the supply chain, and potential on-board vehicle checks in the future, offering multiple layers of compliance assurance.

Disadvantages:

1. **Limited Usability Outside the EU:** For this system to function reliably, the same fuel marker system would need to be adopted internationally. If non-EU countries do not prioritize its implementation, EU drivers could face challenges when traveling abroad, as the fuel marker system may not be recognised. Theoretically, additional markers from non-EU markets could also be recognized as "valid markers" through bilateral agreements and kept in the systems. From the EU's point of view, it would make sense to have a coordinated set of markers ready in the software in advance, which could then be used by other markets outside the EU. This means that CNF vehicles from different economic areas could still be functional in the other country.

2. **Binary Compliance Detection:** The system only allows a simple "yes/no" decision regarding compliance, which may limit flexibility. For instance, partial refuelling or mixed fuel use may not be accurately managed, and any detected non-compliance would trigger the same response regardless of context.

3. **Reduced Flexibility in Inducement Mechanisms:** Unlike digital solutions, this system doesn't support nuanced responses, which limits the driver's ability to control inducement reactions based on fuel usage patterns or compliance needs. This rigidity could inconvenience users in specific scenarios, such as emergency refuelling or when partial CNF fuelling is detected.

4. **Compatibility Issues with Certain Fuels:** For gaseous fuels, fuel markers may be less effective because chemically identical fuels cannot be easily distinguished by markers. This limitation restricts the system's applicability for a range of fuel types, reducing options for consumers who might prefer or require these alternative fuels.

5. **Cost Implications for Petrol Stations:** Although generally low-cost, implementing a fuel marker system will require petrol stations to meet stricter conditions for monitoring and compliance, potentially increasing operation-

al costs, particularly if specific infrastructure modifications are needed such as storage capacities.

Option 3: 100% Digital Fuel Tracking System from Upstream to Downstream (DFTS w/Digital Handshake)

Digital Fuel Tracking (DFTS) using a digital handshake enables comprehensive tracking and monitoring of fuel compliance, supporting the EU's goal of CNF-only fuelling. By utilizing existing data in the fuel supply infrastructure, filling stations, and vehicles, DFTS can be implemented with minimal delay and low cost.

Advantages:

1. **Technology Availability and Fast Implementation:** DFTS can be deployed quickly, leveraging existing data networks at most petrol stations (e.g., for transactions, stock management, and analytics). Since no new hardware is required for connected vehicles, DFTS can roll out rapidly with minimal setup, pending regulatory approval. This solution is ready to start field implementation as soon as it is approved by the EC.

2. **Cost Efficiency:** DFTS offers a cost-effective approach. The scalability of the system is high, and its compatibility with existing infrastructure lowers implementation costs.

3. **Ease of Use and High Customer Acceptance:** The fuelling process remains unchanged for the end customer, making it easy for consumers to adopt. Payment processes could also be streamlined via the digital handshake, and the system can apply region-specific tax rates automatically, adding convenience.
4. **Data Security and Compliance:** DFTS employs a secure, encrypted data room concept to manage data shared between stakeholders, ensuring compliance with the EU's GDPR. Data anonymity is maintained at the OEM level, and only non-GDPR-relevant data is exchanged with DFTS. This approach protects user privacy while providing the necessary data for compliance.

Furthermore, DFTS fuelling monitor is aware of the vehicle fuelling history, so potential connection latency does not lead to a loss of filling data. It can be corrected after the connection is stabilized again. By implementing such a mechanism, the DFTS takes care of, that no slip appears in the total system, e.g. if conventional instead of CNF is refilled during a lack of data connection.

5. **Enhanced Monitoring and Flexibility Mechanisms:** DFTS allows for multiple-vehicle responses (e.g., performance reduction, mileage thresholds, or penalty notifications) based on compliance. This flexibility supports customized inducement measures based on legal requirements and provides transparent information to drivers regarding system status and any penalties. Drivers are notified of suspicious fuelling events, enabling full transparency.

6. **Regulatory Geofencing Capability:** The DFTS system can deactivate the fuelling monitor when the vehicle exits the EU, allowing operation outside regulated territories. This ensures compliance within the EU while providing flexibility for cross-border travel.

7. **Future-Ready and Scalable Applications:** DFTS allows carbon-reduced fuel usage to be counted in sustainability reporting from 2026 onward. It also supports flexible scalability of CNF production, which can be managed through partial inducement legislation, gradually increasing CNF demand as supply ramps up.

Disadvantages:

1. **Vulnerability to Data Latency and Transmission Failures:** The DFTS system relies on real-time data transmission, making it susceptible to delays or failures, which could impact system reliability. Immediate response times are critical in cases where legally mandated actions are time-sensitive. This latency could create compliance risks or increase system costs for fast responses that are not usually implemented in today's existing systems.

2. **Susceptibility to System Failures:** As with all digital systems, DFTS is susceptible to failures in both hardware and software. Any disruptions in data transfer could compromise compliance monitoring, which may lead to complications in enforcing fuel usage penalties or reset procedures. In order to avoid this, DFTS must use multiple trust centre approaches, as with all digital systems, so DFTS can assure, that in case of system failures data can be recovered.

3. **Data Privacy and GDPR Compliance Challenges:** The system generates significant amounts of data about vehicle fuelling behaviour, raising GDPR concerns. Although the data is anonymised and handled by OEMs, balancing user privacy with data utility may require stringent data management practices to comply with GDPR regulations.

4. **Limitations in Cross-Border Fuelling Flexibility:** If implemented without regulatory geofencing, DFTS monitoring may restrict users from refuelling with non-CNFs outside the EU. While regulatory geofencing can deactivate DFTS upon exiting the EU, a failure to do so could limit cross-border functionality.

5. **Limited Infrastructure Availability Initially:** Although DFTS utilizes widely existing infrastructure, a few filling stations may lack the necessary connectivity to the internet in the introductory phase.

Requirements for Implementation:

1. **Reliable Data-link between Stations and Central Host:** Most petrol stations already have data links for transactions and analytics, but DFTS requires continuous internet connectivity to ensure smooth operation.

2. **Qualified Filling Stations:** Stations must meet connectivity and compliance standards to interact with the DFTS system effectively. They should be capable of supporting real-time data exchange.

3. **Legislative Definition of Penalty Enforcement:** To ensure DFTS compliance, clear guidelines are needed regarding penalty enforcement. Options include vehicle inducement responses, direct prosecution with financial penalties, notification of regulatory authorities, or reporting to inspection agencies.

Option 4: Hybrid Approach – Upstream: Fuel Marker & Sensor until EU Border – Downstream: DFTS w/Digital Handshake.

Advantages:

This Hybrid Approach allows for partial inducement to gradually increase the fuel demand according to the fuel supply. However, customers can only steer by alternating fuelling between CNF and fossil fuels. The penalty indication is as well possible when the wrong fuel was used or whether there is a tampering suspicion. The Fuelling history can be saved in the vehicle as well.

Regulatory Geofencing and flexibility

mechanisms can also be implemented relatively easily. Several vehicle reactions, such as performance reduction, km threshold to stop the engine, are possible merely depending on legal requirements.

The driver could use alternate fillings between CNF and fossil fuels for sustainability reporting already from 2026 onwards. Starting from 2035 no alternated fuelling is allowed, but partial inducement is already possible before 2035.

The system offers high flexibility in terms of penalty indication and the driver can be easily informed on suspicious fuelling events, has full transparency about possible suspicious events and penalties, and can run and fill the vehicle autonomously in case of emergency cases. For driving outside the EU, this solution can deactivate the Fuelling Monitor when leaving the regulated EU territory. On-board monitoring of flexibility mechanism criteria is possible and can deliver transparent information about the driver, including current system status and potential countermeasures.

Disadvantages:

This multi-option approach could require investment as well as the prospective maintenance costs for filling stations. As the sensor does not allow a decision on the blending ratio, blends between CNF and fossil fuel cannot be treated by the system. A challenge will also be expected when adding an additional detector to the nozzle to provide information to side controllers which can retrofit the fueller. Especially, in the ramp-up phase a flexibility mechanism cannot decide on the blending ratio.

The proposed solution, which relies on fuel markers and sensors, may not be feasible for certain fuels, thereby limiting user choice. Specifically, it can be pointed out that the inability to use drop-in fuels could restrict options for users. For gaseous fuels, the effectiveness of these markers diminishes when the chemical composition is identical. Implementing such a system would require more stringent requests and conditions for petrol stations. Although technically feasible, the associated costs could be significant.

Customers may be limited in terms of retail site choice, as hardware infrastructure may not be available at every retail site, especially in the introductory phase. Furthermore, the individual challenges like connectivity and latency as well as the limitations for gaseous fuels remain with this option.

In addition, disadvantages for the digital link appears as described in Option 3.

Option 5: Vehicle On-Board Fuel Detection Function

Advantages:

1. **Enhanced Fuel Security:** The on-board detection function provides reliable verification that only CNF are used, protecting against accidental or unauthorized use of conventional fossil fuels. This secures both environmental benefits and potential tax incentives associated with CNF use.

2. **Minimal Infrastructure Requirements:** This detection system requires no new investment or modifications at fuelling stations, which only need to supply certified CNF-compliant fuels. For customers, this minimizes disruption as the technology integrates seamlessly with existing fuel station infrastructure.

3. **Cost-Efficiency and Fast Implementation**: As the technology leverages existing engine management systems without requiring new hardware, the detection function is relatively low-cost and could be implemented quickly. This reduces additional manufacturing costs and enhances affordability for customers.

4. **Privacy and Security Protections:** The absence of data connectivity and cloud-based tracking preserves customer privacy, while the system's low vulnerability to cyber threats protects against tampering or fraud. Customers benefit from a secure and tamper-resistant fuel management system.

5. **Compatibility with Legacy Vehicles:** There is potential for retrofitting existing vehicles, allowing a broader fleet to comply with CNF mandates. This could encourage faster CNF adoption without the need for customers to invest in new vehicles.

Disadvantages:

1. **Restricted Cross-Border Functionality:** Since the detection system responds to non-CNFs by limiting vehicle operation, it may restrict vehicle functionality in regions where CNF is not widely available. This can be inconvenient for customers who travel outside the EU, as they may face reduced performance or operation stops when refuelling with conventional fuels abroad. There are flexibility mechanisms that can address this disadvantage. These are described in Section 6.4.

2. **Limited Flexibility for Partial Refuelling:** Customers may experience sudden performance limitations if partial refills with conventional fuels are detected, reducing system flexibility and usability in emergency refuelling situations.

3. **Incompatibility with Drop-in Fuels and Some Biofuels:** Depending on the on-board technology used, the detection function may not be compatible with certain renewable fuels that chemically resemble fossil fuels. This reduces the flexibility of fuel choices, particularly in non-EU regions where biofuels may be more accessible

4. **Potential for Increased Maintenance:** The detection function might require regular inspections to ensure accuracy. Regular sensor checks would be necessary to verify that the system correctly identifies fuel types without erroneous inducements.

5. **Higher Vehicle Costs:** Although the system uses existing technology, retrofitting or upgrading vehicle management systems to support CNF detection may increase initial purchase costs for CNF-compatible vehicles. This could be a financial burden for some customers and impact vehicle affordability. However, it is important to put this into perspective, as the cost of the additional functionality is very low in terms of CAPEX, likely even less than that of an ESP/ABS system, especially when compared to the overall cost of a vehicle.

6. **Operational Risks with Sensor Malfunctions:** In cases where the detection system malfunctions, customers could experience unexpected vehicle shut-downs or reduced performance, impacting reliability. If the sensor mistakenly detects non-CNF, it may induce system limitations even when CNF is used, leading to driver inconvenience and safety concerns.

What is required for the option?

This option would require an early established system to allow for inducement. The vehicle also needs to be aware of the actual fuel quantity filled and report misfuelling events to be saved and reported with a separate software. Additional regulatory geofencing software must be implemented and be able to switch of the system outside the EU. The test procedure for inspections needs to be clearly defined for distinct measurement parameters per fuel.

Option 6: Vehicle On-board Fuel Molecular Sensor

Advantages:

1. **High Certainty in Fuel Type Detection:** NIR spectroscopy provides a reliable method for identifying the molecular structure of the fuel used, ensuring that only approved CNFs are detected and used. This technology gives drivers and regulatory bodies confidence that the vehicle operates within compliance.

2. **No Additional Requirements for Petrol Stations:** Petrol stations are only required to supply the correct fuel, with no need for additional equipment or modifications to their infrastructure. The responsibility for fuel verification is entirely on the vehicle, streamlining operations for fuel stations.

3. **Security of Fuel Compliance:** The on-board NIR system ensures that only CNF-compliant fuel is used, preventing unauthorized or incorrect fuel from entering the vehicle. This measure enhances regulatory compliance and reduces the risk of misfuelling.
4. **Immediate Availability and already homologated:** sensors are produced in series since 2021 in Europe and already homologated by Legal Authorities in some countries.

5. **High versatility to Measure Fuel Quantity or Partial Refuelling:** On-board NIR sensors are trained to detect many different CNF from fossil fuels from 0% to 100%. So the addition of new fuel fingerprint or the limitation to use only CNF can be updated by reflashing the sensor memory

6. **Increase Flexibility for Drivers Traveling Outside the EU:** By coupling the sensor with GPS localization, it is possible to authorise or not the use of fossil fuels. This option is already tested for LEZ area to detect low emissions renewable and non-fossil fuel to enter or not in the city centre.

Disadvantages:

1. **Higher Cost and Need for Maintenance:** NIR spectroscopy is a sophisticated technology, requiring complex on-board hardware that could significantly increase vehicle costs. The addition of such technology also raises production costs and could make CNF vehicles more expensive for consumers. The addition of this technology would increase the demand for maintenance.

2. **Reduced Flexibility for Drivers Traveling Outside the EU:** Drivers may face challenges using non-CNFs outside the EU, as the system's inducement mechanism is likely to activate even with conventional fuels. This limits flexibility for travellers and could cause unintended restrictions during international travel, particularly where CNF is unavailable.

3. **Working Today Only for Liquid Fuels:** the technology must be developed (3 years) to also detect gaseous CNF.

4. **Need to Have a CNF Database Certified and Up-to-Date:** NIR spectroscopy for fuel detection relies on an extensive fuel fingerprint database, which may take time to establish and maintain by independent authorities.

What is required for the option?

This option is already deployed for CNF and certified in France to detect fossil fuels since 2020, and would require an early established system to allow for inducement. Additional regulatory geofencing software must be implemented and be able to switch of the system outside the EU. The test procedure for inspections needs to be clearly defined for distinct measurement parameters per fuel. The CNF-compliant database must be certified and monitored by an authority.

Option 7: Bidirectional Communication between Vehicle and Gas Station.

Advantages:

1. **Direct Prevention of Misfuelling:** This system includes a blockage valve that prevents the vehicle from being refuelled with the wrong fuel, eliminating the need for penalty indications. This automatic fuel lock mechanism provides a robust preventive measure for CNF compliance.

2. **Transparency and Information for Drivers:** The system can inform drivers via the dashboard of any suspicious fuelling events or potential issues, providing full transparency on system status. Drivers are kept aware of fuel compliance and can see any countermeasures in real-time, enhancing confidence in fuel use.

3. **Flexibility Mechanisms:** The system's bidirectional communication enables flexible inducement responses based on legal requirements, which could include a range of vehicle reactions to accommodate varying compliance needs. This flexibility can be managed by the on-board system, making it adaptable for different compliance scenarios.

4. **On-board Monitoring of System Status:** The system continuously monitors fuel compliance status, providing comprehensive data about fuel type, potential tampering, and any triggered countermeasures. This high level of monitoring ensures that both users and regulators have access to detailed compliance information.

5. **Enhanced Compliance and Accountability:** With real-time data exchange between the vehicle and the fuel station, authorities and OEMs can maintain detailed records, offering a traceable history of fuel transactions. This level of accountability could enhance regulatory compliance and improve fuel integrity tracking. One particular advantage of this system would be the online connectivity for safety functions in the event of a disaster or force majeure. If a natural disaster were to occur, the valve could be unlocked centrally via the regulator "over the air" so that vehicles could be used in the event of a disaster.

Disadvantages:

1. **Limited Usability Outside the EU:** Due to the blockage valve, vehicles may not be refuelled outside the EU if non-CNF is detected. This restriction limits the vehicle's functionality in emergencies or areas where CNF is unavailable, creating an inconvenience for cross-border travellers. There are flexibility mechanisms that can address this disadvantage. These are described in Section 6.4.

2. **Higher Costs Due to Additional Hardware:** The system requires additional on-board sensors and communication hardware, such as NFC, BLE, or Wi-Fi modules, which can increase vehicle manufacturing costs. This additional equipment may raise the price of CNF-compatible vehicles and may not be compatible with the existing fleet.

3. **Vulnerability to Data Transmission Failures:** The system's effectiveness depends on real-time data transmission, which can be susceptible to technical failures, latency issues, or network interruptions. Any delay or failure in data transfer could cause disruptions

in fuel monitoring and compliance, which could become problematic if strict timing is legally required.

4. **GDPR Compliance and Privacy Concerns:** The system generates and transmits data about fuel usage and vehicle status, which raises concerns around user privacy under the EU's GDPR regulations. OEMs would be responsible for managing and protecting this data, but balancing privacy compliance with data utility may require careful planning and resources.

5. **Potential Limitations in Retail Infrastructure:** In the initial stages, not all fuel stations may have the necessary hardware and software to support bidirectional communication with vehicles. This could limit customer choices when refuelling, especially during the introductory phase, until the infrastructure is widely available.

6. **Data Latency Concerns:** If the system relies on precise timing for legal compliance (such as a DFTS system requiring accurate timestamps), any delays in data transmission could pose issues for compliance. These latency vulnerabilities could impact the reliability of fuel compliance measures in legally mandated scenarios.

What is required for the option?

An additional regulatory geofencing software needs to be implemented to switch of the system outside the EU. In order to gather flexibility, convention fuel needs to be accepted to open the filler neck valve. The penalty enforcement is also still to be defined for this option, including the direct prosecution with financial penalty, the information of authorities, or whether the inspection agency can enforce the punishment directly.

Option 8: EU Market Exclusively Supplied with CNF

This option is described and examined for a future year, certainly after 2035. This is more realistically an exercise in exploring the potential that this could be possible in a longer time-scale to help achieve the policy of the EU for climate neutrality.

Advantages:

1. **Full Transition to sustainable Fuels:** Limiting the market to CNF after 2035 ensures a complete phase-out of fossil fuels within the EU, directly contributing to EU climate goals and decarbonisation of the legacy fleet. This approach eliminates reliance on fossil fuels, making significant progress toward net-zero emissions.

2. **Simplified Fuel Options for Consumers:** Consumers would no longer need to choose between fossil fuels and CNF, making the transition straightforward. By 2035, all fuel stations within the EU would only offer CNF, simplifying fuel selection and contributing to a more consistent fuelling experience.

3. **Compatibility with Current Infrastructure:** The existing fuel infrastructure can remain largely unchanged. Since only the type of fuel supplied changes, no extensive modifications to the network are needed, avoiding the costs and disruptions associated with new infrastructure.

4. **Potential to Use Conventional Fuel Outside the EU:** Although only CNF would be sold within the EU, vehicles designed to use CNF could still operate on conventional fuel if necessary when traveling outside the EU. This flexibility supports cross-border travel without requiring modifications to accommodate both fuel types.

5. **No Additional Inspection Requirements:** With only CNF available, vehicle inspection processes remain unchanged, simplifying compliance requirements. This consistency keeps regulatory processes manageable for consumers and vehicle inspection agencies alike.

Disadvantages:

1. **Lack of Incentive During the Transition Phase:** There are currently, neither for customers nor filling stations strong incentives to adopt CNF if conventional fuels are still available. Without additional incentives or regulations, many may delay switching to CNF until the final phase-out, slowing the initial uptake of CNF.

2. **Potential Supply Challenges for Non-EU Travel:** If CNF vehicles regularly travel outside the EU, drivers could face difficulties refuelling with compatible fuels in regions where CNF isn't readily available. This could require travellers to plan carefully or risk limited access to compatible fuels in non-EU countries.

3. **Market Adjustment and Price Volatility**: The forced transition to CNF by a specific date would cause fluctuations in fuel prices as the market adjusts. As fossil fuel suppliers exit the market, the initial costs of CNF could rise temporarily due to supply and demand shifts, impacting consumers.

4. **Dependence on Successful CNF Ramp-Up:** Achieving a smooth transition to only CNF depends on a successful ramp-up of CNF production, distribution, and supply. Any delays in scaling up CNF could lead to supply shortages, which would disrupt the fuel market and inconvenience consumers.

Option 9: Mass Balanced CNF supply to each CNF vehicle

Advantages:

1. **High Flexibility and Scalability:** The mass balance or extended book-and-claim system provides flexibility for CNF suppliers and customers, making it highly scalable. This approach simplifies the implementation process, benefiting the legacy fleet without additional complexity.

2. **Low-Cost Barrier to Entry:** This system has a minimal cost impact on CNF vehicles for customers. Since mass balancing works within the existing fuel distribution network, it leverages current infrastructure, which keeps costs low and reduces the need for new facilities or technologies.

3. **Positive Impact on Legacy Fleet:** Mass balancing is compatible with existing vehicle fleets, meaning no additional modifications or technologies are required in most cases. Vehicles can still operate on conventional fuel outside the EU, making it practical for international use without additional adaptations.

4. **Ease of Implementation and Wide Network Coverage:** The system can be implemented quickly and reliably within the current distribution networks. This ensures that customers have broad access to CNF without requiring separate supply chains, providing a seamless experience across the entire fuel network.

5. **Reduced Environmental and Logistical Costs:** Mass balancing minimizes logistics by eliminating the need for CNF to be transported to every fuel station. This approach reduces associated emissions and logistical complexities, contributing to a lower ecological footprint.

6. **Avoids Complexity in Vehicles:** Since CNF usage is tracked through industry records rather than vehicle sensors, there's no need for complex on-board sensor technologies. This reduces vehicle costs and eliminates the need for frequent inspections related to CNF compliance.

7. **Industry Responsibility Over Consumer Burden:** The responsibility for CNF compliance lies with the fuel industry rather than individual consumers. This reduces consumer responsibility and ensures CNF requirements are met systematically without individual action.

8. **Successful Implementation for the Development of Green Electricity:** This approach could be replicated for an accelerated uptake of CO_2 neutral fuels.

Disadvantages:

1. **Absence of Fuel Usage-Based Penalties and Offsetting if not Combined with a DFTS:** Since individual fuel consumption isn't directly traceable, it's challenging to implement penalties or offsetting mechanisms based on actual CNF use. There's no way to determine whether a particular consumer is using CNF, limiting accountability at the user level.

2. **No Physical Traceability:** Mass balancing lacks direct physical traceability of CNF, as the system tracks quantities on paper or electronically rather than by physical separation. This can make it challenging to verify CNF usage on a granular level. This requires additional measures.

3. **Certification and Auditing Needs:** To ensure system integrity, certification, detailed record-keeping, and regular audits are required. This increases the regulatory and administrative burden on the fuel industry to maintain accurate and transparent records.

4. **Risk of Fraud and Greenwashing if not combined with a DFTS:** The lack of physical traceability raises potential concerns around fraud and greenwashing. Without strict controls, there is a risk that some companies could misrepresent CNF usage, undermining consumer trust in the system's environmental benefits.

Option 10: Fuel Usage Balancing – FUB

Advantages:

1. **End-User Focus:** The system places the responsibility for compliance and monitoring on the vehicle and its operator, removing the need for petrol stations to manage complex inducement systems. Regulatory geofencing ensures the system is confined to the EU, limiting administrative challenges for filling stations. This approach simplifies station operations while giving vehicle users direct control over compliance.

2. **Penalty Indications:** The system can detect and indicate penalties for specific non-compliance events, such as incorrect fuel usage, missing CNF certificates, or signs of tampering. This ensures that end-users are aware of their infractions and can take corrective action. By providing immediate feedback on compliance issues, the system builds trust and supports enforcement.

3. **Fuelling History Storage:** The vehicle can maintain a complete and secure record of all fuelling events. This history can be reviewed to verify compliance, support sustainability reporting, or provide evidence in case of disputes. This feature increases transparency and simplifies monitoring by regulatory authorities.

4. **Compatibility with Inducement Systems:** The system supports various vehicle reactions tailored to legal requirements. For example, performance reduction, mileage thresholds, or engine stoppage can be triggered based on compliance violations. This flexibility ensures that the system can adapt to differing legal frameworks while maintaining effectiveness in encouraging CNF usage.

5. **Virtual CNF Credits for Sustainability Reporting:** Drivers can utilise virtual CNF credits, allowing them to balance fuel consumption with sustainability goals. For example, a regulatory framework could require 50% of fuel to be compensated by mass balancing initially, with full compensation enforced by 2035. This approach supports incremental adoption while creating accountability for sustainability targets. Virtual credits also offer an opportunity for integrating sustainability into digital applications or reporting platforms.

6. **Regulatory Geofencing:** The system includes geofencing capabilities to manage compliance based on the vehicle's location. For instance, the Fuel Monitor can be deactivated when the vehicle operates outside EU borders, allowing users to refuel freely without inducement restrictions. This ensures the vehicle remains fully operational during cross-border travel while maintaining compliance within EU boundaries.

7. **Transparency for Drivers:** The on-board monitoring system provides clear, real-time information to the driver. This includes the current system status, compliance level, and any countermeasures triggered by violations. By keeping drivers informed, the system encourages proactive compliance and reduces the likelihood of accidental non-compliance. Transparency also helps build trust in the system, making it more likely to gain user acceptance.

8. **Potential for Retrofitting Older Vehicles:** Developing retrofit-compatible FUB devices could enable the integration of mass balancing into legacy fleets. By providing cost-effective retrofit options, the system could expand its reach, ensuring compliance across older vehicles that would otherwise be excluded. This strategy supports a smoother and more inclusive transition to CNF.

9. **Integration with Connected Services:** The FUB system could integrate with connected services, such as vehicle dashboards or mobile applications. Drivers could use these platforms to monitor compliance, manage CNF credits, and access certificates in real time. These tools could also simplify administrative processes, making the system more user-friendly and attractive to consumers.

10. **Incentives for Early Adoption:** Financial incentives, such as reduced taxes on CNF-compatible vehicles, discounted fuel prices, or subsidies for installing FUB devices, could encourage early adoption. This would accelerate the transition to CNF while offsetting the upfront costs of compliance for end-users.

Disadvantages:

1. **Vehicle Equipment Costs:** Each vehicle must be equipped with a Fuel Usage Balancing (FUB) device. This hardware requirement increases the upfront cost of vehicles.

2. **Increased Responsibility for Drivers:** The system shifts the responsibility for managing CNF certificates to vehicle operators. Drivers are required to understand and manage their compliance obligations, including maintaining accurate records and resolving penalties.

3. **Potential for Certification Fraud:** Without robust auditing and verification systems, there is a risk of CNF certificates being falsified or manipulated. Fraudulent behaviour could undermine the integrity of the system and erode trust among consumers and stakeholders. Strict certification protocols and oversight mechanisms will be required to address this challenge.

4 **Dependence on Infrastructure Readiness:** The success of the system depends on the widespread availability of compatible infrastructure, such as reliable CNF supplies, geofencing systems, and verification platforms. Any delays in establishing this infrastructure could hinder adoption and limit the effectiveness of the system.

Option 11: Combined Mass balancing - DFTS w/ Digital Handshake

In addition to the advantages outlined under option 9, the combined option offers the following

Advantages:

1. **Flexibility:** The option allows for partial inducement to gradually increase the fuel demand according to the fuel supply. The Driver could use virtual CNF credits for sustainability reporting, e.g. if agreed 50% of fuel filling may only be compensated by mass balancing. The full compensation could be activated within 2035. However, due to mass balancing customers can only steer by virtual CNF credits

2. **High Flexibility and Scalability:** The combined Combined – Upstream: Mass balancing – Downstream: DFTS w/ Digital Handshake system provides flexibility for CNF suppliers and customers, making it highly scalable. This approach introduces the possibility to monitor the vehicle operations and to activate the inducement system, and simplifies the implementation process, benefiting the legacy fleet without additional complexity. The fuelling history can be saved in the vehicle.

3. **Low-Cost Barrier to Entry:** DFTS offers a cost-effective approach, as no retrofitting is necessary for vehicles or filling stations. The scalability of the system is high, and its compatibility with existing infrastructure lowers implementation costs.

4. **Technology Availability and Fast Implementation:** DFTS can be deployed quickly, leveraging existing data networks at most petrol stations (e.g., for transactions, stock management, and analytics). Since no new hardware is required for connected vehicles, DFTS can roll out rapidly with minimal setup, pending regulatory approval. This solution is ready to start field implementation as soon as it's approved by the EC. Also mass balancing is compatible with existing vehicle fleets, meaning no additional modifications or technologies are required in most cases. Since CNF usage is tracked to a wide extend through industry records rather than vehicle sensors, there's no need for complex on-board sensor technologies. This reduces vehicle costs and eliminates the need for frequent inspections related to CNF compliance.

5. **Ease of Implementation, Wide Network Coverage and High Customer Acceptance:** The fuelling process remains unchanged for the end customer, making it easy for consumers to adopt. Payment processes could also be streamlined via the digital handshake, and the system can apply region-specific tax rates automatically, adding convenience.

6. **Enhanced Monitoring and Flexibility Mechanisms:** DFTS allows for multiple vehicle responses (e.g., performance reduction, mileage thresholds, or penalty notifications) based on compliance. This flexibility supports customized inducement measures based on legal requirements and provides transparent information to drivers regarding system status and any penalties. Drivers are notified of suspicious fuelling events, enabling full transparency.

7. **Regulatory Geofencing Capability:** The DFTS system can deactivate the fuelling monitor when the vehicle exits the EU, allowing normal operation outside regulated territories. This ensures compliance within the EU while providing flexibility for cross-border travel.

Disadvantages:

Although this system offers significant benefits and flexibility for customers some inherent disadvantages exist related to the communication between vehicles and filling stations and are outlined under option 3:

- **Vulnerability to Data Latency and Transmission Failure**
- **Susceptibility to System Failures**
- **Data Privacy and GDPR Compliance Challenges**
- **Limitations in Cross-Border Fuelling Flexibility**
- **Limited Infrastructure Availability Initially**

6.4. Assessment Options for Effective Inducement Systems & Flexibility Mechanisms

To support the EU's CO_2 Neutral Fuel (CNF) requirements, an effective inducement system must incorporate two essential features:

1. **Fuelling Monitor:** This system tracks CNF use to ensure the vehicle is fuelled exclusively with CNF.

2. **Inducement System:** A mechanism that reacts if non-CNF is detected, enforcing compliance through various responses.

The EC's current proposal includes a stringent inducement system where the vehicle cannot start if non-CNF is detected. However, for practical implementation and customer acceptance, a flexibility mechanism is essential. Flexibility could be achieved by adapting approaches already under discussion in the EU7 emission standards, such as inducement systems for Diesel SCR and OBM (On-Board Monitoring). References include the "DRAFT OBM Euro 7 LDV implementing act Annex III 12102023" by the CLOVE consortium, which supports progressive inducement measures.

Potential Inducement Steps for Flexibility

The following graduated inducement steps illustrate potential responses that can increase or decrease in severity depending on fuel compliance, which are based on the currently discussed options within EU7 standard:

- **"Go":** Allows the vehicle to operate normally with a positive CNF confirmation.

- **“Suspicious”:** In cases where CNF compliance is unclear (e.g., connectivity issues or emergency refuelling), the system flags the event without immediate action. A penalty could be assessed later if non-CNF use is confirmed.
- **“Warning”:** A visual warning is displayed to the driver if the system detects repeated suspicious behaviour, prompting the user to refill with CNF.
- **“No Go Step 1”:** Displays a warning and restricts usage within specific mileage or time limits. Workshop intervention is required to verify the refuelling history and reset the system.
- **“No Go Step 2”:** Implements a start restriction, preventing the vehicle from starting after being shut down. Restarting is limited until the vehicle is inspected and reset by a workshop.

Inducement system options with regards to customer and filling station acceptability

1. Stop Vehicle Operations

- **Description:** This approach involves stopping the vehicle if non-CNF is detected. The vehicle would halt immediately upon detecting non-CNF, or at the next engine start if the detection occurs while the engine is off (e.g., during fuelling). This approach aligns with the initial EC proposal.
- **Advantages:** This option enforces strict CNF compliance, ensuring the vehicle can only be operated within the regulatory framework.
- **Challenges:** Abruptly stopping the vehicle, especially on the road, poses severe safety risks. If the vehicle halts at the next engine start (e.g., after a refuelling stop), the driver may not be able to move the vehicle away from potentially hazardous areas, such as a fuelling station. This restriction also lacks flexibility, which can inconvenience users who may encounter temporary CNF shortages.
- **Restoration of Vehicle Operations:** The vehicle requires workshop intervention to resume operations.
- **User Acceptance:** Very low. Safety concerns and the inability to use the vehicle without CNF refuelling, especially outside the EU, would likely deter customers from accepting this option.

2. Progressive Reduction of Vehicle Performance

- **Description:** This option progressively reduces vehicle performance if CNF is not refilled. For instance, the vehicle’s maximum speed or engine torque would be incrementally reduced, limiting its drivability and usability as non-CNF use continues. This gradual inducement allows users to return home or reach a refuelling station, in line with some UNECE regulations, where vehicles exhibit reduced performance due to specific system malfunctions detected by the OBD system.
- **Advantages:** This flexible approach permits emergency travel and is user-friendly as it provides an option to “limp home” if CNF refuelling is not immediately available. Reduced vehicle performance prompts users to refill with CNF without fully compromising usability.
- **Challenges:** If the driver relies on fossil fuels for extended periods, the vehicle’s performance may be significantly degraded, which could pose an inconvenience, though not to the extent of halting operations altogether.
- **Restoration of Vehicle Operations:** Full functionality is restored upon CNF refuelling.
- **User Acceptance:** High. Users retain emergency use options, and the approach is less punitive than an immediate halt. Acceptance is also bolstered by its allowance for travel outside the EU without compliance penalties.

3. Maximum Mileage Allowed

- **Description:** This option defines a set mileage threshold after which the vehicle cannot operate until it refuels with CNF. This inducement is structured similarly to AdBlue systems in heavy-duty vehicles, where certain mileage limits apply when compliance additives are low. After the specified mileage is reached, the vehicle will not start again unless it has been refuelled with CNF.
- **Advantages:** By defining a clear mileage allowance, drivers are informed about the remaining distance they can travel with non-CNF, allowing them to plan a compliant refuelling stop. This staged inducement provides flexibility while ensuring that compliance is maintained within a set distance.
- **Challenges:** For drivers without access to CNF, meeting the mileage threshold could require additional planning to avoid non-compliance. This approach may be restrictive in areas with limited CNF infrastructure, where reaching a refuelling station may not always be feasible.
- **Restoration of Vehicle Operations:** Workshop intervention is required to restore operations if the threshold is exceeded.
- **User Acceptance:** High. Drivers appreciate the control and advanced notice of mileage limits, allowing them to make refuelling decisions pro-actively.

4. Financial Offsetting

This inducement system maintains vehicle performance while imposing financial costs for non-CNF use. There are two primary financial offsetting options:

a) Payment of Carbon Emissions (at Each Refuelling)

- **Description:** When the vehicle detects non-CNF use, an additional fee applies at the next refuelling. For example, a surcharge could be applied directly at the fuel station or as a separate carbon tax. If refuelling occurs outside the EU, the vehicle logs the fossil fuel consumption, applying the surcharge upon re-entry.
- **Advantages:** This method incentivises CNF use without disrupting vehicle operations, providing users flexibility. Additionally, dynamic pricing could deter non-CNF use over time, especially with incremental fee increases for repeated non-compliance.
- **Challenges:** Requires advanced digital solutions for real-time fee adjustments. Dynamic pricing at stations may be challenging if stations lack the capability for on-the-fly price changes, and compliance monitoring may be harder outside the EU.
- **Restoration of Vehicle Operations:** Not required.
- **User Acceptance:** Intermediate. Financial penalties are preferable to operational restrictions, though they may frustrate customers if the fees accumulate unexpectedly.

b) Payment of Carbon Emissions (During Vehicle Inspections)

- **Description:** The vehicle tracks non-CNF use, with offset fees assessed during regular vehicle inspections. For vehicles operating outside the EU, this option may involve a deferred offset fee upon re-entry. Digital tracking solutions would ensure an accurate record of non-CNF usage, facilitating the offset calculations at inspection time.
- **Advantages:** Minimizes immediate costs for users, allowing them to pay offset fees at pre-scheduled inspections. Provides flexibility for long-distance travel, and penalties are proportional or higher to non-CNF use over time.
- **Challenges:** Delayed fees may be unexpectedly high if non-CNF use has accumulated, leading to customer dissatisfaction if not promptly communicated. However, via a digital solution (DFTS) and the refuelling history, the current payment status could be made available in the vehicle dashboard to be transparent for the cus-

tomer and not overwhelm in next inspection.

- **Restoration of Vehicle Operations:** Not required.
- **User Acceptance:** Low. While vehicle operations are unaffected, delayed penalties can lead to frustration if users face significant fees at inspections.

6.5. Regulatory Geofencing

Regulatory geofencing is a direct consequence from the inducement systems chosen to ensure compliance with CNF requirements. This influences how vehicles function outside EU borders and affecting the resale value of used vehicles in non-EU regions.

Three primary scenarios illustrate the regulatory geofencing options and their implications for vehicle usability, enforcement, and potential misuse outside the EU:

Scenario 1: Restricting Vehicle Operation Outside the EU

In this strictest scenario, vehicles are restricted from traveling outside the EU unless CNF fuelling compliance can be guaranteed in non-EU regions. This option would require advanced monitoring and verification mechanisms that ensure only CNF-compatible fuels are used, regardless of geographic location.

- **Advantages:** This approach ensures full compliance with EU standards, eliminating any risk of fossil fuel usage outside EU boundaries. Vehicles operating in this mode can only use CNF, aligning with EU climate goals even when abroad.
- **Challenges:** The strict limitations on vehicle operation outside the EU may limit market appeal for certain users. Additionally, maintaining compliance outside EU borders may require a global network of CNF-compatible fuelling stations or innovative tracking and validation technologies.

Scenario 2: Permitting Non-CNF Use Outside the EU

In this scenario, the vehicle is free to use any available fuel outside EU borders, bypassing CNF restrictions when outside the EU. While this option offers flexibility for cross-border travel, it also introduces the risk of misuse, as some users may attempt to circumvent CNF requirements by fuelling with non-CNF outside the EU.

- **Advantages:** This flexible approach accommodates travel needs and maintains vehicle functionality abroad without restricting fuel choices. It minimizes operational barriers for users who frequently travel or reside near EU borders.
- **Challenges:** The lack of CNF enforcement outside the EU may encourage non-compliance, as users can take advantage of cheaper fossil fuels abroad. This scenario would likely require additional tracking measures to monitor fuel types and consumption, adding complexity to CNF compliance.

Scenario 3: Monitoring and Offsetting Non-CNF Use upon Re-entry into the EU

This balanced approach allows vehicles to use any fuel type outside the EU but requires them to account for any non-CNF use upon re-entry. When the vehicle crosses back into the EU, it recognizes non-CNF import and triggers an offsetting mechanism to reconcile the use of non-CNF abroad.

- **Advantages:** This method combines flexibility for cross-border travel with a mechanism for compliance within the EU. The offsetting system deters fossil fuel use outside the EU by associating a financial or regulatory cost with non-CNF fuelling.
- **Challenges:** This option relies on accurate fuel monitoring and consumption data to avoid discrepancies, and it requires an efficient offsetting mechanism upon re-entry. Users may find the offsetting process inconvenient, and enforcement may be challenging if fuel records are incomplete or tampered with.

Requirements for Implementing Regulatory Geofencing

To implement regulatory geofencing effectively, several technical and regulatory measures must be addressed:

1. **Accurate Fuel Monitoring:** Vehicles must have a reliable method to track the type and quantity of fuel used, even in cases of partial refuelling. This includes:
   - **Fuel Tracking Technology:** Enhanced fuel sensors are needed to record both the type and amount of fuel dispensed. Monitoring systems must detect misfuelling events, even with partial fills, to prevent circumvention of regulations.
   - **Digital Fuel Records:** A secure, tamper-proof digital record of fuelling events is essential, especially for vehicles re-entering the EU. This enables accurate offsetting calculations and helps authorities ensure compliance.

2. **Additional Regulatory Geofencing Software:** The vehicle needs specific software to activate and deactivate CNF requirements automatically based on location. This system ensures that the vehicle's inducement mechanism can seamlessly switch off when it leaves the EU and is reactivated upon return.
   a) **Yes/No Decision Sensor:** To distinguish between CNF and non-CNF use, vehicles require a yes/no sensor system that identifies fuel type reliably across borders. This sensor system must enable the inducement mechanism to adapt based on fuel type and location.
   b) **Digital solution:** No additional hardware is necessary. A digital option (e.g. DFTS) could serve to identify the fuel type (CNF or non-CNF), since the fuelling history is tracked. Also, this system must enable the inducement mechanism to adapt based on fuel type and location

3. **Handling Sensor Malfunctions and Penalties:** If the sensor detects misfuelling inaccurately, it could penalize users unfairly. Regular sensor inspections would be needed to verify proper functionality, as well as protocols for handling sensor malfunctions to prevent false penalties. Additionally, provisions should be in place for users to dispute penalties related to sensor errors, ensuring fair treatment. For a digital solution (B) the fuelling history could be checked on implausibility during regular inspection to assure proper functioning.

4. **Offsetting Mechanism for Non-CNF Use:** Vehicles must have a seamless offsetting system that reconciles non-CNF use when re-entering the EU. Options include:
   - **Direct Payment Offsets:** This system could automatically calculate and apply a carbon offset fee based on recorded non-CNF usage, providing a direct financial deterrent to misfuelling abroad.
   - **Inspection-Based Offsetting:** For vehicles without immediate offset payment capabilities, offset fees could be settled during regular vehicle inspections based on the vehicle's digital fuel records.

5. **Customer Communication and Transparency:** To foster user acceptance, customers should be informed about how regulatory geofencing works and any associated costs of non-CNF usage. This includes:
   - **Clear User Notifications:** When non-CNF use is detected, drivers should receive notifications that outline potential offsetting costs, penalties, or inducement actions.
   - **Support for Cross-Border Users:** For drivers who frequently cross EU borders, clear guidance on regulatory geofencing and offsetting requirements would ensure smoother travel experiences and prevent unexpected costs.

07
REGULATORY EVALUATION

This chapter evaluates the described monitoring methodologies from a policy perspective. Regulations are analysed to identify adaptations that may be required to recognise individual CNF monitoring methodologies. We describe the advantages, disadvantages and impacts from a regulatory side. We estimate the probability and time duration for potential implementations and formulate brief amendments if possible. Step by step, all monitoring options are described in the next sections.

First, we would like to describe the general regulative amendments, which are necessary for all monitoring methodologies. Additional required changes are described in each option below.

- **New Euro 7 Regulation (EU) 2024/1257 Delegated Regulation,** originally the introduction of a new vehicle class for the exclusive use of CNFs was planned for Euro 6. Meanwhile, Euro 7 fully entered into force. A delegated act is required to allow the Commission to propose an implementing act for a new CNF-only vehicle class. A delegated act could be rejected by parliament or council if a majority is formed. Also, a 2-month consultation period is set, which can be expanded by another 2 months if requested by the parliament. The necessity of a delegated act would likely delay the introduction of a new vehicle class.

- **New Euro 7 Regulation (EU) 2024/1257 Implementing Regulation,** in this act the definition of CO_2 neutral fuels as proposed in Chapter 4 should be introduced. In addition, all eligible monitoring methodologies should be mentioned. Third, the Commission should propose an inducement and should propose a flexibility mechanism as discussed in Chapters 5 & 6. This is the main regulative component for a new vehicle class.

- **Amendment to** Regulation (EU) 2023/851 (CO_2 regulation for cars and light-duty vehicles) to consider all light-duty vehicles powered exclusively by CO_2 neutral fuels and within the criteria of the developed implementing act in EURO 7 as zero-emission vehicles and provide calculation rules for the fleet average of manufacturers.

- **Amendment to** Regulation (EU) 2024/1610 (CO_2 regulation for heavy-duty vehicles) to consider all light-duty vehicles powered exclusively by CO_2 neutral fuels and within the criteria of the developed Implementing Act in EURO 7 as zero-emission vehicles and provide calculation rules for the fleet average of manufacturers.

Consideration of Alternative Fuels Infrastructure Directive AFIR Regulation 2023/1804**:**

The recognition of CNF filling stations and CNF products in AFIR could assist their wider and faster implementation. The deployment of alternative fuel infrastructure across the EU has been addressed since the European Union Directive 2014/94/EU, now repealed by Regulation 2023/1804. Both the Directive and the Regulation address the need for wider access to "alternative fuels"[8] in Europe and include a requirement for both new vehicles and refuelling and charging stations to display labels that allow drivers to select the appropriate fuel for their vehicle.

To ensure traceability of biogenic content throughout the supply chain, biofuel pro-

8. Alternative fuels definition according to Article 2(4) of Regulation 2023/1804 'alternative fuels' means fuels or power sources which serve, at least partly, as a substitute for fossil oil sources in the energy used for transport and which have the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector, including: (a)'alternative fuels for zero-emission vehicles, trains, vessels or aircraft': electricity, hydrogen, Ammonia. (b) 'renewable fuels': biomass fuels, including biogas, and biofuels as defined in Article 2, points (27), (28) and (33), respectively, of Directive (EU) 2018/2001, synthetic and paraffinic fuels, including ammonia, produced from renewable energy, (c) 'non-renewable alternative fuels and transitional fossil fuels': natural gas in gaseous form (compressed natural gas (CNG)) and liquefied form (liquefied natural gas (LNG)), liquefied petroleum gas (LPG), synthetic and paraffinic fuels produced from non-renewable energy;

ducers have implemented sustainability management systems that include certification and verification processes. These systems ensure compliance with the sustainability and greenhouse gas (GHG) reduction requirements set out in Article 29 of the Renewable Energy Directive. The adoption of recognised certification schemes, such as ISCC EU and 2BS, among others, provides a framework to validate compliance with environmental and social criteria, as well as traceability from the origin of raw materials to delivery to the final consumer. These efforts not only promote sustainability and biodiversity protection, but also enable the verification of greenhouse gas emissions reductions along the entire supply chain.

Both provide for the use of a new single harmonised set of fuel labels. These labels are displayed:

- On the owner's manual and near the fuel filler cap or cap on new cars, and cars and may also appear on electronic manuals available through the car's multimedia centre.
- On fuel dispensers and nozzles at all public service stations.
- At vehicle dealers.

With regard to the labelling of alternative fuels on dispensers, it is specified that if the technical specification standards for a fuel do not include labelling provisions, the Commission may order the European standardisation bodies to introduce labelling specifications in order to comply with the Regulation.

In the absence of labelling provisions in the product specifications, the Commission requested CEN (European Committee for Standardisation) to undertake the design and formatting of new labels to comply with the general provisions of the Directive 2014/94/EU. This work was carried out in the Technical Committee 441 (TC 441), which included experts from the EU automotive and fuel industries, representative consumer organisations, national standardisation bodies, several EU governments and the European Commission. This work resulted in the publication of EN 16942, which defines the design and size of these new labels. The legislation requires the labels only on new vehicles placed on the market for the first time or registered on or after 12 October 2018.

The existing labels that must be displayed on vehicles and at petrol pumps are shown in table 7.1:

Table 7.1

Fuel Grade	Marking to EN 16942:2016	Part Number
Gasoline with up to 5% Ethanol	E5	EK FG!-E5
Gasoline with up to 10% Ethanol	E10	EK FG!-E10
Gasoline with up to 85% Ethanol	E85	EK FG!-E85
Diesel with up to 7% Biodiesel	B7	EK FG!-B7
Diesel with up to 10% Biodiesel	B10	EK FG!-B10
Diesel with up to 20% Biodiesel	B20	EK FG!-B20
Diesel with up to 30% Biodiesel	B30	EK FG!-B30
Diesel with up to 100% Biodiesel	B100	EK FG!-B100
Paraffinic Diesel Fuel	XTL	EK FG!-XTL
LPG	LPG	EK FGI-LPG

CNFs may be labelled, for example, as XTL in the case of paraffinic diesel such as HVO or B100 in the case of 100% biodiesel. For the visibility of the end-user, it is important that CNFs are labelled and recognized at filling stations

Option 1 – Mechanical Adaptation of Tank Filler/ Nozzle

The mechanical adaptation of filler nozzle/receptacle requires mainly adaptation in new standardization of fraud-proof new filling technologies. In the following, the main regulations are described, which could be amended.

The necessary standardization for mechanical adaptations of filler nozzles for liquid fuels are described in the appendix. The modification of the nozzle/filler neck will involve the following standards and related working groups, as well as an amendment to the Directive 2009/126/EC of the European Parliament and of the Council of 21st October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations.

Also for gaseous fuels the standardization for fuel nozzles are described in the annex. As described in the applicable chapter 4, the CNF receptacle will require a new profile or size, not compatible with traditional fuel or other gaseous fuels.

The profiles of the receptacles and the critical dimensions of the nozzles are standardized and described in CEN, ISO standards or in UNECE regulations, which shall be amended accordingly.

The number of new standardizations show the high effort and time required to introduce such a monitoring methodology. From a political perspective, a mechanical solution such as requirement for new nozzles comes with high administrative burden, enormous international efforts and will take many years to be realized.

Option 2 – Fuel Marker along Upstream and Downstream

1. How to define a coloured marker for fuels?

- A **coloured marker** is a chemical additive that is added to fuels to make them visually identifiable, often used to combat fraud (distinguishing between subsidized and non-subsidized fuels, different taxation schemes, etc.).
- The marker must meet several criteria: it should be **easily detectable, stable** over time and under different conditions (temperature, pressure, storage), and should not **alter the fuel's properties**.

2. Types of Markers Used:

See table 7.2

3. Necessary Additives for Fuel Marking:

- **Dyes and chemical markers** must be stable in the fuel, inert to avoid reactions with other fuel components, and must not produce toxic by-products during combustion.
- **Fluorescent markers** must be visible under specific wavelengths, usually in the UV

Table 7.2

Marker Type	Description	Use	Detection Method	Advantages	Disadvantages
Visible Dyes	Organic dyes dissolved in fuel, often azo or pyridine-based compounds.	Visual identification for subsidized fuels (agricultural, marine).	Visual observation, simple test	Simple to use, quick identification	Can be counterfeited, non-discreet detection
Molecular Markers	Invisible chemical compounds detectable by chemical analysis (e.g., spectrometry).	Fuel traceability, anti-tax evasion.	Spectrometry, chromatography	Very precise, hard to counterfeit	Requires expensive detection equipment
Isotopic Markers	Stable isotopes embedded in the fuel, unique to each batch or region.	Highly secure tracking, fiscal control.	Mass spectrometry	High reliability, discreet detection	High production cost, specialized detection
Fluorescent Markers	Molecules that absorb UV light and emit visible fluorescence.	Quick detection in the supply chain.	UV lamps, optical sensors	Easy detection, portable	Limited to low-light environments, moderate cost
Nano-particles	Ultra-fine particles detected by physical methods like light scattering.	Securing the supply chain.	Light scattering, magnetic methods	Very discreet, hard to counterfeit	Complex to produce and detect

spectrum, while **isotopic markers** require more complex detection techniques (mass spectrometry).

4. Institutions and Authorities Responsible for Setting Standards:

- At the international level, organizations such as the International Organization for Standardization (ISO) issue recommendations for fuels, though they don't specifically cover markers.
- In Europe, regulations are covered by directives like the Fuel Quality Directive (98/70/EC) and REACH regulations for chemical substances.

5. Time Required to Establish New Standards:

- Establishing new standards can take several years, particularly when markers need to be assessed for their environmental impact, safety during combustion, and compliance with local and international regulations.
- The process typically involves technical trials, stakeholder consultations (governments, oil industries), and adjustments based on test results.

6. Where to Add Markers and Perform Controls (Including Time Required)

Defining a coloured marker for fuels depends on various factors, including the need for stability, visibility, and adherence to environmental and safety regulations. International authorities like **ISO** and national regulators play key roles in setting standards, though the process can be lengthy. Different types of markers vary in detection methods and technical constraints, with varying costs and levels of complexity.

Table 7.3

Phase	Add Marker Here?	Perform Control Here?	Methods of Detection	Personnel Required	Time Required for Control
Refinery (Production)	Yes	No	Not applicable at this phase	None	Not applicable
Fuel Terminals/Depots	Yes	Yes	Spectrometry, UV detection, visual check	Trained inspectors, lab staff	15 - 30 min (per batch, including sampling and analysis)
Pipeline Injection (Transport)	Yes (occasionally)	No	Not applicable at this phase	None	Not applicable
Retail Stations	Yes (sometimes)	Yes	Visual check, UV detection	Basic personnel for visual; trained for advanced tests	5 - 15 min (quick check for visual or UV detection)
In-Transit Vehicle Inspection	No	Yes	UV detection, optical sensors, sampling	Minimal for basic checks	5 - 10 min (on-the-spot detection with UV or optical tools)
Border/Customs	No	Yes	UV detection, spectrometry (portable)	Basic training or specialized	10 - 20 min (depending on detection method and sample size)
Laboratory Analysis	No	Yes (in-depth checks)	Mass spectrometry, chromatography	Highly trained personnel	1 - 3 hours (for detailed chemical analysis)

Option 3 – 100% Digital Fuel Tracking from Upstream to Downstream (DFTS w/ Digital Handshake)

The Digital Fuel Tracking System allows a reliable, verifiable and audit-proof digital tracking of the CO_2 intensity of fuels in fuel blends as well as the proof of an exclusive use of CNF in vehicles. It offers advantages beyond the verification of renewable fuels in CNF vehicles. Along the supply chain, a digital tag is attached to every step of fuel delivery until the vehicle user which certifies the CO_2 emissions of the fuel at every stage of the supply process. A certification scheme allows operators along the supply chain and especially end users (companies, transport service providers) to use the CO_2-related information for their carbon footprint calculations and CO_2 reporting required e.g. by CSRD, CountEmissionsEU and/or the Taxonomy Regulation.

Upstream part: Digital Tracking of Physical Fuel Distribution Network

Currently, this methodology is in use in pilot projects for CO_2 footprint reporting in commercial fleets.

We assume that the current certification scheme can be used to introduce digital tracking of fuel distribution network where the upstream data corresponds fully to those reported to the Union Database (UDB). Following, CNF's shall also report/provide upstream data with their proof of sustainability.

Like for all other monitoring methodologies as well, the relevant retail standards shall be amended to ensure that only qualified retail is able and allowed to sell CNF and provide corresponding audit-proof data for the fuel characteristics.

Downstream part: Digital handshake between fuel station and vehicle

Currently this methodology is in proof-of-concept stage and ready for demonstration.

Audit-proof retail qualification selling CNF: existing standards for fuel retail should be amended to ensure that only qualified retail is allowed to sell CNF as being able to deliver the necessary audit-proof evidence/processes ensuring compliance to specified standards.

Common ISO standard(s): Standard interfaces for fuel stations should be developed to ensure interoperability between different fuel suppliers and vehicle manufacturers and enable a swifter market penetration of the DFTS. They describe in detail the communication protocol, and the dataset that DFTS shall manage. The final customer should be able to refuel their vehicle in any fuel station equipped with an ISO-compliant DFTS system.

It may take 3-5 years to develop a common ISO standard. The standard is however not a prerequisite for the operability of the DFTS. Fuel stations could provide CNFs together with DFTS with proprietary interfaces and data already before a common standard is set. This way, an early introduction and use of DFTS methodology for e.g. automated CSRD reporting is possible.

Data privacy and cyber security: The ownership of data remains with the corresponding data provider along the fuel supply chain. All data processed on DFTS are anonymised, encrypted and therefore have no GDPR relevance. This means that there are no increased requirements for data protection. The existing framework of data privacy and cyber security rules already covers the data communication process related to the DFTS and must at most be formally adapted as described below.

For the cyber security of the data along the value chain (data, storage, back-end), the Cyber Resilience Act (CRA) and NIS2 Directive apply. NIS2 Annex I "Sectors of high criticality, 1.) Energy"; might need to be amended to introduce a new category "renewable fuels" beside the existing oil, gas and hydrogen categories.

Cyber security of in-vehicle data: According to Regulation (EU) 2024/1257, vehicle manufacturers must ensure the secure transmission of data related to emissions by taking cyber-security measures in accordance with UN R155. UN R155 refers to ISO/SAE 21434 and follows a risk-based approach. It obliges the OEM to implement and process a risk assessment as part of a cyber security management system (CSMS). The OEM must consider any potential for misuse/ manipulation accordingly by identifying and considering security assets during the engineering phase and mitigate the risk through appropriate technical measures (security concept). This is already commonly applied today as protection against tuning. UN R156 regulates Software update and software update management system (SUMS).

Vehicle Type Approval: Regulation (EU) 2024/1257 should be amended to extend rules in regard to data access, data communication and data protection against misuse and manipulation to DFTS-relevant data. Fuel-related data should be made available to vehicle users, similar to environmental data.

The intended new Implementing Regulation to Regulation (EU) 2024/1257 for the type approval of CNF vehicles will need to remain technology-neutral to allow for the possibility to monitor the use of CNF through a digital device, able to communicate with the filling station (DFTS). The implementing regulation should describe a proper inducement system, that would activate in case of filling operation of non-CNF.

Option 4 - Hybrid Approach - Upstream: Fuel Marker & Sensor until EU Border - Downstream: DFTS w/ Digital Handshake.

Upstream part: Fuel Marker (as described in option 2)

Downstream part: Digital Fuel Tracking System (as described in option 3

Option 5 – On-Board Fuel Detection Function

The vehicle on-board fuel detection function represents a significant advancement in enabling the use of CNF in modern vehicles. Its key advantage is the ability to detect the correct fuel without requiring significant changes to the infrastructure or vehicle, as it utilises existing sensors in the vehicle. This makes it a more practical and less disruptive solution, requiring fewer regulatory changes for compliance. However, the effective implementation of the on-board fuel detection function depends on the harmonization across diesel and gasoline standards.

- Specifically, the standards need to ensure that CNF, such as biodiesel blends (e.g., B20, B30) or paraffinic diesel (e.g., HVO, GTL), are standardized to allow consistent engine calibration and the accurate detection of fuel properties.
- Therefore, CO_2 neutral diesel and gasoline fuels should either comply with EN 590 or EN228 standards or a new harmonized standard will need to be developed to ensure that this technology can reliably detect the fuel's physical properties such as density, viscosity, heating value, cetane number and bulk modulus, similarly to what is currently done with certified fuels. This standard alignment is essential for maintaining vehicle performance and emissions compliance, regardless of the specific CNF used.
- Developing or revising ISO EN standards for carbon-neutral diesel and gasoline fuels involves a multi-step process including industry experts, creation of a specialised working group, a period for public consultation, approval, publication and lastly, the implementation of the new standard across several countries.
- The time frame for these steps can vary depending on stakeholder consensus, regulatory urgency and the potential acceleration driven by political or environmental pressures. However, given the current push for decarbonisation this process is expected to take a total of 3 to 5 years.

Option 6 – Vehicle On-Board Fuel Molecular Sensor:

In contrast to the physical sensor approach in Option 5, which would likely require the combination of two or three sensors to achieve acceptable accuracy, Option 6 employs a single, advanced Near-Infrared (NIR) spectroscopy sensor. This sensor provides precision akin to a "DNA fingerprint" by scanning thousands of molecules in the fuel, accurately identifying its molecular structure. NIR technology allows for detailed and reliable differentiation of CNFs, far beyond what traditional physical properties like viscosity or density can reveal.

The NIR sensor is based on **opto-electronics and semiconductor** existing technology, has been commercially deployed in the truck and bus market since 2021 and due to the absence of technological barriers, enabling immediate **mass production** at a controlled cost. The technology has been in use for more than three years in Europe, particularly for trucks and buses, and is now ready for deployment in light-duty vehicles.

Option 6 works seamlessly with **digital handshake** systems, which ensure traceability from fuel production through distribution to the vehicle's fuel tank. The NIR sensor confirms that the molecular structure of the fuel going into the engine matches the fuel traced throughout the supply chain. These two systems are **complementary**, combining the power of molecular detection with end-to-end digital certification to guarantee compliance.

Option 7 – Bidirectional Communication between vehicle and gas station.

Table 7.4 describes key criteria of bidirectional communication between vehicle and gas station from a regulatory perspective. Items like security and fraud resistance, data security and involved public authorities are mentioned below.

Table 7.4

Criteria	NFC Bidirectional Communication	Locks/Constraints to Address	Deployment Feasibility (+/–)
Security and Fraud Resistance	Very high: Third-party authentication, anti-tampering during refuelling.	Who controls: A trusted third-party (e.g., a certification authority or regulatory body) must issue and manage digital certificates for fuel stations and vehicles.	++ High level of security ensures widespread adoption. –: Requires establishment of a global/regional control authority, adding complexity.
Implementation Complexity	Moderate: Requires NFC infrastructure, digital certificates, internet connectivity.	How to control: Ensure interoperability between different fuel stations and vehicle manufacturers. Standardization across regions needed.	++: NFC technology is mature and widely available. –: Requires new infrastructure in many fuel stations, adding costs and time for roll-out.
Fuel Detection Accuracy	Good: Only verifies the authenticity of the CNF provider, no fuel composition detection.	Frequency of checks: Regular audits and certification renewals for fuel stations. Vehicles could perform periodic checks during refuelling or through on-board diagnostics (OBD).	++: Verifies fuel provider authenticity, which is sufficient for CNF certification. –: Lacks direct fuel composition verification, reducing precision in fuel quality checks.

Criteria	NFC Bidirectional Communication	Locks/Constraints to Address	Deployment Feasibility (+/–)
Cost of Deployment	Moderate: Infrastructure costs for gas stations and some vehicle retrofits.	How to control costs: Explore cost-sharing models between fuel stations, fuel suppliers, and vehicle OEMs. Standardize hardware and certification to minimize costs.	++: Moderate costs, with potential for shared infrastructure costs. –: High initial investment required for fuel stations, especially in regions without NFC-enabled infrastructure
Real-Time Fuel Validation	Yes: Ensures only CNF is used during the refuelling process.	Cyber-security compliance: Adherence to ISO/SAE 21434 for cyber-security risk management in automotive systems. Communications between vehicle and fuel station must be encrypted and secure.	++: Ensures secure, real-time validation, preventing fraud. –: Requires secure, encrypted communication and compliance with cyber-security standards, which adds complexity.
Flexibility and Scalability :	High Can be scaled across different fuel stations and vehicles with CNF.	Scalability constraint: Requires global/regional agreement on standards and protocols to ensure cross-border compatibility.	++: High scalability across regions with the right standards in place. –: May face challenges in regions with different regulatory frameworks or infrastructure gaps.
Deployment Complexity and Cost	Requires retrofitting fuel stations and vehicle compatibility (for NFC). Costs include NFC hardware installation, software integration, and certification management.	Deployment constraints: The cost of retrofitting existing infrastructure, including fuel dispensers and vehicles. Training for fuel station staff and ongoing certification renewals.	++: Infrastructure already exists in some industries (payment terminals, etc.), making the transition easier. –: High up-front cost for wide-scale deployment and certification management, especially in less developed regions.
Cyber-security Compliance (ISO 21434)	Requires full compliance with ISO/SAE 21434 for cyber-security in automotive systems. This ensures the encryption of data and protection from potential cyber-attacks.	How to control: Secure communication protocols and encryption measures are essential. Regular audits and updates to maintain compliance with cyber-security standards.	++: High level of cyber-security enhances trust in the system and prevents fraud. –: Adds complexity and cost for compliance, especially for smaller operators.

Option 8 – EU Market Exclusively Supplied with CNF

As described in chapter 5 this option would mean that only fuels, which fits in the definition of CNF (see chapter 4) are available in all EU Members States from 2035. This is highly improbable taking into account the current announced investment and legislative development.

The share of renewable energy carriers in the transport sector is regulated in the Renewable Energy Directive (RED). A basic description of this regulation is provided in the annex of this report (please insert link). The current goal of the RED III is an energetic share of renewable energy of 29% in 2030, which includes multipliers for different compliance options, or a greenhouse gas (GHG) reduction of 14.5%. Targets beyond 2030 are not available and will be discussed in the next review in 2027. EU member states are currently implementing the RED III in national law until May 2025. According to Eurostat, Sweden has the highest share with 29% renewable sources in the transport sector – Croatia has the lowest share with 2.4% in 2022.

Based on current EU climate goals, the EU wants to achieve -55% GHG emissions in 2030 and is currently debating -90% in 2040.

Provided the availability of CNF is dedicated to the supply of all new LDVs and HDVs, this could be a more realistic approach for the near future, as the production capacity could meet that demand whilst growing over time in line with the increased number of new vehicles sold.

Once 100% CNF in the European fuel market is achieved e.g. in 2050 then monitoring methodology will become obsolete. All new vehicles would run exclusively on CNF. If the revision of the RED leads to 100% CNF in future it automatically limits the necessity of a CNF monitor methodology.

Option 9 - Mass-Balanced CNF Supply to Each CNF Vehicle

From a regulation methodology perspective mass balancing is a well-established and highly efficient concept, recognised under several policies. For example, the RED and European Emission Trading System (ETS) are based on mass balancing concepts. Such a monitoring methodology could be implemented for already existing vehicles if customers wish to drive exclusively with CNFs. In the RED, fuel suppliers must prove that a certain amount of renewable energy is brought to the transport market. It doesn't matter which gas filling station (in national borders) is supplied nor which vehicle uses the fuel. A certification scheme along the value-chain from the producer to the filling station verifies that all production and sustainability criteria are met. The EU has built the Union database for renewable fuels to ensure the traceability of these fuels. With careful but feasible development, the existing RED mass balancing system could be extended to enable the monitoring of CNF-only vehicles.

To link the fuel to the vehicle the RED needs to be coupled to vehicle regulations and (national) registration. Otherwise, it is impossible to show which CO_2 tailpipe emissions have been compensated using CNFs. In principle, automotive manufacturers require access to the RED system for verification.

Proposals to combine fuel and vehicle regulations already exist. In May 2020, the German Ministry for Economic Affairs and Energy has commissioned a study on a 'Crediting System For Renewable Fuels'. Here, automotive manufacturers can purchase credits from CNF producers to reduce the carbon footprint of their vehicles. It should be mentioned that credits for CNF-only vehicles can't be used to meet RED targets in addition. The study includes necessary political amendments for an introduction of a crediting system. The authors address both regulations: the CO_2 emission standards and type approval regulation. In a follow-up study commissioned by Neste, advantages and cost calculations for such a crediting system have been made (more information is available here). In Switzerland, a crediting system for eFuels will be introduced from 2025 onwards. The crediting system is an option to prove the exclusive use of CNFs following a mass balancing approach.

An alternative approach would be to obligate the fuel supplier to meet an additional quota, which is as high as new CNF-only vehicles consume in a respective year. Here, the responsibility switches from the automotive manufacturer to the fuel supplier. Therefore, probably an additional quota has been brought in the RED. In any case, it must be proven that enough additional CNFs are brought into the market that meet the consumption of a new vehicle. The consumption can be reported digitally via on-board metering or based on statistical values. This can be done upfront or year-by-year. As mentioned, following a mass balancing approach the purchased CNF might be not exactly in a dedicated vehicle but from a holistic perspective the GHG emissions are neutralized, and the customer of the CNF-only vehicle has purchased additional CNF amounts.

The existing Commission proposal on a new vehicle class for CNF excluded any mass balancing approach. The allowance of a mass balancing system requires a policy shift, which would need to recognise the degree of security that can be achieved by the available technologies and operational methodologies. Given the efficiencies that are available, a mass balancing concept should not be neglected per se.

Option 10 – Fuel Usage Balancing – FUB

The Fuel Usage Balancing proposes that individual vehicles track their carbon emissions and balance them against the amount of CNF they consume. This method monitors carbon output at the vehicle level, ensuring that emissions are balanced with the CNF used. However, it focuses on CO_2-intensity of the fuel used rather than verifying the actual fuel composition.

Benefits:

- Emission Monitoring: Provides vehicle-specific data on carbon emissions, encouraging accountability and allowing drivers to track their environmental impact.
- Carbon Balancing: Helps ensure that emissions are balanced with the carbon-neutral fuel consumed.
- End-User Balancing provides data regarding actual CNF-use-share for individual vehicles. This data can be used for incentives e.g. lower road-tolls (Eurovignette).
- **Fuel Usage-Based Incentives/Penalties and Offsetting:** Since individual fuel consumption is directly traceable, it is easy to implement penalties or offsetting mechanisms based on actual CNF use. EUB creates a reliable way to determine whether a particular consumer is using CNF, ensuring accountability at the user level.

Challenges:

- No Direct Fuel Verification: The system tracks emissions but does not guarantee that CNF is being used. There is no direct monitoring of fuel composition, leaving potential gaps in compliance.
- Software and cloud services require cyber security and fraud resistance as discussed in option 3. New digital protocols and standards might be developed and online connection is required.

Option 11 – Combined – Upstream: mass balancing – Downstream: DFTS w/ Digital Handshake)

Upstream part: Mass balancing

See mass balancing in option 9.

Downstream part: Digital Fuel Tracking System

See DFTS in option 3.

CONCLUSION

This comprehensive report is the outcome of a cross-sectoral industry co-operation, with individual companies and trade associations from various sectors such as OEMs, OEM suppliers, fuel producers and suppliers, fuel retailers and retail equipment suppliers.

The report materialises the members' engagement to respond positively to the Commission's request to the industry to propose an overview of the methodologies able to prove the use of the CO_2 neutral fuels.

The experts of the WGMM have performed this overall assessment of all identified monitoring methodologies to provide to the Commission and Member States experts the best overview and technical input to enable an informed decision in this regulatory process. The WGMM experts are furthermore ready to support the work of the TCMV with complementary technical advice and clarification.

Moreover, the WGMM members also issued a series of recommendations regarding the definition of CO_2 neutral fuels and the consistency of this definition throughout European regulations. This is an important aspect to consider when designing the methodology for the recognition of zero-emission vehicles running on CO_2 neutral fuels.

09

APPENDIX

9.1. Detailed Description of Technology Options

Option 1 – Mechanical adaption of tank filler / nozzle

Responsible Stakeholders Involved

Fuels Producer	Importer	Refinery	Tank Farm	Distributor	Filling Station: Acceptance	Filling Station: Delivery	Vehicle
Fuels Producer					Mechanical Design of Nozzle/Receptacle		

UPSTREAM: fuel chain from the point of origin or from the fuel producer to the filling station (fuel incoming side).
The fuel provider is responsible to provide the CO_2 neutral fuels and use existing schemes as proof of origin

DOWNSTREAM: fuel chain from the fuel station (delivery side) to the vehicle.
The CO_2 NF Vehicle can be filled only by special dispenser equipped with the mating nozzle.
No other devices needed on-board the vehicle.

Description

This system involves the "downstream" part of the fuel chain. The mechanical adaptation of the fuel receptacle alone is not enough to be accounted as a complete monitoring system and it shall be combined with another method covering the "Upstream" part of the fuel chain. For example, with a certification scheme (see method #7 for a description of this part).

With this preamble, we assume that the right fuel arrives at the filling station and it is placed in a dedicated storage. The fuelling station installs a dedicated dispenser equipped with a specific fuel nozzle, which is not able to connect with the receptacle used for the fossil version of the fuel in use. In this way, the vehicle can receive only the correct fuel and no further methods are required on-board, like sensors or inducement systems.

Worldwide accepted standards have been designed to cover the following aspects of liquid and gaseous refuelling:

- Definition of all technical requirements that lead to a well-known, simple and easy filling of vehicles with fuel.
- Low total cost of ownership of car filler necks, nozzles, and dispenser equipment.
- Reliability all over the world.
- Exchangeability of components on both sides: dispensers and vehicles.
- Environmental aspects: no exhaust of hydrocarbon, e.g. vapour recovery systems.
- Simple systems, usable in highly and less developed areas.

Regarding liquid fuels, the modification of the nozzle/filler neck will involve the following standards and related working groups, as well as an amendment to the Directive 2009/126/EC of the European Parliament and of the Council of 21st October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations.

EN 13012 Scope: This document specifies safety and environmental requirements for the construction and performance of nozzles to be fitted to metering pumps and dispensers installed at filling stations and which are used to dispense liquid fuels and aqueous urea solution into the tanks of motor vehicles, boats and light aircraft and into portable containers, at flow rates up to 200l/min-1.

- EN 16321-1 and 2 Scope: This European Standard specifies the measurement and test methods for the efficiency assessment of petrol vapour recovery systems for service stations (Stage II).
- ISO 9158 Main issue: Nozzle outside diameter unleaded gasoline: max. 21,3mm
- ISO 9159 Main Issue: Nozzle outside diameter leaded gasoline and diesel ≤50 L/min: min. 23,6 mm to max. 25,5 mm
- ISO 13331 Scope: This International Standard ensures compatibility between new petrol-powered vehicle designs and refuelling vapour recovery nozzles — both active and passive systems — by their dimensions and specifications.
- SAE J 285 Scope: This SAE Recommended Practice provides standard dimensions for liquid fuel dispenser nozzle spouts and a system for differentiating between nozzles that dispense liquid into vehicles with spark ignition and compression ignition...
- SAE J1140 Scope: This SAE Recommended Practice was developed primarily for gasoline-powered passenger car and truck applications to interface vapour recovery systems, but may be used in diesel applications,... for filling.
- SAE J829 / SAE J1114 / SAE J 3144: Different fuel filler caps that are in use with the equipment that is defined above.

Regarding gaseous fuels, where there are leak-proof connections, the CO_2 neutral fuel receptacle will require a new profile or size, never used for traditional fuel or other gaseous fuels.

The profiles of the receptacles and the critical dimensions of the nozzles are standardized and described in CEN, ISO standards or in UNECE regulations, which shall be amended accordingly:

- ISO 14469-1 Road vehicles — Compressed natural gas (CNG) refuelling connector (nozzles and receptacles)
- ISO 16380 CNG/H2 blends receptacle and nozzle
- ISO 12617 3.1MPa LNG connector
- ISO TS 21104 1.8 MPa LNG connector
- ISO 19825 LPG receptacle
- EN 13760 LPG nozzles
- ISO 16923 CNG/biomethane filling stations (no nozzle)
- ISO 16924 LNG filling stations (no nozzle)
- UNECE Regulation 110 (CNG vehicles)
- UNECE Regulation 67 (LPG vehicles)

Option 2 – Fuel Marker along Upstream and Downstream

Description

The Renewable Fuel Marker enables all market participants (from the mineral oil industry to vehicle manufacturers) to introduce climate-neutral fuel as a new fuel variant with two safety features with very little effort, maximum speed and flexibility in the introduction by 2035. The physical features are already being tested in the field, for instance during the DeCarTrans project, where physical safety features are:

- Colour
- Chemical tag

Fuel marker products can be used for the marking and colouring of synthetic products such as 'methanol to gasoline', GTL, HVO, or petroleum products, mineral oils, aliphatic and aromatic hydrocarbon solvents and fuels. They usually are free-flowing liquids and may contain an additional labelling system. The product can be easily pumped, poured or dispensed directly from the container. As synthetic fuels are being developed as drop-in alternatives to conventional fossil fuels, they are very similar in their chemical composition. They are burnt under the same engine conditions.

Target

The Fuel Marker is connected to all relevant stakeholders, including the Customs Directorate and the Ministry of Finance. Confirmation of CNF for pure CNF vehicles, plausibility check and tracking of the fuel (incl. CO_2 footprint).

- Visual inspection of only CNF vehicles using colour recognition similar to the known procedures for "red" diesel or heating oil. The blue colour could be used to visually distinguish between renewable and fossil fuels.
- The colour of the chemical tag is checked by a marker to prevent fraud. For the Customs Directorate, analysis methods can typically be supplied by the additive supplier, and supervised by the regulator.

-> Additives are already available that have Customs tariff numbers for some Member States

-> By adding the blue dye, mixing of CNF with petroleum fuels can be chemically detected. This property is helpful in a quick test by customs, e.g. at a motorway service station.

-> Technical data sheets would give the correct dosage rate for the additive.

-> The owner of the labelling company would then be obliged to carry out proper labelling of the renewable fuel and to monitor this regularly.

-> Since 01.04.2010, two new analytical methods for determining the content of colourants have been legally valid in Germany, which are more precise, reliable and time-saving compared to the old methods. These are called HPLC methods. HPLC means 'high performance liquid chromatography' (is no longer correct, it is HPLC and GCMS method and in my opinion not so important).

Boundary Condition

The option utilises data that is already available in the fuel supply system, which ensures rapid implementation.

Marker

- The marking of fuels is already known and established in the market.
- Marking can be carried out in the tank farm
- Marking can be carried out in the tanker vehicle

Sensor Layout

Chemical detection of the additive using a yet-to-be-developed sensor integrated either in the car or in the fuel dispenser is an innovative development that has the potential to significantly improve safety and efficiency in the handling of renewable fuels. Such an additive sensor would be designed to detect the specific chemical compounds of the specific additive and measure their concentration by analysing the chemical properties of it and converting them into electrical signals. This could be realized by different mechanisms such as electrochemical, optical or mass sensitive detection methods. For example, an electrochemical sensor based on a specific redox mechanism could be used to detect traces of the specific additive in the fuel. Alternatively, an optical sensor based on the absorption or emission of light at specific wavelengths could be used to detect volatile organic compounds (VOCs). By integrating such a sensor into the fuel dispenser, real-time monitoring of fuel quality could take place. Installed in the car, the sensor could continuously monitor fuel quality. The development of such a chemical sensor requires interdisciplinary collaboration between fuel developers, additive manufacturers, the automotive industry and its suppliers, and gas station equipment manufacturers to create a robust, sensitive and selective device that meets the specific requirements of the application site.

System Layout

The Fuel marker (colour and chemical tag) in combination with digital fuel tracking system comprises the following tasks:

- Colouring for the clear identification of CO_2-reduced products
- Chemical marking for physical labelling of renewable fuels with CO_2-reduced effects
- Detection of fuel blends - intentional or unintentional (tamper resistance)

Responsible Stakeholders

All stakeholders associated with the fuel marker, from the tax warehouse (optional refinery) to the vehicle (end customer).

Option 3 – 100% Digital Tracking from Upstream to Downstream (DFTS w/ Digital Handshake)

Responsible Stakeholders

All stakeholders which are connected to DFTS, upstream from tank farm (optional refinery) to the vehicle (end customer).

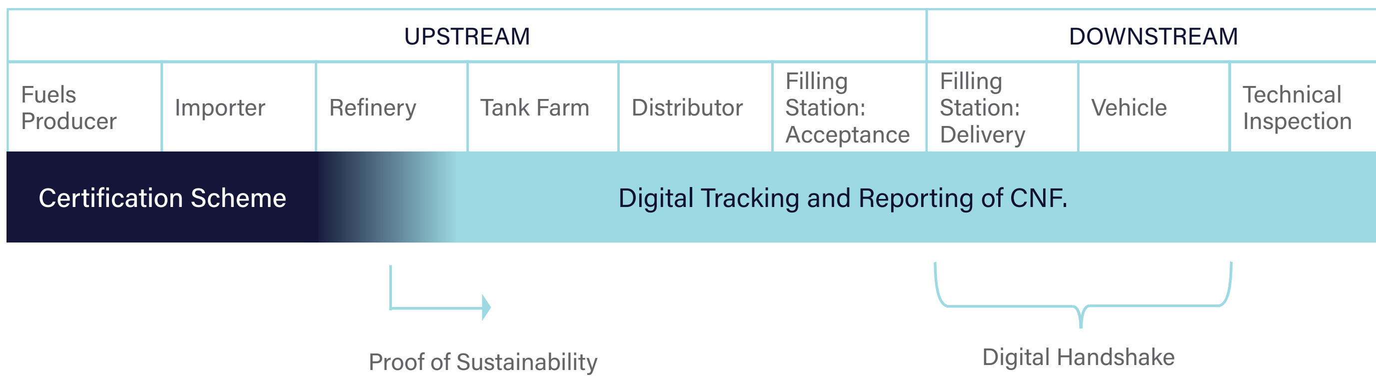
Description

DFTS enables all market stakeholders (from fuel production to consumption) to utilise CO_2 Neutral Fuel (CNF) as new fuel variant by digital certification.

It includes CO_2 tracking and certification of sustainability reports of CNF along the fuel supply chain from the refinery to the filling station (Upstream). And incorporates digital fuelling monitor as software variant in vehicle. The vehicle will perform a digital handshake with filling station to allocate refilling event with filling station (Downstream). Based on this filling event, the vehicle can check, whether filled fuel was CNF and accordingly can perform an inducement reaction, if the check result is negative.

Target

DFTS digitalizes the entire fuel supply chain from fuel production to end consumer (all relevant stakeholders). DFTS provides confirmation of CNF for CNF only vehicles, plausibility checks and tracking of fuel (incl. CO_2 footprint). DFTS performs digital pairing of vehicle and fuel supply chain.



Boundary Condition

Option utilizes data, which is already available in fuel supply system, assuring fast on-boarding. Willingness to share data at specific data points (see system layout). The option considers the supply chain from tank farm (optional refinery) to fuel consumption in every vehicle. DFTS can be used for all types of fuels (e.g. Diesel, Gasoline, Gaseous Fuels) and all types of vehicles (e.g. passenger cars, heavy-duty vehicles or non-road applications).

System Layout

DFTS digitally links the different stakeholders from fuel production to consumption.

The setup starts at the tank farm with the proof of sustainability (PoS) as the main entry information. The PoS is originated by an already established certification scheme (e.g. Nabisy, ISCC), and transferred to DFTS. DFTS will hand it through the fuel supply chain to the end customer. Optionally, DFTS could also on-board stakeholders further upstream of the tax warehouse, if necessary, depending on PoS availability.

DFTS provides an accurate, certified proof of the fuel quantities consumed in the systems. At the end of the chain, every CNF vehicle is provided with this certificate. The vehicle is able to decide for an inducement reaction.

DFTS includes the following tasks:

- Monitoring of CO_2 tracking
- Quantity balancing through each stakeholder along the supply chain
- Recognition of fuel mixing - intended or unintended (manipulation robustness) along the fuel supply chain up to the filling station, as well as in the vehicle's tank
- Takes care of time delays in the supply chain (delayed certification)
- Performs long-term plausibility check on system inconsistencies
- Takes care of regularly recertification if system requires adaptations (also legally initiated)

For each stakeholder specific DFTS data entry points are defined e.g., tank level sensor data, incoming/outgoing delivery bills, calibrated dispenser pump data. These data entry points need to be connected to the DFTS by one-time digital on-boarding via a standardized interface. Data will be hosted by the DFTS operator in a secure, encrypted, and private data space including dedicated data sharing agreement between DFTS provider and the individual market participants. The DFTS operator will also be certified.

DFTS also cares about vehicle and filling station connection – the digital handshake – which monitors the filling events of the vehicles. DFTS digital handshake should be as simple as possible, a software variant only (without additional hardware for OEM) and vehicle needs to be connected to the internet.

DFTS has the flexibility of gradual tracking of the CO_2 footprint and the potential blending ratio with fossil components. It can further support monitoring of CO_2 footprint during an introduction period of CNF (e.g. gradual increase of GHG reduction from 80% in 2030 to future 100%). Furthermore, DFTS can provide the end customer with a CO_2 footprint certificate, which can be utilized for sustainability reporting as proof of compliance with contractual CO_2 reductions or as a marketing and advertising instrument.

Option 4 – Hybrid Approach – Upstream: Fuel Marker & Sensor until EU Border – Downstream: DFTS w/ Digital Handshake

This "Triple Solution" enables all market participants (from the fuels industry to vehicle manufacturers) to introduce climate-neutral fuel as a new fuel variant by combining two safety features and a digital solution with very little effort, maximum speed and flexibility in the introduction by 2035. **The physical features are already active in field tests as part of the DeCarTrans project (funded by the Federal Ministry of Transport and Digital Infrastructure).**

The physical safety features are:
- Colour
- Chemical tag

Fuel marker products can be used for the marking and colouring of synthetic products such as 'methanol to gasoline', GTL, HVO, or petroleum products, mineral oils, aliphatic and aromatic hydrocarbon solvents and fuels. They usually are free-flowing liquids and may contain an additional labelling system. The product can be easily pumped, poured or dispensed directly from the container. As synthetic fuels are being developed as drop-in alternatives to conventional fossil fuels, they are very similar in their chemical composition. They are burnt under the same engine conditions.

The marking system includes CO_2 tracking and certification of sustainability reports for carbon-neutral fuel along the fuel supply chain from the fuel depot to the filling station (upstream), and includes a digital refuelling monitor as a software variant in the vehicle. The vehicle performs a digital handshake with the petrol station in order to assign the refuelling event to the petrol station (downstream). Based on this event, the vehicle checks whether the refuelled fuel is CNF and, if the test result is negative, reacts accordingly.

Boundary Condition

The option utilises data that is already available in the fuel supply system, which ensures rapid implementation.

Markers:
- The marking of fuels is already known and established in the market.
- Marking can be carried out in the tank farm
- Marking can be carried out in the tanker vehicle

DFTS:
- DFTS digitises the fuel supply chain and maps the transfer of the marker plausibility check, e.g. by a sensor. Readiness to share data at certain data points (see system structure). The option takes into account the supply chain from the control depot (optional refinery) to fuel consumption in each vehicle.

System Layout

Fuel Marker & DFTS connect the various stakeholders from fuel production to consumption physically and digitally in a secure data space. The current structure for the DFTS starts in the tax warehouse with the proof of sustainability (PoS) as the main input information from an already established certification system (e.g. Nabisy, ISCC). The marker concept can be applied both at the tax warehouse and at the supply stage by means of additivation in the truck. Optionally, DFTS could also integrate actors upstream of the tax warehouse if this is necessary from the PoS perspective.

The DFTS provides the exact certified fuel quantities at vehicle level. At the end of the chain, each CNF vehicle receives a certificate and can opt for an incentive response/mode.

The triple solution is certified and takes responsibility for data hosting and can be seen as a data container that carries the certificate through the system.

The Fuel marker (colour and chemical tag) in combination with DFTS includes the following tasks:
- Colouring for clear identification of CO_2-reduced products
- Chemical labelling for the physical identification of renewable fuels with CO_2-reduced effects
- Monitoring of the CO_2 tracking process
- Quantity balancing by each actor along the chain
- Detection of fuel blending - intentional or unintentional (tamper resistance)
  - Colour
  - Chemical
  - Digital
- Consideration of time delays (delayed certification)
- Carries out a long-term plausibility check of system inconsistencies both in the supply chain and in the vehicle's tank.
- Takes care of regular recertification if the system requires adjustments (also initiated by law)

Specific DFTS data input points (data is already available) are defined for each stakeholder, e.g. tank level sensor data, incoming/outgoing delivery notes, calibrated petrol pump data. The data points must be linked to the DFTS once via standard interfaces. The data is hosted by the DFTS in a secure, encrypted and private data room, including a special data sharing agreement with each partner. If desired, the data can be used for additional new services with third parties if the participant agrees. The DFTS operator is also certified.

Of course, DFTS also takes care of the connection between the vehicle and the petrol station - digital handshake, refuelling processes to be monitored. DFTS digital handshake should be as simple as possible, a pure software variant (without additional hardware for OEM), and the vehicle must be connected to the Internet.

DFTS offers the flexibility of tracking gradual changes in the CO_2 footprint and the possible blending rate with fossil fuel. In the transition phase from fossil fuels to CNF, DFTS will be able to monitor the gradual increase in GHG reduction (e.g. when introducing CNF, it could start with 80% GHG reduction and gradually increase to 100% in the future).

In addition, a certificate can be issued to the end customer using DFTS, which could be used for sustainability reporting (CSRD). This could provide certified proof of significant CO_2 reduction. The data from the DFTS can also be used as a marketing tool for sustainable products or services.

Responsible Stakeholders

All stakeholders involved in the triple play, from the tax warehouse (optional refinery) to the vehicle (end customer).

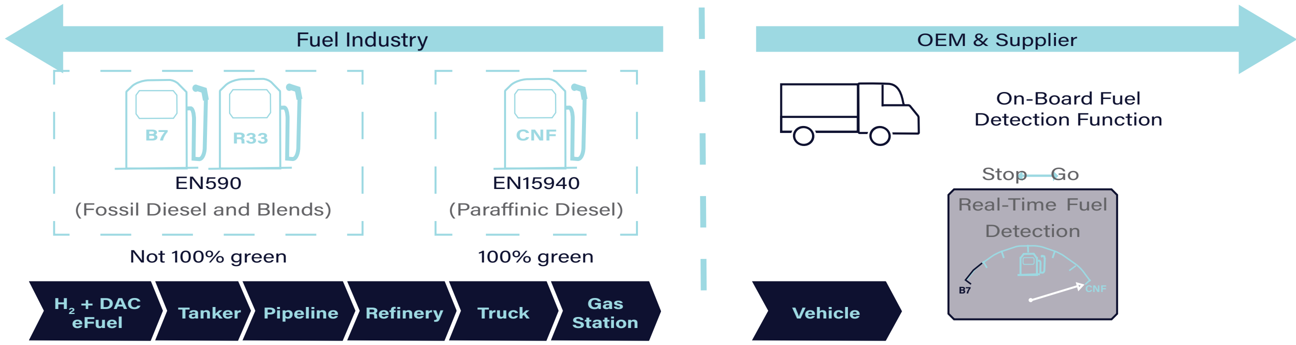
Option 5 – Vehicle On-Board Fuel Detection Function

Responsible Stakeholders

The Vehicle On Board Fuel Detection Function is a methodology that is related to vehicle and engine manufacturers (OEMs). The responsibility is with the OEM to homologate and certify a vehicle fulfilling the related regulations. Suppliers will be able to develop together with OEMs the required technology for this purpose. Upstream of the vehicle, the fuel producers, logistics and retailing industries to ensure and guarantee that the fuel released at the filling station under a certain label is according to the defined fuel standards and also to be guaranteed e.g. by an audit process that the retailed fuel is a CO2 Neutral Fuel.

Description

Today's existing vehicle and combustion engine technology has a high reliability and is affordable to enable individual mobili-



ty, transportation of goods and raw materials and many other purposes. Typical vehicles sold today have a lifetime >10 years and will operate beyond year 2040.

Already most of today's vehicles are suitable for the use of synthetic fuels such as paraffinic fuels (EN15940 labelled as "XTL") and synthetic gasoline fuel (from Methanol-to-Gasoline process denoted as "MTG"). Both are often denoted as "eFuels". Paraffinic fuels and MTG have a strong potential for emissions reduction due to the absence of aromatic hydro-carbon molecules and produce less soot emissions than fossil fuels. These fuels can be produced carbon-neutrally by using green hydrogen and capturing the CO_2 from renewable sources, air or by using biomass as input feed to the production process.

An audit process must be established to certify that the fuels are carbon-neutrally produced. Thanks to their differences in the chemical composition, the fuel properties differ from the fossil fuels and the usage of these new fuels could induce a different system response for CNFs. A fuel detection function could be based on the existing vehicle and engine system technology without new sensors or interfaces to implement.

While such functions could be realized in an engine management system, it is also likely to realize functions that alter the engine operation when a non-carbon-neutral fuel would be used, likely to reduce performance and/or operability. Several levels of alteration from initially warning the driver and then limiting or stopping the vehicle operation could be considered, like those applicable to the latest diesel cars/vans/trucks with SCR (Selective Catalytic Reduction).

The detection function possibly could also be implemented in vehicles that are already on the market. The fuel detection function could operate on a vehicle and engine management system level without any further data connection and services in the data cloud. Therefore, in such a configuration this methodology would protect the owner's data privacy and also should be resilient against cyber-attacks and IT fraud or tamper attempts. The comparatively low complexity of detection function and lower demands on additional infrastructure would allow also a fast realization and effective implementation on a vehicle.

Target

The On-board fuel detection targets the powertrain system to be capable to detect that the vehicle was fuelled with a defined fuel grade that has certain properties.

Boundary Condition

The fuel detection refers to CO_2 Neutral Fuels that are defined through an own fuel standard and differing from the fossil fuel standard with reference to its fuel properties. It also must be ensured that the fuel retail industry guarantees that the sold CO_2 Neutral Fuels are within the agreed and regulated CO_2 reduction (currently 100% proposed.)

System Layout

The system consists of a vehicle with a tank system and a powertrain drive which consists of an engine, a transmission gear and optionally of an electric motor (e.g. HEV P0, P1 or P2 topology). Both fuel tank and engine are connected and fuel is supplied from the tank to the engine and in particular to a fuel injection system. Also, the injection system has a return line to the tank for the leakage fuel from the high-pressure fuel pump, from the fuel injectors and from the fuel rail. Such a system is controlled by an Engine Control Unit. The Software consists of several layers among whereas the application layer is often denoted as Engine Management System (EMS). The EMS regulates the driver's pedal input on the engine response and controls the air path and fuel injection in an optimal way while respecting the emissions regulations Such systems are calibrated on certified fossil fuels. Using a CO_2 Neutral Fuel with different properties would lead to a different system response in various sub-systems and therefore sensed. Hence a Fuel Detection Function can measure the difference in system response and therefore recognize when a fossil fuel or a CO_2 Neutral Fuel is in use. While the detection function is embedded in an EMS, also the inducement method could be defined in the same layer. Certain actions could be implemented in case that a non-Carbon Neutral Fuel would be in use e.g. from MIL Lamp on, limp home mode, engine stop could be easily implemented like it is already available on SCR after treatment systems when aquas urea is not sufficiently available anymore.

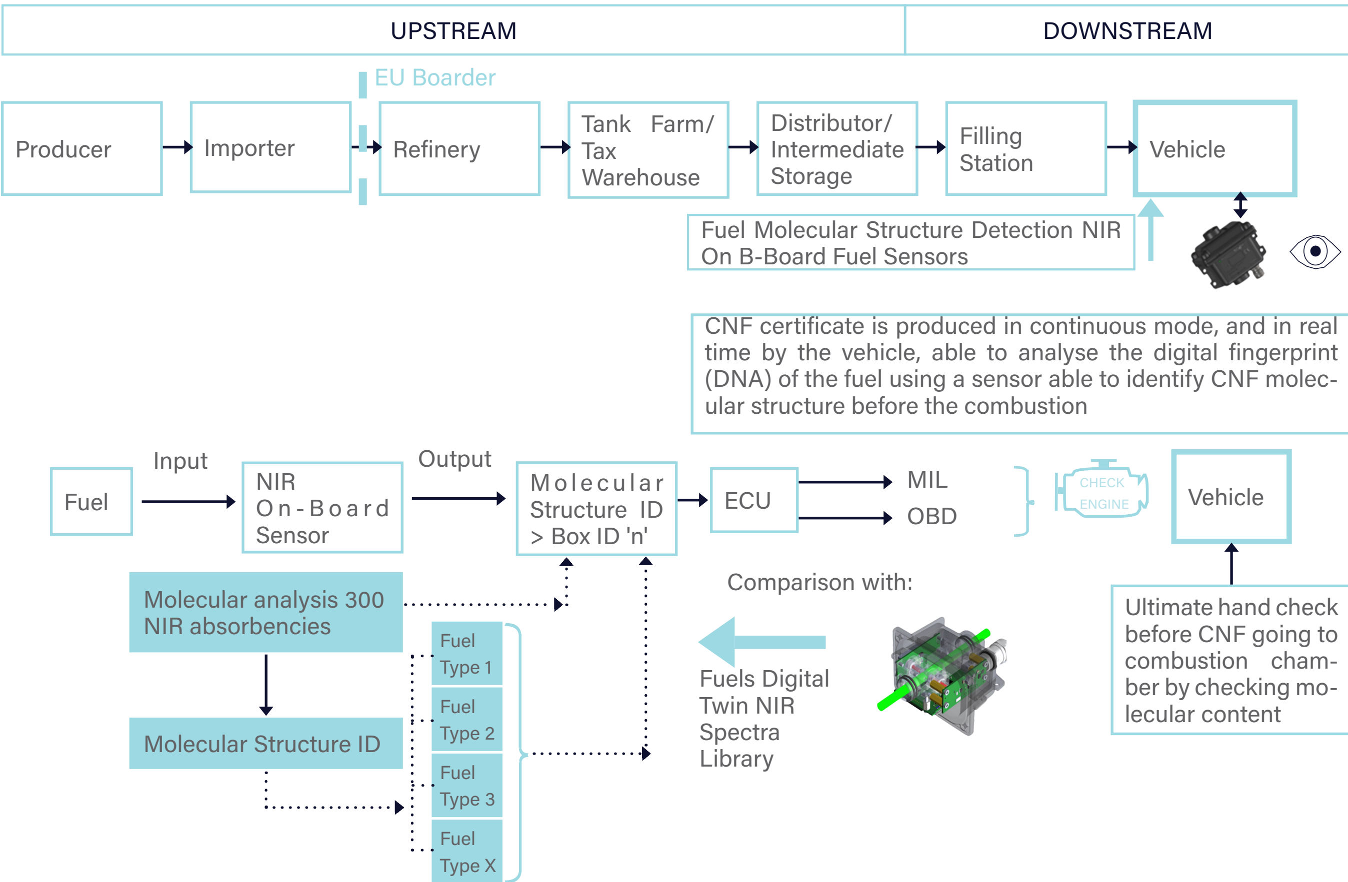
Summary of Vehicle On-Board Fuel Detection

- The Vehicle On-Board Fuel Detection could detect CO_2 Neutral Fuels which have different properties compared to the fossil fuels.
- Fuel producers, logistics and retail industry to audit that the sold fuels are Carbon Neutral by an audit process.
- The Vehicle On-Board Fuel Detection can be used on existing vehicle technology. It could be implemented on new vehicles as well as retrofit to existing vehicles. It would work on existing Engine Management Systems with existing sensors and actuators.
- The methodology would not rely on any vehicle connectivity technology and therefore would independently work. However, for monitoring purpose, a connection to a data cloud would be beneficial and could be combined with other services and functionalities.

Option 6 – Vehicle On-board Fuel Molecular Sensor

In the realm of fuel quality measurement, several sensor technologies are employed to assess the physical and chemical properties of fuels. However, these technologies are limited in their ability to distinguish between different fuel types within the defined European fuel standards (EN590, EN228, EN15940, EN14214, EN15293). This limitation arises because the physio-chemical properties of fossil fuels or CNF within these standards do not significantly differ to allow clear separation between fossil and 100% fossil-free fuels.

In contrast, NIR spectroscopy has been extensively used in various process industries (chemical, refining, pharma…) since the 1970s-80s for quality control of organic products (feedstocks; finished products), including fuels in refineries since the 1990s. This method is rapid, miniaturized, non-destructive, and can be conducted in situ, making it ideal for real-time applications to create intelligent vehicles. By directly analysing the molecular structure of fuels, NIR spectroscopy provides



detailed insights into the fuel's origin and composition (99.9% composed with Carbon, hydrogen and oxygen atoms), thus enabling the identification of CNFs fingerprint. This capability supports the accurate and reliable differentiation between fossil fuels and renewable, synthetic, or carbon-neutral fuel

Need for Trust and Confidence

The ability to guarantee that only CNFs are being burned in internal combustion engines (ICE) is crucial for gaining the trust and confidence of regulatory bodies in Europe. Ensuring the integrity of the fuel supply chain from production to combustion requires a robust and reliable detection system. The NIR spectroscopy technology provides this assurance by acting as the final verification step between the fuel tank and the engine. This system confirms the molecular content of the fuel, providing 100% confidence that the fuel being used meets CNF standards. This final check is key to securing regulatory approval and supporting the transition to sustainable fuel solutions.

Description

The On-board HW Fuel Molecular Structure Detection system utilizes Near-Infrared (NIR) spectroscopy technology to analyse and identify the molecular structure of fuels in real-time. This advanced method is capable of distinguishing between various types of fuels, including carbon-neutral fuels (CNF), based on their unique molecular fingerprints. This technology has been widely used in process industries since the 1970s and is recognized for its rapid, non-destructive, and in situ capabilities, making it ideal for real-time applications in vehicles.

Postulate 3 is linked to Near Infrared Spectroscopy Principle

3/ CNF propoerties are measured inside defined European fuel standards
- Diesel: EN590 (B7) / EN15940 (XtL)/ EN14214
- Gasoline: EN228 (E-5 / E-10) / EN 15293 (Super Ethanol E85)

→ Ideal target for CNF

- CNF molecular structure and chemistry is very different than standard fossil fuels molecular structure and chemistry

Then if difference in the molecular content is significant (in %v), it s feasible to identify any biofuel, renewable fuel, synthetic fuel, CNF from fossil fuel by optical sensors (NIR) and models ID predicting molecular structure

Postulate 3 is linked to Near Infrared Spectroscopy Principle

- Molecular Structure is function of
  - The process used for producing the finished product
  - The feedstock

Fuel Molecular Structure & Chemistry = $\mathscr{F}$(Process; Feedstock)

Fuel Molecular Structure & Chemistry = $\mathscr{N}$(NIR) - Absorbencies

→ Ideal target for CNF

Target

The primary target of this technology is to enable vehicles to autonomously identify the molecular content of the CNF being used in compliance with environmental regulations.

Boundary Condition "Fit for life approach"

The effectiveness of NIR spectroscopy in fuel molecular structure detection can be influenced by several factors, all of which have been resolved through extensive use and implementation of these sensors in current vehicle systems:

- Fuel Temperature: Accurate measurements require temperature compensation mechanisms to account for variations in molecular vibrations. Current sensors in use already include these compensation features, ensuring precise readings regardless of temperature fluctuations.
- Flow Conditions: Stable flow conditions are essential for precise readings, as turbulence can cause measurement inaccuracies. This has been addressed in existing sensors through design optimizations that ensure stable flow during fuel analysis.
- Fuel line Pressure: Sensors must be designed to operate under specific pressure conditions or include pressure compensation to ensure reliable data. Modern sensors already in service are designed to answer to these features, making them robust and reliable under varying fuel line pressure conditions.

System Layout

The system layout for the on-board fuel molecular structure detection sensor includes:

- NIR Sensor: Installed in the fuel line, it emits NIR light through the fuel, with downstream detectors measuring the absorption spectrum to determine the molecular structure of the fuel, leveraging extensive calibration models and databases.

- ECU Integration: The processed data is transmitted to the Engine Control Unit (ECU) to put the engine in degraded mode if the fuel measured in not a CNF at 100%.
- Communication Module: Interfaces with on-board diagnostic systems (OBD) and external monitoring platforms for continuous data transmission and regulatory compliance.

Responsible Stakeholders

The successful implementation and operation of this technology involve various stakeholders:

- Technology Providers: A wide range of companies worldwide specialize in providing NIR spectrometers and analysers.
- Vehicle Manufacturers: Integrate the NIR sensor and data processing units into new and existing vehicle models.
- Regulatory Bodies: Establish standards and guidelines for the use of molecular structure detection technologies in automotive applications.

This technology can also be combined with other advanced options such as the Digital Handshake, which involves mass balancing and digital tracking of fuel origin to ensure the authenticity and compliance of CNFs throughout the supply chain.

Summary of key Advantages of On-board Fuel Molecular Structure Detection by NIR Spectroscopy

- Direct Molecular Structure Analysis: Allows for precise identification of any CNF types based on their molecular fingerprints.
- In Situ Measurements: Enables real-time analysis and decision-making, enhancing vehicle 100% autonomy (smart cars) to decide if the fuel is fossil or non-fossil in compliance with CNF Regulations
- Established Technology: Widely used in various industries for decades, providing a proven, reliable method for fuel quality control.
- Available in mass volume (opto-electronics / semicon market)
- Non-Destructive Testing: Maintains the integrity of the fuel sample while providing comprehensive analysis.
- Fit for Life: Monolithic system with automotive components with lifespans compatible with the vehicle's lifespan, eliminating the need for recalibration.

Option 7 – Bidirectional Communication between Vehicle and Filling Station

Basic Principle

The basic principle targets two main aspects:

- How to generate trust in the CNF delivering partner?
- How to ensure, that no manipulation takes place during the whole fuel transfer duration (anti-tampering)?

Therefore, this solution contains an authentication method of the CNF delivering partner before the start of fuel transfer and a tampering protection during the fuel transfer.

The method was developed for the refilling at a filling station, but it could be used wherever CNF is transferred from one area of responsibility to another (e.g.: tank farm à tanker truck). In the following description the example of a refilling of a vehicle at a filling station is described:

- Delivering partner = filling station
- Receiving partner = vehicle

Description

Authentication of the delivering partner

For the authentication of the delivering partner (filling station) at least one partner

needs an internet connection to an authentication authority. The authentication authority can be any trustworthy organization or association which provides a digital authentication service accessible via internet. Additionally, digital communication between the two partners is necessary. The communication method is not important as long as it is bidirectional. An NFC communication between the filling nozzle and the filler neck in the vehicle is used to initiate the authentication process and to be robust against tampering during the whole refilling process. Depending on the gas station's communication infrastructure, a bi-directional NFC communication could be used. Alternatively, unidirectional NFC communication with a passive sender in the nozzle and an active receiver in the filling neck plus an over-the-air (OTA) communication using BLE or Wi-Fi is possible.

The NFC antenna must be designed in a way that NFC communication starts earliest when the filling nozzle is completely plugged into the filler neck and is immediately interrupted when the nozzle starts to be removed.

One advantage of the suggested solution is that the vehicle does not need to be connected to the internet/cloud during the refilling process. The authentication process of the filling station works in the following way:

1. Start of communication triggered by NFC (nozzle entered filler neck).

2. The vehicle sends a random challenge to the filling station. The random challenge can be any kind of digital security methods (PIN-TAN, Challenge-Response-Method, encrypted message,...). Important: the filling station cannot solve it, only authentication authority can

3. The filling station contacts the authentication authority. Therefore, it must identify itself using a digital certificate of a certified CNF filling station.

4. If the filling station is registered as certified CNF filling station the authentication authority will trust the filling station, solve the challenge and hand back the solution.

5. Filling station will hand over solution to vehicle and the vehicle can check the solution: If the solution is correct the vehicle trusts the filling station.

If the vehicle has an internet connection the authentication process works in a similar way. The difference is that the vehicle gets the challenge from the authentication authority, which can only be solved by the certified filling station.

Anti-Tampering during fuel transfer

To avoid cheating during the refilling process, the NFC communication may not be interrupted during the whole refilling process. For example, after successful authentication the CNF nozzle shall not be replaced by a fossil fuel nozzle. An interrupted NFC communication indicates that the CNF nozzle has been removed. Furthermore, the fuel tank level is continuously monitored. If the fuel tank level increases in the absence of an active NFC communication, then the refilling process is considered to be tampering and appropriate inducement measures can be started.

Prevention of wrong refuelling

In most solutions the detection of the wrong fuel takes place after the refilling. With this proposal the vehicle can prevent the refilling with incorrect fuel when equipped with a device that blocks the fuel flow into the tank (e.g.: valve after filling neck). This is possible because the check for CNF takes place prior to the refilling process.

This solution guarantees an exclusive refilling with CNF as required by EU regulation proposal.

Interactions with other solutions

The solution can be used whenever CNF is transferred, so that further use cases can be taken into consideration. This is helpful each time the partners do not know each other, and trust must be generated (like in the example of refilling at a filling station). In most other cases (upstream) the partners know each other because the fuel was for example ordered at the distributor by the filling station. In that case the advantage of a communication is, that additional information can be exchange between the delivering partner and the receiving partner (e.g.: a digital delivery note). NFC communication and additional information can help to avoid unintended errors and it can improve the accuracy of other solutions.

Example of avoiding unintended errors:
If there is NFC at the filling nozzle of the tanker truck which delivers the CNF to the filling stations and there is an NFC counterpart at the connection of the filling station, an unintended filling up of the wrong fuel tanks could be avoided: The tanker truck rejects the fill-up if it is not connected to the correct CNF tank.

Example of improving the robustness of other solutions:
The fuel tank level sensor is not a reliable and accurate solution to determine the transferred fuel amount. Using a time-stamp could also be critical to ensure synchronicity and uniqueness of refuelling transactions for example if many vehicles are refilling at the same time.

But if there is a communication between vehicle and filling station, the flowing information can be exchanged (electronic receipt):

- VIN (Vehicle Identification Number)
- Information about filling station and used nozzle
- Amount of refilled CNF
- Date, Time

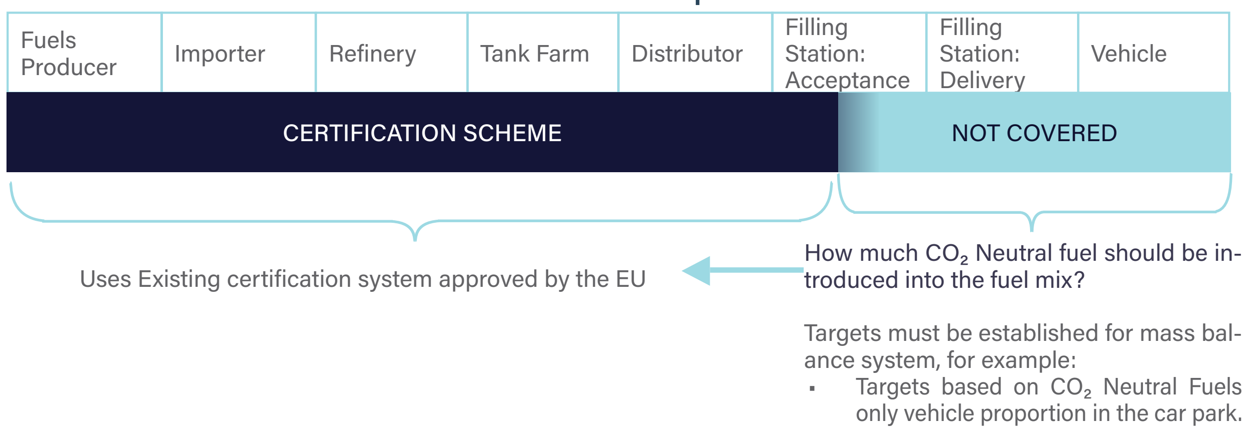
With this information, it's easy to assign the CNF refiling to the right vehicle.

Option 8 – CNF exclusively available in EU market

Classic/fossil fuels will be banned in the EU (or in certain member states) after 2035 for some or all vehicle categories (e.g. diesel or gasoline or methane). All affected vehicles will have to use CNF. When crossing the borders (entry) into the EU (or into affected member states), suitable measures may still have to be defined. The responsible stakeholder is the legislator.

Option 9 – Mass-Balanced CNF supply to each CNF vehicle

Responsible Stakeholders



Target

1. To supply CO_2 neutral fuels into the market-based on the established target.

2. Increasing availability in markets/areas where renewable fuels are not currently available

3. Opportunity for renewable fuels when production or distribution processes do not allow for differentiation between fossil and renewable components

4. A mechanism to track CO_2 neutral fuels can also include sustainability data for easier reporting.

Description

Mass Balancing is already used in several sectors today such as:

- Electricity
- Aviation fuel
- Chemical industry
- Biomethane and biofuels

Mass Balancing is often used when production or distribution processes do not allow for differentiation between fossil and renewable components or when the physical product is not available.

Another approach is the "Book and Claim" system. Where the customer claiming CO_2 neutral fuels does not necessarily use the physical renewable product, but this mechanism ensures that the same quantity is put on the market on a global basis, and therefore consumed elsewhere. A certification mechanism will keep track of all CO_2 neutral fuels produced and then claimed.

For instance, if a certain percentage of vehicles registered in a market (such as Germany) are exclusively powered by CNF (% unit), fuel suppliers are obligated to ensure that an equivalent percentage of CO_2 neutral fuel (%vol) is available within the fuel network.

However, this method does not provide a mechanism for vehicles to identify whether they are running on CO_2 neutral fuel. Additionally, since there is no distinction between fuels at the point of sale, the inclusion of CO_2 neutral fuels is likely to result in an increase in the overall fuel prices in the market.

To ensure compliance and transparency, the proportion of CO_2 neutral fuel introduced must be verified through existing certification processes recognized by the European Union.

System Layout and Boundary Conditions

This mechanism consists of 3 aspects:

1. Existing certification schemes in compliance with RED II to certify the supply from the point of origin to the trader with or without Storage (Distributor).

2. A set of targets established by EU/National Regulation that determine the amount of fuel to be introduced into the fuel mix.

3. There is no distinction between fossil and CO_2 fuels at the retail stations

Option 10 – Fuel Usage Balancing

The Fuel usage Balancing is a software solution that tracks each vehicle's fuel usage. A device in the vehicle measures fuel consumption, transmits this data wirelessly to the software, and stores it in the vehicle's account. The vehicle operator must purchase CNF certificates matching the fuel used. The software platform facilitates acquiring these certificates and directly communicates with the CNF registry to void used certificates. Based on certificate compliance, the system signals the vehicle to activate or not activate inducement actions.

Description

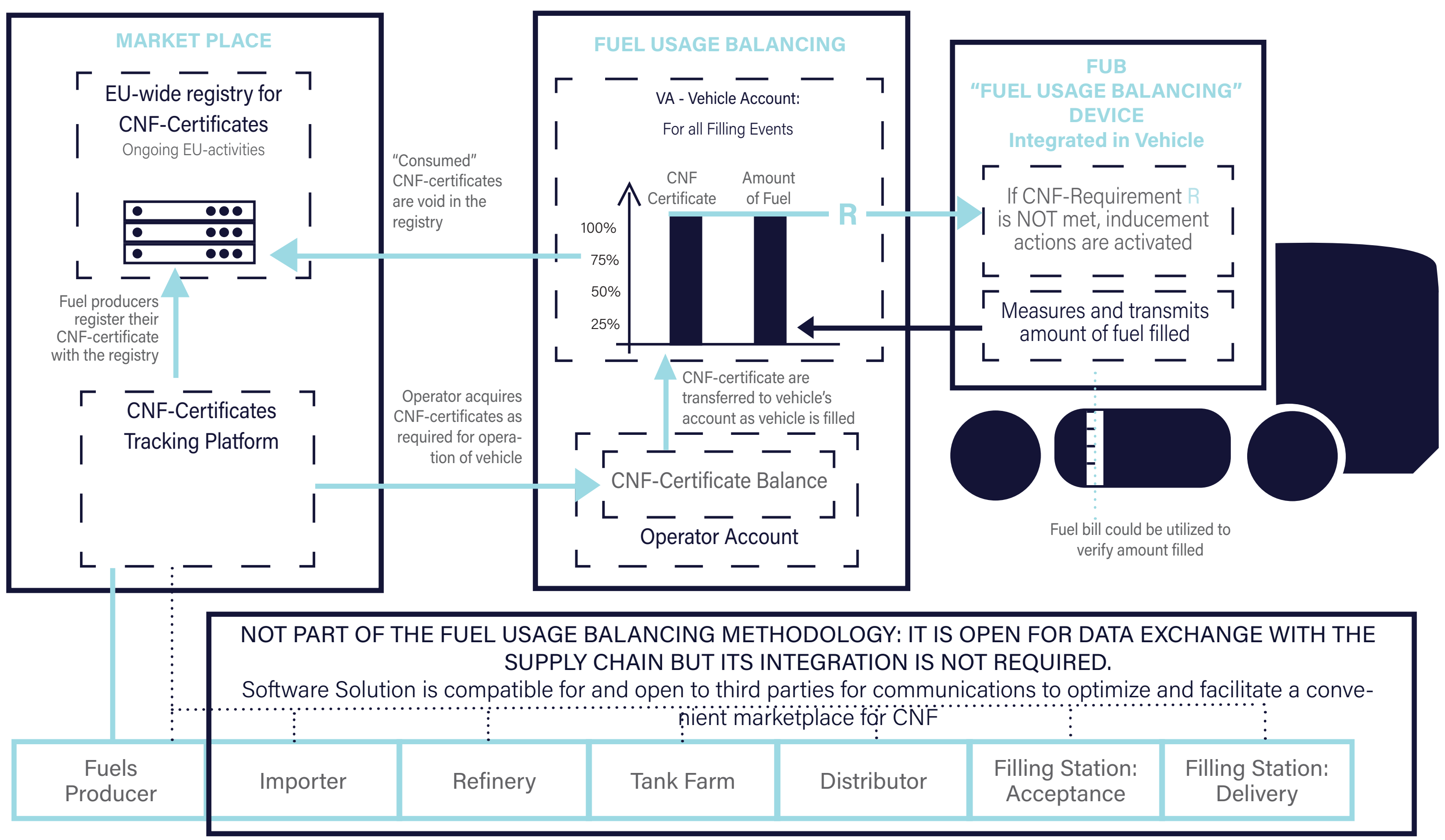
The Fuel Usage Balancing device measures the amount of fuel, e.g. 250kg of biomethane, that is filled into the vehicle's tank system. The Fuel Usage Balancing device can be adapted to all types of fuels, i.e. gaseous, liquid or electricity. It does not detect the origin of the fuel, i.e. whether it is fossil or renewable methane (=biomethane or synthetic methane).

The Fuel Usage Balancing communicates over the air with the Fuel Usage Balancing software solution. The software provides an account for each individual vehicle, receives the amount of fuel-filled information over the air and attributes a corresponding number of CNF-certificates to this vehicle's account transferring them from the operator's account also provided by the software. The Fuel Usage Balancing software is in direct communication with the CNF-certificates trading platform / registry. CNF-certificates IDs that have been attributed to a vehicle's account are transmitted to the trading platform/ registry and hence voided as having been used.

The operator of the vehicle is responsible for acquiring a sufficient number of CNF-certificates in time for each filling process of the vehicle. The Software is open for connecting the operator of the vehicle with other market players involved in providing and distributing CNF creating a digital marketplace for CNF and CNF certificates. Thus, operators have easy and convenient access to acquire CNF-certificates for their vehicles.

If the amount of fuel filled is covered by CNF-certificates as required, the software sends a signal back to the vehicle and the Fuel Usage Balancing Device enables unrestricted operation of the vehicle. In case of insufficient CNF-certificates, the fuel usage balancing can implement a wide range of inducement actions up to denial of operation.

Graph 5.4



Hence, the Fuel Usage Balancing is capable of controlling the operation of individual vehicles depending on complying with required CNF-share in operation and it is capable of activating a broad range of inducement actions. The device can either (a) directly activate/deactivate/limit the filling of or (b) deactivate or limit the consumption (rate) out of the tank system itself, or (c) the device can provide an electronic signal to the vehicle's on-board control system for implementation of inducement actions, or (d) provide data e.g. the actual CNF-coverage for purposes of monetary consequences (incentives to exceed and/or penalties for missing CNF-certificate coverage).

Each vehicle is equipped with a FUB-Device (functionality). The rest of the implementation is software-based. This software connects CNF-certificates directly with individual vehicles. Thus, the Fuel Usage Balancing Methodology eliminates a major barrier to alternative fuels — limited filling infrastructure availability — by enabling the complete supply chain to operate without any changes.

The Fuel Usage Balancing software solution is certified, its communication is encrypted, its data storage and verification methods ensure a reliable proof for each vehicle's CNF compliance. The software solution provides interfaces to all other stakeholders along the supply chain for their documentation requirements if needed. No direct communication between a specific filling station and a specific vehicle is required.

Technically, this method tracks the share of CNF-fuel used by each vehicle, which is analogue to other methodologies previously debated in various drafts of emissions regulations. The vehicle class "running exclusively on CNF" equals the requirement of a 100% actual CNF share. However, during a transitional period, the continuous tracking of the CNF share and the possibility to "program" a minimum required CNF share for each individual vehicle opens up a wide range of incentives and transitional definitions to facilitate a market-driven transition to CNF.

This Method works for all types of energy-carriers, it is applicable to gaseous fuels as well as liquid or electricity. It enables politics to implement a wide range of policies and regulations specifically tailored to the challenges of each type of fuel.

Some more aspects about the Fuel Usage Balancing:

1. It provides extensive flexibility during the transitional phase from its introduction until 2035. This flexibility can be decisive for balancing demand with CNF-production capacities over time and can help assure continued commercial viability from early on throughout the transition period.

2. The CNF-requirements or inducement actions can be activated depending on the geographic position of the vehicle i.e. inducement actions are only activated within the EU, selected states of the EU, country-specific (i.e. road toll), new Member States of the EU.

3. Fuel Usage Balancing can be deactivated completely if sold outside of the EU.

4. The method provides certainty for impact of CNF vehicles to vehicle manufacturers and their CO_2-fleet-emissions planning and reporting purposes as the software provides credible tamper-proof verification of CNF-vehicle numbers and CNF-shares in use for each manufacturer.

5. The Fuel Usage Balancing has an interface for vehicle manufacturers for service and repair purposes e.g. if a FUB relevant part needs to be replaced due to damage or defect.
6. If fully integrated into the tank system, the device can also be retrofitted to existing vehicles if so desired.

7. Implementation and flexible adaptations to market developments of the future are possible, e.g. allow a balancing period, i.e. CNF certificates coverage needs to reach the required CNF-share level (a) ahead of the filling process or (b) within a certain period after the filling process, e.g. a day, week or calendar year.

8. Certificates are as reliable as the certificate scheme itself. As an EU-specific audit is foreseen for fuel producers that enables them to issue CNF certificates and as all CNF-certificates are registered within an EU-wide registry, only the available amount will be sold, i.e. double counting is prevented.

Difference to Option 11:

#11: "Combined Mass Balancing – DFTS w/ Digital Handshake"

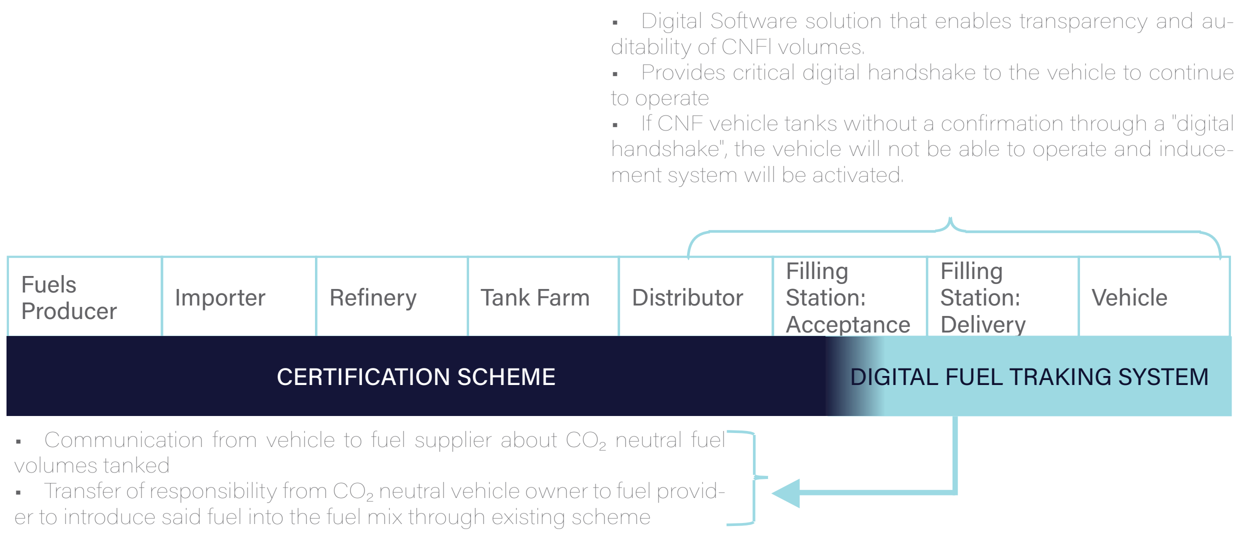
1. The Fuel Usage Balancing follows the fundamentally different approach of directly linking the vehicle with the CNF-certificates without the need of involvement of any party in between. This is a key element for a swift and convenient transition to CNF as the complete supply chain can operate without any changes.
2. It shifts the responsibility of acquiring CNF-certificates to the operator of the vehicle, the same entity that is responsible for acquiring the fuel.
3. The FUB does not require the key element of method #11 – a digital handshake with the filling station, but rather a handshake with the FUB software on the vehicle's operator side.
4. A Fuel Usage Balancing is not intended to physically track CNF, i.e. whether the actual molecules are of Carbon-neutral origin or not. It is based on the mass-balancing principle applied and controlled on an individual vehicle level.

Option 11 – Combined – Upstream: Mass Balancing – Downstream: DFTS w/ Digital Handshake)

Responsible Stakeholders Target

To enforce and monitor the amount of CO_2 neutral fuels that are used by CO_2 neutral fuel-only vehicles introduced into the market.

To enable a transition toward CO_2 neutral fuels while ensuring market viability.



Description

This strategy is founded on two core principles: Mass Balancing and DFTS

Mass Balancing

See option 9.

Digital Fuel Tracking System (Software solution)

In this case, DFTS digitally connects the data provided by the existing certification scheme with the CO_2 Neutral only vehicle at the retail station. All data should be stored and secured in a data-space. The current setup could start at the tax warehouse with the proof of sustainability (PoS) as the main entry information. DFTS solution will be certified and takes the responsibility for data hosting and can be considered as a data container to take the certificate through the system. The data provided by the DFTS will ensure that the vehicle only operates with retail stations that ensure that their absolute value of CO_2 neutral fuel is introduced in their fuel mix.

The combination of these two principles allows to operate on a market-driven basis, mandating that owners of CO_2 neutral vehicles exclusively purchase CO_2 neutral fuels. These consumers will select their preferred fuel service provider, which must offer a digital software solution to facilitate the accurate allocation of CO_2 neutral fuel from the vehicle owner to the fuel provider, thereby supplying the resulting CO_2 neutral fuel into the overall mix.

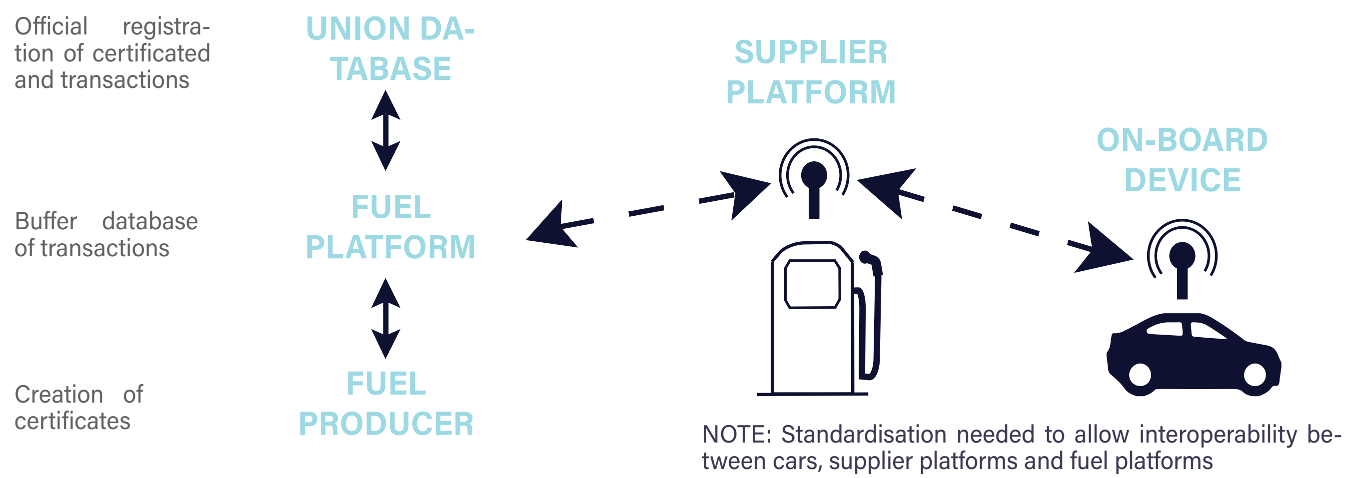
Under this system, customers who opt for CO_2 neutral fuels are not guaranteed to receive the physical renewable product, Instead, the approach ensures that an equivalent amount of CO_2 neutral fuel is supplied to the market and consumed elsewhere, aligning with the principles of sustainability and environmental responsibility based on the renewable energy directive approved certification schemes. This method emphasizes the importance of digital tracking to maintain the integrity of the CO_2 neutral fuel claims.

This monitoring solution leverages both principles to ensure that the vehicle has an inducement system mechanism to monitor the usage of CO_2 neutral fuels.

System Layout and boundary conditions

This mechanism consists of 2 aspects:

1. Existing certification schemes in compliance with RED II to certify the supply from the point of origin to the trader with or without Storage



(Distributor).

2. A Software solution that leverages different devices that are installed in the filling station and on the vehicle, which can communicate with each other over the air (OTA). The device in the filling station is in turn connected to the digital fuel platform mentioned before. The device on the vehicle is connected to the engine control unit of the vehicle. Each time that the CNF vehicles require a filling operation, a new digital handshake between the vehicle and the filling station takes place. CNF vehicles transmit to the Fuel supplier the mandate of bringing CNF to the pool through the fuel digital platform. Only if the certificates are available (or can be booked), the digital handshake will be completed successfully, and the vehicle will continue to operate normally. If CNF is not available or if the handshake doesn't take place, the vehicle activates the inducement system (to be defined).

This software solution will have to be transparent and auditable (similar to existing European certification scheme) to enable a correct and clear accounting of the CO_2 neutral fuel volumes that the fuel supplier has sold to CNF vehicles. The resulting volume would have to be introduced to the fuel mix accompanied with the respective European certificate applicable for the CO_2 neutral fuel.

The filling station (publicly available or for captive fleets) is connected to this digital platform and 'consumes' the certificates according to the amount of delivered fuel. The platform will offer the possibility of defining different compensation criteria, such as the full compensation between fuel delivered and acquired certificates at the end of a predefined period (for example once a month).

This solution leverages the existing fuel supply infrastructure and certification scheme for RFNBOs and biofuels of the European Union (REDII/III) to provide a robust solution that enforces the use of CO_2 neutral fuel vehicles in the market, as long as they tank CO_2 neutral fuel.

This solution has a market-driven approach as the CO_2 neutral vehicle owners will have the mandate to only buy CO_2 neutral fuels. They will choose their fuel service provider which will need to have a software solution available that allows for the correct transfer from the vehicle owner to the fuel provider to introduce the CO_2 neutral fuel into the fuel mix.

Similar to solution 5 (DFTS 100%), this approach enables for an efficient deployment of CO_2 neutral fuels into the market which leverages the existing infrastructure and minimizes unnecessary costs in order to successfully decarbonise this new type of vehicle class. Furthermore, by leveraging existing certification schemes, certification of sustainable fuels will be kept harmonized based on the Renewable Energy Directive.

9.2. Description of Relevant Regulations

Category A: Other regulations that suggests requirements towards CNF Definition, Fuelling Monitor or Fuelling Inducement System
Category B: Other regulation that might adopt its scope with introduction of new vehicle category running exclusively on CNF

Abbreviated Regulation	Category	Context
RED	A	The European Renewable Energy Directive (RED III) is part of the "Fit for 55" package, increases the ambition of the 2030 renewable energy target and sets concrete targets for Member States to meet in sectors such as industry, transport and buildings (district heating and cooling). 1. Overall objective: RED III aims to increase the share of renewable energy in the EU's overall energy consumption to 42.5% by 2030, with an additional indicative target of 2.5%. 2. Definitions: 'Renewable fuels' means biofuels, bioliquids, biomass fuels and renewable fuels of non-biological origin; 'Biofuels' means liquid fuel for transport produced from biomass; 'Biomass' means the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetable and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin; 'Renewable fuels of non-biological origin' means liquid and gaseous fuels the energy content of which is derived from renewable sources other than biomass 3. Transport Sector Member States must choose between two compliance options: A binding share of at least 29% renewables in the final energy consumption in the transport sector by 2030. A binding target to reduce greenhouse gas intensity in transport by 14.5% within the same time-frame. The new rules also set a combined binding secondary target of 5.5% for advanced biofuels (feedstocks set in Annex IX part A) with at least 1% of RFNBO in the share of renewable energy supplied to the transport sector by 2030. The energetic quotas include several multipliers e.g. a double counting for advanced biofuels and RFNBOs Sustainability and greenhouse gas criteria: Renewable fuels must meet the sustainability criteria set in the Directive to ensure that there is no adverse impact on biodiversity and the food and feed chain. In addition, all renewable fuels must meet emission reductions (50-65% biofuels, 70% RFNBOs).
Eurovignette	B	Regulation for truck toll system within the EU. Different CO_2 classes exist based on tailpipe CO_2 value. CNF trucks may have a huge economic benefit if they are considered as zero-emission vehicles in this regulation. CO_2 emission class 5 – zero-emission vehicles explicitly including vCNF. See Recital (26) In order to reward the best performing heavy-duty vehicles, Member States should be allowed to apply the highest level of reductions in charges to vehicles operated without tailpipe emissions.
GHG Accounting Transport Services	B	"Input data and sources – providing a harmonised approach to input data, by creating incentives to use primary data, permitting modelled data, increasing the reliability, accessibility and appropriateness of default values, and mitigating discrepancies between national, regional and sectoral datasets." vCNF should take default data "0" but receive full incentive as primary data.
CVD	B	Clean heavy-duty vehicles should be defined through the use of alternative fuels in line with Directive 2014/94/EU. Where liquid biofuels, synthetic or paraffinic fuels are to be used by procured vehicles, contracting authorities and contracting entities have to ensure, through mandatory contract clauses or through similarly effective means within the public procurement procedure, that only such fuels are to be used in those vehicles. vCNF need to be recognised without further public fuel procurement procedures.
DE-EstG	B	CNF income tax reduction.

Cyber Resilience Act	A	Requirements on cyber security for digital solutions shall comply with this Expert Regulation, + UN155.
EU7	A	CO_2 targets Regulation (EU) 2019/631 mentions in Article 1.2 "... measured in accordance with Regulation (EU) 2017/1151". This means the emissions type-approval legislation contains the CO_2 measurement procedure (in Annex XXI). CO_2 measured at tailpipe is used, there is no recognition of CNF. Euro 7 is published as Regulation (EU) 2024/1257, defining general obligations for manufacturers requesting an emissions type approval of an LDV or HDV vehicle. The implementing legislation with details of the measurement procedures is still under development. Only remaining reference to special vehicle category for CO_2-neutral fuels is in Recital 30: "Where the Commission makes a proposal for the registration after 2035 of new light-duty vehicles that run exclusively on CO_2 neutral fuels outside the scope of the CO_2 fleet standards, and in conformity with Union law and the Union's climate-neutrality objective, this Regulation will need to be amended to include the possibility to type-approve such vehicles."
Implementing Act under ETS	A	Under ETS (art.14.1), a zero-emission factor is attributed to the biomass in all sectors under this Directive, including aviation, maritime and transport. However, RFNBOs and RCFs are also considered as zero, raccording to a new Implementation Act in summer 2024.
IPCC Guidelines	B	Defines accounting rules for national CO_2 inventories, all sectors incl road transport. Biofuels defined as carbon neutral, eFuels not defined and hence might be treated with TTW logic like fossil.
ADR	B	European Agreement concerning the International Carriage of Dangerous Goods by Road". The ADR comprises regulations for road transport with regard to packaging, load securing, classification and labelling of dangerous goods. Today, all EU members are also signatories to the ADR. The ADR becomes effective through implementation in the respective national law. The provisions of the ADR are thus legally anchored and thus mandatory for the transport of dangerous goods. Furthermore, the ADR regulates how infringements or complete disregard of the regulations are handled and sanctioned.
RID	B	The Regulation concerning the International Carriage of Dangerous Goods by Rail (RID). This Regulation applies to international traffic. Directive 2008/68/EC transposes RID into the EU's internal law, including for national transport. The provisions on the carriage of dangerous goods by rail are also harmonised with the provisions for road transport (ADR) and inland waterways transport (ADN).
ADN	B	The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) aims at ensuring a high level of safety of international carriage of dangerous goods by inland waterways; contributing effectively to the protection of the environment by preventing any pollution resulting from accidents or incidents during such carriage; and facilitating transport operations and promoting international trade in dangerous goods.
EN228	B	Automotive fuels - Unleaded petrol - Requirements and test methods. This European Standard specifies requirements and test methods for marketed and delivered unleaded petrol. It is applicable to unleaded petrol for use in petrol engine vehicles designed to run on unleaded petrol.
EN590	B	Automotive fuels - Diesel - Requirements and test methods. This European Standard specifies requirements and test methods for marketed and delivered automotive diesel fuel. It is applicable to automotive diesel fuel for use in diesel engine vehicles designed to run on automotive diesel fuel.
EN589	A	Specifies requirements and test methods for marketed and delivered automotive liquefied petroleum gas (LPG), with LPG defined as low pressure liquefied gas composed of one or more light hydrocarbons which are assigned to UN 1011, 1075, 1965, 1969 or 1978 only and which consists mainly of propane, propene, butane, butane isomers, butenes with traces of other hydrocarbon gases. This standard is applicable to automotive LPG for use in LPG engine vehicles designed to run on automotive LPG. It could accommodate BioLPG.
EN15940	B	Automotive fuels - Paraffinic diesel fuel from synthesis or hydro-treatment - Requirements and test methods. This European Standard describes requirements and test methods for marketed and delivered paraffinic diesel fuel containing a level of up to 7,0 % (V/V) fatty acid methyl ester (FAME). It is applicable to fuel for use in diesel engines and vehicles compatible with paraffinic diesel fuel. It defines two classes of paraffinic diesel fuel: high cetane and normal cetane.
EN858-1	B	Separator systems for light liquids (e.g. oil and petrol). Principles of product design, performance and testing, marking and quality control. This standard specifies definitions, nominal sizes, principles of design, performance requirements, marking, testing and quality control for separator systems for light liquids. This standard applies to separator systems for light liquids, where light liquids are separated from wastewater by means of gravity and/or coalescence.
EN858-2	B	Separator systems for light liquids (e.g. oil and petrol). Selection of nominal size, installation, operation and maintenance. This European Standard applies to separator systems used to separate hydrocarbons of mineral origin from wastewater. It does not apply to grease and oils of vegetable or animal origin nor to separation of emulsions or solutions. This European Standard provides guidance on the selection of nominal sizes, as well as the installation operation and maintenance of light liquid separators manufactured in accordance with EN 858-1. It also gives advice on the suitability of cleansing agents if they are discharged to a separator.
TRBS-3151	B	Machinery and System Safety: Vermeidung von Brand-, Explosions- und Druckgefährdungen an Tankstellen und Gasfüllanlagen zur Befüllung von Landfahrzeugen", or respective EU/national regulations.
10th BImSchV	B	Tenth Ordinance on the Implementation of the Federal Emission Control Act (Ordinance on the Properties and the Labelling of the Qualities of Fuels - 10th BImSchV.
DWA TrWS 781	B	Technical guideline for water-hazardous substances - Filling stations for motor vehicles. The TrWS is a generally accepted rule for the technical and operational requirements for filling stations for motor vehicles.
EN15293	B	Automotive fuels - Automotive ethanol (E85) fuel - Requirements and test methods. This document specifies requirements and test methods for marketed and delivered automotive ethanol (E85) fuel. It is applicable to automotive ethanol (E85) fuel for use in spark ignition engine vehicles designed to run on automotive ethanol (E85) fuel.
EU Taxonomy	B	Annex 6.5.: "Acquisition, financing, hiring, leasing and operation of vehicles of categories M1 (232), N1 (233), both of which are covered by Regulation (EC) No 715/2007 of the European Parliament and of the Council (234), or L (two- and three-wheeled vehicles and quadricycles) (235)." Annex 6.6.: ""Acquisition, financing, leasing, rental and operation of vehicles of classes N1, N2 (240) or N3 (241) for the carriage of goods by road that fall under the EURO VI standard (242) stage E or its successor."

CO_2 Emissions Performance Standards for new passenger cars and for new light commercial vehicles	B	In 2019, the EU published the CO_2 emissions performance standards for new passenger cars and for new light commercial vehicles (2019/631), replacing the regulations 443/2009 and 510/2011 with stricter targets for 2025 and 2030. These standards apply to light-duty vehicles, including both passenger cars (M1) and light commercial vehicles (N1). As part of the Fit-for-55 package, the regulation was revised in 2023 to align with the EU's greenhouse gas emissions targets, aiming for a reduction of 55% by 2030 and to achieve climate neutrality by 2050. Since 2021, the average emissions target has been set at 95 gCO_2/km for passenger cars and 147 g CO_2/km for light commercial vehicles, based on the NEDC (New European Driving Cycle) emission test procedure. For targets applicable from 2025 onwards, emissions will be measured using the WLTP (Worldwide Harmonised Light Vehicles Test Procedure), with the 2021 average emissions as a baseline. These baseline values have been adjusted using the ratio of measured WLTP to the declared NEDC CO_2 emissions, resulting in a 118 gCO_2/km for passenger cars and 205 gCO_2/km for light commercial vehicles. In the 2023 revision of the regulation, the 2030 reduction targets were strengthened, increasing from -37.5% to -55% for new cars and -31% to -50% for light commercial vehicles, relative to the 2021 baseline. This translates to targets of 95g CO_2/km for passenger cars and 147 g/km for light commercial vehicles. Furthermore, the revision introduced a 100% reduction target for both cars and light commercial vehicles, effectively setting the target at 0 gCO_2/km. Since these standards focus only on tank-to-wheel CO_2 emissions and not on the total greenhouse gas emissions of a vehicle over its lifetime, they essentially limit the viable technology options to vehicles with zero greenhouse gas emissions during their use phase. This approach, rather than adopting a more technology-neutral stance that also considers the well-to-tank CO_2 emissions, narrows the range of potential solutions and fails to fully address these emissions, potentially undermining the goal of climate neutrality by 2050. However, the revised regulation includes a provision for the development of a life cycle assessment methodology by the European Commission by December 2025, where vehicle manufacturers may voluntarily report their life cycle CO_2 emissions from January 2026. The regulation also includes several other provisions such as an incentive mechanism for zero- and low-emission vehicles to encourage their uptake of in the market, financial penalties to manufacturers that exceed their fleet average targets, pooling options of manufacturers to jointly meet their emissions targets and eco-innovations aimed at promoting the development of technologies that reduce real-world CO_2 emissions that are not reflected in the type-approval process. Additionally, a revision of the regulation is required in 2026, based on a biennial report by the European Commission, to assess its progress and effectiveness.
CO_2 Emissions Performance Standards for new Heavy-Duty-Vehicles	B	Manufacturers will have to comply with targets for fleet-wide average CO_2 emissions starting from 2025. These targets will apply to new HDVs registered in the reporting period of a given year, namely from 1 July of that year to 30 June of the following year. The amended Regulation has a wider scope, covering nearly all emissions from HDVs as it applies not only to heavy lorries but also to medium lorries, city buses, coaches, and trailers. As illustrated below, the revised targets are also more ambitious, aiming for increasing CO_2 emission reductions in the coming decades: ▪ 45% by 2030 ▪ 65% by 2035 ▪ 90% by 2040 Definition for zer-emission and low-emission vehicles exist. Apply financial penalties in case of non-compliance with CO_2 targets. The penalty level is set at 4,250 euro per gCO_2/tkm, starting from 2025.
Union Database (UDB)	B	The RED II envisions the application of a "Union database" (UDB) for liquid and gaseous transport fuels (see Art. 28(2) Directive (EU) 2018/2001 – RED II). The database aims to ensure the tracing of liquid and gaseous transport fuels that are eligible for being counted towards the share of renewable energy in the transport sector in any Member State.
EN13012		This document specifies safety and environmental requirements for the construction and performance of nozzles to be fitted to metering pumps and dispensers installed at filling stations and which are used to dispense liquid fuels and aqueous urea solution into the tanks of motor vehicles, boats and light aircraft and into portable containers, at flow rates up to 200l/min^{-1}.
EN 16321-1 and 2 Scope		This European Standard specifies the measurement and test methods for the efficiency assessment of petrol vapour recovery systems for service stations (Stage II).
EN 13760:2021 LPG equipment and accessories - Automotive LPG filling system for light and heavy duty vehicles - Nozzle, test requirements and dimensions		This document specifies the minimum design, construction, test requirements and the critical dimensions for filling nozzles for the dispensing of automotive Liquefied Petroleum Gas (LPG) to vehicles of categories M and N, as defined in Regulation (EU) 2018/858, that are fitted with the Euro filling unit (light-duty or heavy-duty).
EN 14678-1:2013 LPG equipment and accessories - Construction and performance of LPG equipment for automotive filling stations - Part 1: Dispensers		This European Standard covers the requirements for the design, manufacture, testing and marking of LPG dispensers for automotive LPG filling stations with a maximum allowable pressure of 25 bar (2 500 kPa).
EN 14678-3:2013 LPG equipment and accessories - Construction and performance of LPG equipment for automotive filling stations - Part 3: Refuelling installations at commercial and industrial		Contains the equipment and installation requirements for LPG refuelling installations, which are required to safely dispense LPG at commercial and industrial premises.
EN 13856: 2002 Minimum requirements for the content of the user manual for automotive LPG systems		This standard specifies the minimum requirements for the contents of the user manual for Automotive LPG propulsion systems fitted in road vehicles.
EN16942: + A1: 2021 Fuels - Identification of vehicle compatibility - Graphical expression for consumer information - Use of labels described in the standard and creation of a repository of symbols		This standard lays down harmonized identifiers for marketed liquid and gaseous fuels. The requirements in this standard are to complement the informational needs of users regarding the compatibility between the fuels and the vehicles that are placed on the market. The identifier is intended to be visualized at dispensers and refuelling points, on vehicles, in motor vehicle dealerships and in consumer manuals as described in this document. Marketed fuels include for example petroleum-derived fuels, synthetic fuels, biofuels, natural gas, LPG, hydrogen and biogas and blends of the aforementioned delivered to mobile applications.
ISO 9158	B	Nozzle outside diameter unleaded gasoline: max. 21,3mm
ISO 9159	B	Nozzle outside diameter leaded gasoline and diesel ≤50 L/minute: min. 23,6 mm to max. 25,5 mm.
ISO 13331 Scope	B	This International Standard ensures compatibility between new petrol-powered vehicle designs and refuelling vapour recovery nozzles — both active and passive systems — by their dimensions and specifications.

SAE J 285 Scope	B	This SAE Recommended Practice provides standard dimensions for liquid fuel dispenser nozzle spouts and a system for differentiating between nozzles that dispense liquid into vehicles with spark ignition and compression ignition...
SAE J1140 Scope	B	This SAE Recommended Practice was developed primarily for gasoline-powered passenger car and truck applications to interface vapour recovery systems, but may be used in diesel applications,... for filling.
SAE J829 / SAE J1114 / SAE J 3144	B	Different fuel filler caps that are in use with the equipment that is defined above.
ISO 21058:2019 Road vehicles — Dimethyl Ether (DME) refuelling connector		This document applies to Dimethyl Ether refuelling connectors, which consist of the Nozzle (mounted on dispenser side) Receptacle (mounted on vehicle). Referred to in this document as D15.
ISO 24605:2024 Road vehicles — Dimethyl ether (DME) refuelling connector with pressure equalizing port		It applies only to dimethyl-ether refuelling connectors with a pressure-equalising port, with a pressure-equalising port consists of a nozzle with a pressure-equalising port and a receptacle with a pressure-equalising port (mounted on vehicle). The refuelling nozzle and pressure-equalising port are integrated so that the connecting of the refuelling path and pressure-equalising path is performed with a single action (mounted on the dispenser side). Referred to in this document as M15.
ISO 17840-4:2018 Road vehicles - Information for first and second responders - Part 4: Propulsion energy identification		This document defines the labels and related colours for indication of the fuel and/or energy used for propulsion of a road vehicle, especially in the case of new vehicle technology and/or power sources, including hybrid drive lines.
ISO 14469:2017 Road vehicles - Compressed natural gas (CNG) refuelling connector	B	It specifies CNG refuelling nozzles and receptacles constructed entirely of new and unused parts and materials, for road vehicles powered by compressed natural gas.
ISO 16380:2014 + Amd1:2016 Road vehicles - Blended fuels refuelling connector	B	It applies to compressed blended fuels (CNG/H2) vehicle nozzles and receptacles hereinafter referred to as devices, constructed entirely of new, unused parts and materials.
ISO 12617:2015 Road vehicles - Liquefied natural gas (LNG) refuelling connector - 3,1 MPa connector	B	It specifies liquefied natural gas (LNG) refuelling nozzles and receptacles constructed entirely of new and unused parts and materials for road vehicles powered by LNG. This International standard is applicable only to such devices designed for a maximum working pressure of 3,4 MPa (34 bar) to those using LNG as vehicle fuel and having standardized mating components.
ISO TS 21104:2019 Road vehicles - Liquefied natural gas (LNG) integrated low pressure refuelling and venting connector - 1,8 MPa connector	B	Withdrawn standard which specifies liquefied natural gas (LNG) refuelling nozzles and receptacles constructed entirely of new and unused parts and materials for road vehicles powered by LNG. This document is applicable only to such devices designed for a working pressure of 1,8 MPa to those using LNG as vehicle fuel and having standardized mating components.
ISO 16923:2016 Natural gas fuelling stations - CNG stations for fuelling vehicles	B	It covers the design, construction, operation, inspection and maintenance of stations for fuelling compressed natural gas (CNG/biomethane) to vehicles, including equipment, safety and control devices. The nozzle is not included in this standard.
ISO 16924:2016 Natural gas fuelling stations - LNG stations for fuelling vehicles	B	It specifies the design, construction, operation, maintenance and inspection of stations for fuelling liquefied natural gas (LNG/bioLNG) to vehicles, including equipment, safety and control devices. The nozzle is not included in this standard.
ISO 19825:2018 Road vehicles - Liquefied petroleum gas (LPG) refuelling connector		It applies to Liquefied Petroleum Gas vehicle nozzles and receptacles, which have a gauge service pressure in the range of 110 kPa (Butane rich at 20 °C) and 840 kPa (Propane at 20°C).
UNECE Regulation 115		This Regulation applies to: Part I: Specific LPG retrofit systems to be installed in motor vehicles for the use of LPG in the propulsion system. Part II: Specific CNG retrofit systems to be installed in motor vehicles for the use of CNG in the propulsion system.
UNECE Regulation 110 revision 7 – May 2024		Uniform provisions concerning the approval of: I. Specific components of motor vehicles using compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system II. Vehicles with regard to the installation of specific components of an approved type for the use of compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system.

9.3. List of Possible CO_2 Neutral Fuels at the Pump by Type of Engine Technology

	Drop-in Fuels			
	Diesel Engine (Compression Ignition)	Petrol Engine (Positive Ignition)	Liquefied Petroleum Gas (LPG) Engine (Positive Ignition)	Natural Gas Vehicle (NGV) Engine (positive Ignition)
	HDV & LDV	LDV	LDV & HDV	HDV & LDV
List of renewable components	Diesel type HVO, Biodiesel, Diesel type eFuel (eDiesel)	Petrol type HVO (bionaphta), Bioethanol, Petrol type eFuel (eGasoline), Ethanol-to-Gasoline (ETG), Methanol-to-Gasoline (MTG), bioETBE	LPG type HVO (bioLPG), LPG type efuel (eLPG), renewable DiMethylEther, eDiMethylEther (from eMethanol)	Biomethane, eMethane
List of possible CO_2 Neutral Fuels (already commercialised today or possibly commercialised in the future)	B7: 7% biodiesel + 93% of mixture of Diesel HVO and eDiesel (EN 590)	E10: up to 10% bioethanol, up to 22% bioETBE + mixture of bionaphta, bioETBE, ETG, MTG, and eGasoline. (EN 228)	100% bi-LPG (EN 589)	100% biomethane (EN 16723-2)
	B10: 10% biodiesel + 90% of mixture of Diesel HVO and eDiesel (EN 16734)	E20: Up to 20% bioethanol, up to 22% bioETBE + mixture of bionaphta, bioETBE, ETG, MTG and eGasoline. (EN XXX) On going discussions at CEN level	BioPropane and renewable propane with up to 12% drop-in renewable DME	Mixture biomethane and eMethane
	B20: 20% biodiesel + 80% of mixture of Diesel HVO and eDiesel (EN 16 709)	E85: 60% to 85% bioethanol and 15% to 40% other renewable fuels (bionaphta, bioETBE, eGasoline or ETG, MTG or mixture of those). (EN 15293)	Renewable DME and renewable Liquid Gas blends for Drop-In and Non-Drop-In DME.	100% eMethane
	B30: 30% biodiesel + 70% of mixture of Diesel HVO and eDiesel (EN 16 709)	98-E5: around 14% bioETBE + complement with a mixture of bionaphta, ETG, MTG and eGasoline. (EN 228)	Renewable & Recycled Carbon DME Diesel engines or blended with 100% BioLPG/ BioPropane	
	B100: 100% biodiesel (EN 14 214)		Standard for DME and LPG-DME blends are in the process to be developed.	
	HVO100: 100% Diesel type HVO (EN 15940)		Mixture bioLPG and eLPG (EN 589)	
	100% eDiesel (EN 15940)		100% eLPG (EN589)	
	ED95: 95% bioethanol + 5% cetane improver			

Non Drop-in Fuels	
Diesel Engine (Compression Ignition)	Otto Engine (Positive Ignition)
Blends of Diesel type renewable hydrocarbons and renewable alcohols	M100 (ISO 6583, eMethanol and biomethanol) for PC, HDV and off-road vehicles
eDME & bioDME	

* This is not an exhaustive list
*Equivalents might be used to technical standards
* This is not an exhaustive list

9.4. List of Abbreviations

Abbreviation	Full Name
BEV	Battery Electric Vehicle
bioETBE	Bio Ethyl Tertiary-Butyl Ether
BLE	Federal Office for Agriculture and Food of Germany
CAPEX	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture Storage
CNF	CO_2 Neutral Fuel
CNG	Compressed Natural Gas
COREPER	Committee of Permanent Representatives in the European Union
DFTS	Digital Fuel Tracking System
DG CLIMA	Directorate General for Climate Action
DG GROW	Directorate General for Internal Market, Industry, Entrepreneurship and SMEs
DME	DiMethylEther
ECU	Engine Control Unit
ETG	Ethyl glucuronide
FAME	Fatty Acid Methyl Ester
FUB	Fuel Usage Balancing
GTL	Gas-to-Liquid
HDV	Heavy Duty Vehicle
HEFA	Hydro processed Ester and Fatty Acids

Abbreviation	Full Name
HVO	Hydro-treated Vegetable Oil
ICE	Internal Combustion Engine
ISCC	International Sustainability and Carbon Certification
LCA	Life-Cycle Analysis
LDV	Light Duty Vehicle
LNG	Liquefied Natural Gas
MtD	Methanol to middle distillates
MTG	Methoxytriglycol
NFC	Near Field Communication
NIR Sensor	Near-infrared spectroscopy
OBD	On-board diagnostic systems
OEMs	Original Equipment Manufacturer
OPEX	Operational Expenditures
PoS	Proof of Sustainability
RFNBO	Renewable Fuels of Non-Biological Origin
SAF	Sustainable Aviation Fuel
TCMV	Technical Committee on Motor Vehicles
UCO	Used Cooking Oil
UDB	Union database
W-t-W	Well to Wheel
XTL	Anything to Liquid
ZEV	Zero Emission Vehicle

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