Truckin' on

Using the heavy duty CO_2 standard to drive investment in fuel decarbonisation

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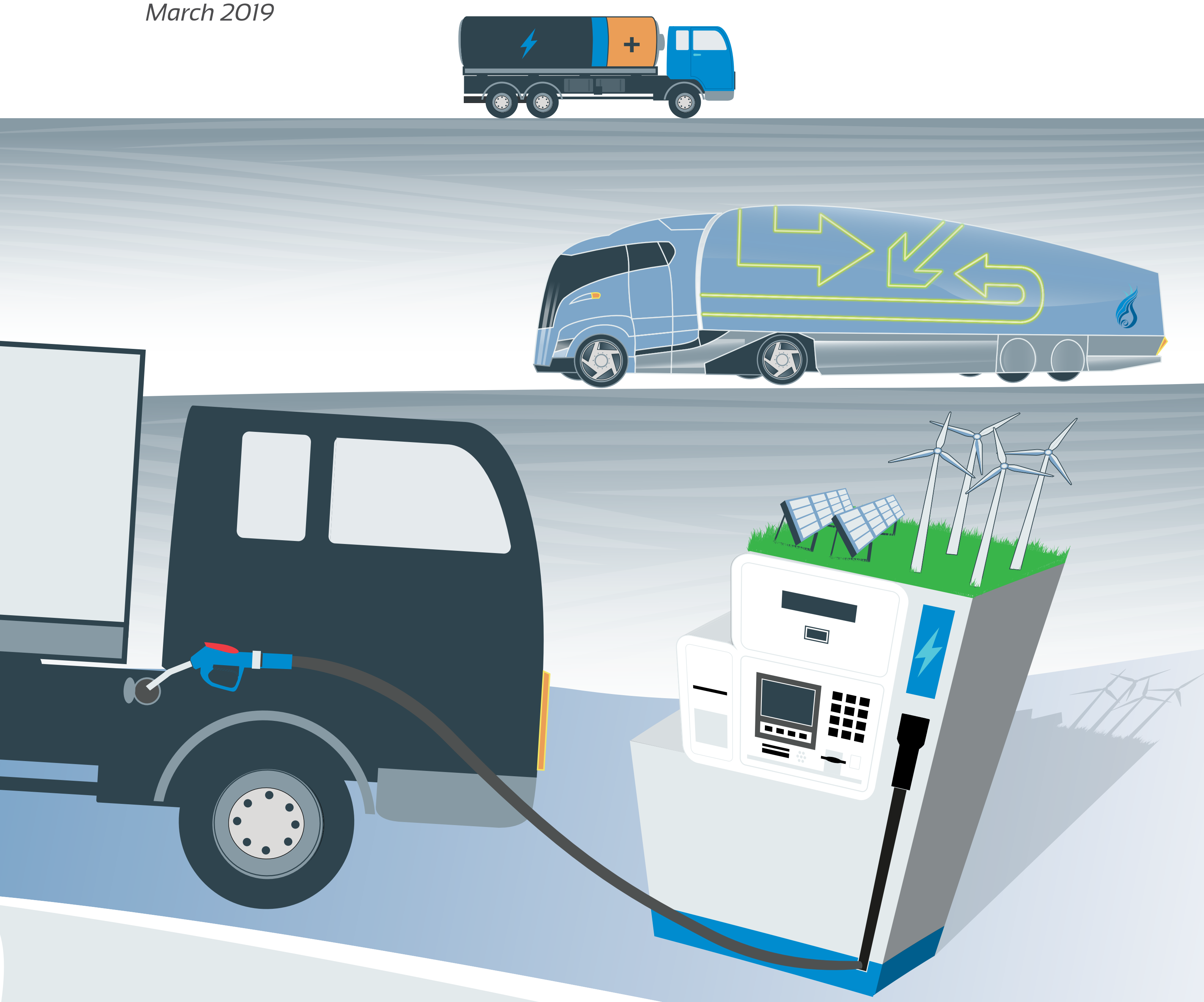

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Executive summary

The European Union is in the process of finalising its first ever CO_2 emission standard for heavy duty vehicles, with a proposal from the European Commission targeting 30% reduction in CO_2 emissions for Class 4, 5, 9 and 10 heavy duty vehicles by 2030. Currently the proposed standard allows for compliance through efficiency improvement, through the manufacture of zero and low emission vehicles and through the use of fuels that release less physical carbon dioxide on combustion than diesel fuels, but the standard provides no option for compliance through reducing the upstream emissions associated with fuel production. CO_2 reductions from alternative fuels are currently incentivised through the Renewable Energy Directive, while emissions reductions at the refinery are incentivised through the ETS.

While EU policy separates vehicle efficiency from the lifecycle carbon intensity of the fuels used, in practice the decarbonisation of the heavy duty sector (and similarly of marine and aviation sectors) will require a combination of lower emission vehicles and lower carbon intensity fuels. Indeed, many of the technologies required for the decarbonisation of heavy duty fuels are expected to play a major role in long term decarbonisation of the EU economy, but have struggled to date to reach successful commercial application – these include biomass to liquids advanced biofuel technologies, power to liquids technologies to produce electrofuels, and the implementation of carbon capture and sequestration and green hydrogen production at the refinery. It is therefore natural to ask whether there is an opportunity to leverage the heavy duty standard to accelerate development of these key technologies, in a way that would support achievement of EU climate objectives beyond the heavy duty sector.

A major difference that exists between existing fuel decarbonisation policy and the proposed heavy duty vehicle CO_2 emissions standard is that the heavy duty standard is a regulation applying directly and consistently to heavy duty manufacturers across the whole EU, and containing clearly defined costs of non-compliance (through a set excess-emissions charge). Manufacturers will need to set compliance strategies well in advance of 2030 given the lead time to develop and engineer more efficient trucks, and given these compliance strategies and the known cost of non-compliance manufacturers should have a clear idea of the value to them of carbon reductions that could be used within the standard. This contrasts with the alternative fuels sector, where the value signal from policy is much more market dependent, and very challenging to predict in advance, while the value signal from the ETS for refinery emissions reduction projects is simply too weak to support novel but expensive projects. If some fuel decarbonisation credits were allowable for compliance in the heavy duty standard, this relative value certainty could be used to accelerate the development of high capital expenditure projects that have proved difficult to attract investment to under existing alternative fuels policy. Adding a fuel decarbonisation credit option in the heavy duty standard would also add flexibility to compliance strategies for heavy duty vehicle manufacturers, and allow the cost of the programme to be reduced should deploying emissions reduction technologies on heavy duty vehicles prove to be more expensive than anticipated by the impact assessment.

This report provides an outline for a programme to allow specific types of fuel decarbonisation project to generate credits for compliance by manufacturers with the heavy duty standard, insofar as they deliver carbon savings in the production of heavy-duty fuels (primarily diesel, potentially also diesel alternatives such as DME). It envisions a system whereby manufacturers would form binding 'credit-offtake agreements' with project operators, committing the projects to supply the carbon savings they generate to the vehicle manufacturer (retiring them from use against targets in other climate obligations such as RED or ETS) and committing the manufacturer to offtake all credits generated up to an agreed level. These contracts would be undertaken on the basis of either an upfront payment or investment from the manufacturer to the project operator, or on the basis of a credit purchase agreement with guaranteed credit prices set for the duration of the contract. The proposal envisions a limited window for project registration. This registration window would be open until a set date, for instance the end of 2025, and a period of up to 15 years during which credits would be eligible for transfer into the heavy duty obligation – but these and other details should be consulted on with the relevant stakeholders prior to introducing a mechanism of this sort in legislation.

The fuel decarbonisation projects considered for inclusion in this mechanism would currently contribute to meeting targets in the RED or ETS, and be incentivised on that basis. It is important for the credibility and integrity of any new scheme that these projects may not be double counted and rewarded under multiple EU policies. It is therefore recommended that any lower carbon fuels used to generate credits towards heavy duty CO_2 standard compliance should be excluded from counting towards existing targets under the RED or ETS.

On the face of it, it would seem difficult to translate carbon reductions from fuels measured in tonnes of CO_2 into compliance with a CO_2 emissions standard set in tonnes of CO_2 per gram-kilometre per vehicle, but it is shown that the structure of the proposed heavy duty standard is such that the conversion is mathematically simple. All that is required to allow the calculation of the compliance contribution of tonne of carbon savings is to set an assumption on the operational lifetime of the heavy duty vehicles sold. The other necessary assumptions to convert between absolute carbon savings and CO_2 emissions reduction (on vehicle loads and activity) are already defined in the proposed standard. Given an assumed average vehicle operational lifetime of 15 years, it is shown that the excess emissions charge of 6,800 €/tkm per vehicle is equivalent to a carbon price of 282 €/tCO_2e.

Four families of fuel decarbonisation projects are identified as examples that have a clear role in long term EU decarbonisation strategy and that could benefit from additional policy support to accelerate commercial deployment: biomass to liquids (BtL) projects; electrofuels projects; green hydrogen use at the refinery; CCS at the refinery. For all of these project types, a clear long-term (15 year) carbon price signal of the order of 200 €/tCO_2e has the potential to aid deployment. In particular, low-end estimated costs from the literature for biomass to diesel projects using pyrolysis and upgrading or gasification and Fischer-Tropsch synthesis, for green hydrogen, and for CCS, are consistent with commercial deployment given a carbon price signal around 200 €/tCO_2e. Electrofuels currently have higher expected costs, but projects able to lock-in low cost electricity supplies may also be viable at this level of incentive. Examples are presented building on the cost curves prepared by the Joint Research Centre for the heavy duty standard impact assessment showing cases in which it could be beneficial for a manufacturer to invest in fuel decarbonisation credits to meet the final few percentage points of their CO_2 emissions standards for given heavy duty vehicle classes. In one example, the value of the CO_2 emissions reductions transferred into the heavy duty standard would support the development of a Fischer Tropsch biofuel facility. In a second example, the value would support introduction of CCS for the power plant of a medium sized refinery.

The regulatory framework outlined herein is conceived as a strictly limited alternative incentive to accelerate the development of key fuel decarbonisation technologies that have struggled to attract investment to date due to uncertainty in the value proposition from other policies. These technologies have a clear role in the EU strategic long-term vision for a decarbonised economy (European Commission, 2018a), with the potential to make major contributions to building blocks 2, 3, 4, 6 and 7 of the strategy. A well designed mechanism need not compete with existing regulatory support, but rather could complement them by adding clarity to the value signal for early technology adopters, paving the way for broader technology roll out subsequently.

Glossary

Acronyms

CCS	Carbon capture and sequestration/storage
DME	Dimethyl ether
ETS	Emission Trading Scheme
FCC	Fluid catalytic cracker
FQD	Fuel Quality Directive
GHG	Greenhouse gas
HDV	Heavy duty vehicle
IEA	International Energy Agency
ILUC	Indirect land use change
JEC	JRC-EUCAR-CONCAWE
JRC	Joint Research Centre
LCFS	Low Carbon Fuel Standard
LNG	Liquefied natural gas
RED	Renewable Energy Directive
RTFC	Renewable Transport Fuel Certificate
SMR	Steam methane reformer
WTW	Well to wheel
ZLEV	Zero or low emission vehicle

Units

€/tCO_2e	Carbon price or value in Euros per tonne of carbon dioxide emissions avoided
€cent/kWh	Electricity price in Eurocent per kilowatt hour
gCO_2/km	Grams of carbon dioxide emitted per kilometre travelled by a vehicle
gCO_2/tkm	Grams of carbon dioxide emitted for every tonne moved a kilometre by a vehicle
g/tkm	Shorthand version of gCO_2/tkm
gCO_2e/MJ	Grams of carbon dioxide equivalent greenhouse gas emissions from delivering a megajoule of energy by fuel combustion

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1. Introduction

On May 17, 2018, the European Commission proposed a regulation setting CO_2 emissions standards for new heavy duty vehicles in the European Union (European Commission, 2018c), with a suggested target of a 15% reduction by 2025 and 30% reduction by 2030 relative to a 2019 baseline. The proposal would allow for heavy duty vehicle manufacturers to comply directly through reducing the emissions from new internal combustion engine heavy duty vehicles, as well as by earning additional 'super-credits' through sales of zero- and low-emission[1] heavy duty vehicles or by using fuels that emit less physical carbon when combusted, such as liquefied natural gas (LNG). Currently, however, the proposal does not allow for any contribution to be made towards compliance by delivering emissions reductions in the well-to-tank part of the lifecycle, through reductions in fuel GHG intensity. Under current EU transport decarbonisation policy, the reduction of GHG emissions associated with the fuel lifecycle is handled through other legislation, the Fuel Quality Directive[2] and Renewable Energy Directive[3].

In this policy paper, we consider the possibility of introducing an additional compliance option under the heavy duty vehicle CO_2 standard by allowing heavy duty vehicle manufacturers to earn credit for supporting investments in specific fuel decarbonisation technologies. This paper develops some of the ideas presented in the Fuels Europe policy paper, "Vision 2050: a pathway for the evolution of the refining industry and liquid fuels" (Fuels Europe, 2018a).

Improved vehicle efficiency and the introduction of vehicle electrification will significantly reduce fuel demand from EU vehicles over the coming decades, but most scenarios for future energy use in transport in the EU and globally include significant continued demand for liquid fuels in 2050 and beyond (cf. European Commission, 2018a). For heavy duty road vehicles, as well as in shipping and in aviation, there are applications that will be persistently difficult to electrify for the foreseeable future. Achieving deep decarbonisation of these modes will therefore require that efficiency improvements are coupled to reductions in the lifecycle GHG intensity of the fuels that are consumed – heavy duty transport decarbonisation is about decarbonising a coupled system of vehicle and fuel.

1.1. Decarbonising fuels

While the value of developing new low carbon sustainable fuel technologies is widely acknowledged, globally the pace of development of advanced biofuel technologies has disappointed some earlier expectations (Malins, 2018). The global biofuel industry remains dominated by the supply of ethanol blended in petrol and fatty acid methyl ester (biodiesel) blended in diesel. The use of these fuels is limited by maximum blend specifications imposed by the characteristics of the current generation of internal combustions engines. It is also limited by the relatively high cost of the feedstocks required. Finally, it is limited by sustainability concerns relating to the use of agricultural commodities for fuel manufacture where they could potentially be fed to humans or animals. The European Union has therefore limited the

1 A 'low emission' vehicle is defined as having emissions less than 350 gCO_2/km, which is about half the fleet average baseline CO_2 emissions.

2 https://ec.europa.eu/clima/policies/transport/fuel_en

3 https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

maximum use of these 'first generation' biofuels that can be counted towards EU climate and renewable energy targets.

Given these practical and sustainability limits on first generation biofuels, European interest in advanced low carbon fuel technologies is resurgent. This includes 'biomass to liquids' technologies that could produce 'drop-in'[4] synthetic biofuels from low value waste and residues, electrofuel technologies to convert electricity into liquid transport fuels via hydrogen, and recycled carbon fuel production taking advantage of energy carriers that would otherwise be wasted or inefficiently utilised.

Reductions in the GHG intensity of transport fuels could also be delivered through innovative measures at the refinery, such as the use of 'green' hydrogen[5] (replacing H_2 produced from "conventional" steam methane reforming) for refinery operations including hydrotreating[6] and hydrocracking[7] or the implementation of carbon capture and storage (including capturing CO_2 from steam methane reforming). For those parts of the heavy duty fleet that are unlikely to be electrified, combining such fuel decarbonisation options with efficiency improvements will be a vital element of maximising delivered emissions reductions in the long term. The same is likely to be true for shipping, and especially for aviation.

While the benefits of developing these technologies are widely accepted, deployment has not yet matched the aspiration. For advanced biomass-to-liquids fuels, commercial deployment remains chimerical despite a raft of support measures having been put in place in North America, Europe and elsewhere. While there are a number of factors that have contributed to the general lack of commercial success for advanced alternative fuel projects over the last decade, a major barrier has been the lack of a well understood long-term value signal from the policy instruments in place. In the EU case, the 2020 targets for advanced biofuel use introduced in the 'ILUC Directive'[8] are a case in point. While in principle the introduction of defined targets for advanced fuels should have improved the value signal, the efficacy of the measure has been limited by several structural factors:

- The targets were set in a Directive subject to Member State implementation and are not fully binding on Member States, such that at the point the Directive was adopted industry could not know what targets it would actually be subject to;
- The targets set in 2015 go only as far as 2020 – beyond 2020, industry was given only a statement of intention, not concrete policy measures;
- In Member State implementations, it is unclear what the value would be to fuel producers from enabling compliance with the targets.
- The value of delivering a given volume of advanced biofuel at any future date is

4 'Drop-in' fuels are those that can be used at high blends or unblended in existing engines without requiring modification or introducing a risk of engine failure or damage.

5 Produced by electrolysis with renewable power.

6 The use of hydrogen to remove unwanted impurities like sulphur from refined fuels.

7 The addition of hydrogen to increase production of high quality fuels from heavy fractions of oil.

8 Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

sensitive to the volumes of advanced biofuels being produced by other market participants, which are very difficult to predict.

The upshot of these structural factors that make the long-term value signal from advanced biofuel targets more uncertain is that investors have been exceedingly cautious of assuming future cash flows from policy when making investment decisions, and therefore the value of these policies to investors has been significantly undermined (Malins, 2018).

On the refinery side, the relatively low value of carbon credits within the EU Emissions Trading Scheme (EU ETS) has dulled the price signal in favour of investing in green hydrogen or CCS, and this combination of low credit prices and the other challenges of deploying new technologies at industrial scales have meant that delivery of these technologies at commercial scale has thus been protractedly delayed.

In short, the combination of a lack of long term policy certainty and the use of policy instruments that do not offer an adequate and identifiable value proposition to investors has made it difficult to attract investment in high capital expenditure low carbon fuel and fuel decarbonisation projects. The investment picture should be clarified and improved somewhat by the adoption of the climate framework for 2020 to 2030, including a recast Renewable Energy Directive with a sub-target for advanced biofuels, but a significant degree of value uncertainty can be expected to remain for investors even after Member State implementations of the post-2020 climate framework have been finalised. This uncertainty is particularly difficult to overcome for new-technology projects where there are very few, if any, commercially operational examples for investors to refer to (let alone commercially successful).

1.2. The heavy duty CO_2 standard

The proposed heavy duty CO_2 standard requires heavy duty vehicle manufacturers selling in the EU market to deliver significant efficiency improvements by 2025 and 2030 compared to a 2019 baseline. The baseline will be calculated across 9 heavy duty vehicle subgroups, covering category 4, 5, 9 and 10 vehicles. Each manufacturer's target average emissions for new vehicles shall be calculated by reference to the mix of vehicles sold across the subgroups. Excess emissions above the manufacturers target value shall incur an 'excess emissions charge' of 6,800 € per gCO_2/tkm per vehicle sold.

While the manufacturer target will be framed as an average gCO_2e/tkm value, the nominal value calculated within the standard shall not in fact be a fleet average, because the requirement is adjusted by reference to typical payload and mileage in each vehicle subgroup. For instance, the emissions rating for a category 4 urban delivery vehicle will be scaled down by a factor of 10 in the calculation compared to the emissions rating of a category 5 long-haul vehicle. This system of adjustments will result in nominal CO_2 emissions ratings at the fleet level that are not representative of actual average emissions values for new sales, but because excess emissions charges will be levied based on these adjusted values the regulation is structured so that any penalties will be directly proportional to estimated excess CO_2 emissions resulting from failing to meet the standard[9]. This is important, because it means that there is a well-defined implied CO_2 penalty price within the standard. The calculation of this implied non-compliance CO_2 price is explained in more detail in Annex A – the resulting

9 If we assume that all regulated vehicles have the same lifetime and that payload and mileage assumptions are representative of lifetime use.

CO_2 price is 282 €/tCO_2e[10]. This calculated carbon price[11] can be understood as the maximum value to a regulated manufacturer of carbon savings delivered by an eligible fuel project.[12]

10 Assuming a 15 year lifetime for new HDVs as used by the JRC in the cost analysis detailed in Krause & Donati (2018).

11 This report adopts the convention of referring to a value applied to a reduction of one tonne of carbon dioxide emissions through regulation as a 'carbon price', in units of € per tonne carbon dioxide abated (€/tCO_2e). Where the carbon price is not explicit from a regulation but can be estimated given assumptions about the carbon savings delivered, it is referred to as an 'implied' carbon price.

12 It should also be noted that the heavy duty CO_2 standard impact assessment anticipates social cost benefits resulting from reduced fuel spend due to improved efficiency. The fuel decarbonisation projects detailed here would not deliver such benefits from reduced fuel spend, though they may offer compensating co-benefits in technology development.

2. Outline proposal for a fuel investment credit in the EU heavy duty vehicle CO_2 standard

As noted in the introduction, decarbonising EU heavy duty transport as part of the transition to a low carbon economy will require both increases in the efficiency of energy use (through aerodynamics and engine efficiency improvements, and the transition to more efficient hybrid and/or electric drivetrains) and reductions in the greenhouse gas intensity of the fuels used (through low carbon liquid fuels and through ongoing reductions in the GHG intensity of electricity). As currently framed, the proposed heavy duty vehicle efficiency standard deals with only the efficiency part of this equation. There is therefore an opportunity to expand the proposed standard to provide an added impetus for a first generation of major investments to produce lower GHG intensity heavy duty fuels.

The appeal of using the heavy duty CO_2 standard as an investment driver for decarbonisation projects for heavy duty fuels is that as a European Union wide regulation the heavy duty standard sets a clear 11 year requirement on manufacturers with a defined penalty associated with falling short of the targets. Each obligated manufacturer is in a position to compare compliance options available to them and associated costs, and make an informed business decision on which combination of compliance options to invest in. The value of investing in a fuel carbon reduction project would be well defined for each individual manufacturer, and unlike in existing fuel mandates the value of compliance to the manufacturer would not be directly affected by rates of supply of other low carbon fuels.

In the rest of this chapter, we outline a potential approach to allow specified investments in fuel decarbonisation to generate credit towards compliance with manufacturer heavy duty CO_2 efficiency targets.

2.1. Outline of a scheme

The basic framework for a fuel investment credit would be as follows:

- Define a set of fuel decarbonisation project-types that would contribute to reducing heavy duty CO_2 emissions and to developing technologies with a role in long term EU decarbonisation.
- Allow manufacturers of heavy duty vehicles to enter contracts with the operators of these fuel decarbonisation projects under which the delivered carbon savings would be counted towards the heavy duty CO_2 standard instead of other EU climate targets.

Beyond these basic points, there are several design questions to be addressed before such a mechanism should be introduced. These include:

- Determine a basis to convert tonnes of CO_2 emissions reductions delivered by a fuel decarbonisation project into a gCO_2/tkm per vehicle credit in the heavy duty standard.

- Determining which types of fuel decarbonisation project should be eligible to generated credits against the heavy duty standard.
- Setting requirements on the nature of the contract between a fuel decarbonisation project operator and a manufacturer.
- Setting a period for which credits should be eligible to contribute in the heavy duty standard.
- Considering whether any limit should be placed on the window to register projects in order to accelerate project development. For instance, if it was required that projects be registered (or even operational) by the end of 2025, this would create an opportunity for these projects to catalyse others before 2030.

2.2. Fuel decarbonisation credits

The purpose of the crediting system described here is twofold. Within the heavy duty CO_2 standard making additional compliance options available provides compliance flexibility, reducing the risk of high compliance costs to society. In the fuel market, an opportunity is presented for an additional crediting system to accelerate technology deployment in key areas that will not only deliver direct carbon savings but indirectly increase the overall rate of adoption of those technologies, contributing to broader EU decarbonisation policy goals (this is discussed further in the final chapter below). Maximising the opportunity to deliver these dual goals requires that project eligibility should be defined to target investments that will have the most value in this technology commercialisation process.

Determining a final set of eligible investment types for the regulation should be undertaken by the Commission in consultation with relevant industries and civil society. Here, we consider four families of technologies where we believe there is a good case to support early investments:

- Biomass-to-liquids projects
    - Gasification and fuel synthesis
    - Pyrolysis and fuel upgrading
    - Other biomass to liquids pathways such as ethanol to mid-distillates
- Electrofuels
- Green hydrogen from electrolysis used at the refinery
- Carbon capture and sequestration at the refinery

Each of these project types would require development of technologies that could play a major role in long-term EU decarbonisation. Accelerating the development of these technologies would have knock on benefits in several areas of the low carbon economy:

- Hydrogen by electrolysis is needed for both electrofuel production and green hydrogen production for refining.
- Fischer-Tropsch fuel synthesis, or other novel fuel synthesis technologies, will be

required both for biomass to jet fuel and power to jet fuel production, as well as having complementarity with renewable chemicals applications..

- Carbon capture and storage can play a role delivering immediate carbon savings in industry, and will be required for some 'negative emissions' energy options such as bioenergy with carbon capture and storage.

All of the project types listed above have the potential to deliver significant lifecycle carbon reductions in EU fuels, while accelerating development of important technologies with wider implications for EU decarbonisation and EU industrial development. To maintain the credibility of the regulation, however, it would be appropriate to set additional requirements on the eligibility of carbon reductions to be counted into the heavy duty CO_2 standard.

2.3. Eligibility of fuel decarbonisation projects

All of the project types discussed have the potential to deliver carbon emissions reductions across a broad range of hydrocarbon products. For refinery investments in green hydrogen or CCS, emissions reductions would be delivered across a range of output products, including fuels supplied for petrol and diesel engines, jet fuel, chemicals feedstocks, heavy fuel oils and other oil fractions. Similarly, synthetic fuel production will often deliver a spectrum of fuel outputs including naphtha, diesel range molecules, jet fuel molecules and other hydrocarbons.

While real emissions reductions can be delivered across this full range of hydrocarbon products, the vehicles regulated by the heavy duty CO_2 standard (category 4, 5, 9 and 10 rigid trucks and tractor-trailers) are primarily diesel vehicles. It is therefore proposed that in order to establish a link between eligible investments and heavy duty decarbonisation that only those emissions savings associated with the production of heavy-duty appropriate fuels should be eligible to be counted if fuel decarbonisation projects would be allowed to contribute to compliance with the heavy duty CO_2 standard. This would include diesel fuels, but could be expanded to include alternative heavy duty fuels such as dimethyl ether (DME), if it can be shown that these fuels are potentially supplied for heavy duty transport once produced. Where a project generates several products, an allocation methodology would need to be adopted to attribute some fraction of the emissions reductions achieved to the heavy duty fuels being produced. One approach to this allocation problem would be to allow only a fraction of generated emissions reduction proportionate to the amount of product energy delivered as diesel and other heavy-duty fuels to be considered for crediting in the heavy duty standard, which would echo the energy-allocation required in biofuel lifecycle analysis under the Renewable Energy Directive. Other allocation approaches may be possible, for instance based on mass or on commercial value of the outputs.

This would mean that if diesel represented three quarters of the output in energy terms from a synthetic fuel project, with the rest split between chemical feedstock, petrol and heavy-ends, up to three quarters of the delivered carbon savings could be eligible to be counted towards meeting manufacturer heavy duty efficiency targets. Alternatively, if conventional hydrogen production was replaced by green hydrogen for a distillate hydrotreating unit processing only diesel fuels, then 100% of the savings achieved would be attributable to the diesel fuel output from the refinery. In contrast, if green hydrogen was used for an FCC feed hydrotreater outputting molecules destined for both the petrol and diesel pools, then an allocation would again be required.

Given that the justification for crediting fuel decarbonisation projects in the heavy duty standard is that the fuel from these projects would be compatible with heavy duty engines, one might consider a requirement that project operators prove that fuels had been supplied directly to regulated heavy duty vehicles. While such a requirement would be notionally consistent with the basis for the crediting scheme, tracking fuel from the point of production to the end-use vehicle would be extremely burdensome, and would go well beyond reporting that is required under the RED or FQD. Enforcing a segregated supply chain for heavy duty diesel apart from the supply chain for diesel used by light duty vehicles would be costly, and deliver no direct environmental benefit. The RED is currently built around a principle of mass balance for supply chain monitoring, under which batches of fuel need not be physical separated throughout the chain provided the amount of fuel assigned a given set of sustainability data that leaves a supply chain facility is the same as the amount entering that facility. By analogy to that mass balance principle, it is argued that it would be reasonable to treat the full amount of reduced CO_2 diesel (and other relevant fuels) supplied to the EU market under this crediting system as if it had been physically supplied to heavy duty vehicles. In the longer term, shrinking consumption of diesel by passenger cars will in any case mean that an increasing fraction of the total diesel supply is consumed by vehicles regulated under the heavy duty standard.

It might also be argued that it was appropriate to allow lower carbon jet fuel production to generate credits, given that *a)* diesel and jet fuels use a similar range of hydrocarbon molecules and *b)* aviation may be seen as a priority destination for low carbon fuels in the longer term. The question of including aviation fuels is discussed further in the next chapter.

Beyond eligible fuel types, it is not the intention of this proposal to create a situation of double counting of low carbon fuel production towards multiple targets. It would therefore be appropriate to require that any carbon savings registered towards the heavy duty CO_2 standard under the proposed framework should be disqualified from being counted towards targets under either the EU ETS (in the case of refinery carbon savings) or the RED (in the case of biofuels and electrofuels). Including such a requirement would also manage the concerns identified in the Commission Impact Assessment (European Commission, 2018b) that allowing lower carbon fuels to contribute towards compliance "would de facto constitute double regulation for these sectors" and "that a WTW approach could undermine the environmental effectiveness of EU legislation as emission reductions counted under RED-II would be double counted under the vehicles legislation".

Finally, it is not the intention of the proposal to create loopholes allowing crediting of biofuels failing to meet the sustainability requirements of existing EU legislation. It would therefore be appropriate to require compliance with the RED sustainability for any carbon savings generated by biofuel projects and electrofuel projects

2.4. Project registration

The first step in developing a fuel decarbonisation project to generate credits towards compliance with the heavy duty CO_2 standard should be the development of a bilateral contract between a regulated heavy duty vehicle manufacturer and a potential supplier of lower carbon fuels. This contract should represent a 'credit offtake agreement' giving the regulated manufacturer the right to all eligible carbon emissions reductions generated by the project (up to some agreed level[13]) in exchange for financially supporting the project (several contracting options for this credit offtake agreement are discussed in the next subsection).

Requiring a bilateral contract in this way would demonstrate that the commitment of the regulated manufacturer had supported development of the project in question. The precise nature of the contractual relationship could vary between cases. The important detail is that a mutually agreed set of terms must guarantee that the project would make emissions credits available to the manufacturer on the prescribed basis when they are generated. The agreement signed between the parties should have a defined duration, the length of time for which the credit offtake guarantee will remain in effect, which could be anything up to the maximum crediting period allowed under the Regulation.

Having agreed terms in principle with a fuel project developer, a manufacturer would be required to register the project and credit offtake contract with the appropriate member state authority, and have eligibility of the project confirmed. Such project registration goes beyond what is generally required within existing alternative fuel support under the RED and FQD, which include no requirement for new projects to be registered prior to generating renewable fuels/ GHG intensity reduction. However, parallels for such project registration requirements can be seen in the California Low Carbon Fuel Standard, under which fuel producers and refiners are required to register fuel production facilities and refinery decarbonisation projects with the California Air Resources Board before they are eligible to generate LCFS credits. The role of the Member State would be to verify that the project type met any imposed eligibility criteria, and to confirm that an agreed credit-offtake contract existed between the parties to the agreement. This could be facilitated through relying on the use of qualified auditors' opinions as evidence of compliance with the project registration requirements. Implementation of this scheme should therefore create only a modest additional administrative responsibility for Member States.

2.5. Structuring a credit offtake contract

As noted above, there are several ways in which one could imagine structuring a credit offtake agreement for a fuel decarbonisation project. Here, we briefly review three possible contractual structures for the arrangement: credit purchase guarantee; funds held in trust; and upfront payment or investment. It is not proposed that the European Union should seek to restrict the commercial flexibility available in setting contractual terms, although it would be appropriate to consult with the affected stakeholders regarding whether any external conditions should be placed on contracts. While the three contractual structures are presented as distinct below, one could also in principle imagine commercial arrangements that combined features of two or even all three approaches.

2.5.i) Credit purchase guarantee

A credit purchase guarantee would be a contractual instrument committing the HDV

13 Given that the stringency of the CO_2 emissions targets increases over the decade, some manufacturers might seek to agree to a gradually increasing credit offtake commitment. In that case, any excess emissions reductions generated by the decarbonisation agreement in the earlier years could be surrendered towards compliance with other existing policies. Allowing such arrangements would seem reasonable provided terms could be mutually agreed on this basis by the parties.

manufacturer to buy all CO_2 credits generated by a fuel decarbonisation project (up to a given annual rate of generation) at a pre-agreed credit price[14]. By locking in the future value of produced CO_2 reduction credits at the start of a fuel decarbonisation project, the fuel project operator would be able to record a predictable and relatively guaranteed future cash flow on its balance sheet, which should make it easier for the operator to finance the project through loans or equity when compared to the much more uncertain future cash flow associated with the RED or the lower carbon price from the ETS.

While the purchase guarantee risk would greatly reduce uncertainty compared to relying on an unpredictable future credit market, some risk would still be borne by the project operator. Should the heavy duty manufacturer become unable to discharge its obligation to purchase credits, the fuel project operator would still be able to take advantage of value from the RED or ETS, or may be permitted to transfer the credit purchase opportunity to a different manufacturer (by mutual agreement).

2.5.ii) Alternative option – funds held in Escrow

An alternative contractual structure would involve the heavy duty manufacturer placing funds into an escrow account with a third party, such as a commercial or development bank. These funds would be transferred to the fuel decarbonisation project operator following surrender of rights to the CO_2 reduction credits from the project on the pre-agreed basis, using a pre-agreed credit price as in the case of the credit purchase guarantee described above. The sum deposited could reflect the full liability over the agreed project period, or might be structured to cover only an agreed number of years of payments, to be 'topped up' on a regular basis subject to successful delivery of the carbon credits. The rationale for the use of an escrow account is that it would provide an additional guarantee of future income for the fuel project operator, by addressing the risk that a manufacturer could depart the market (for instance no longer selling regulated HDVs, or through bankruptcy) without honouring the credit offtake agreement. In the event that the fuel project operator was unable to meet its credit generation obligation, money would be returned from the escrow account to the manufacturer (in addition to any other contractually agreed consequences of credit under-delivery).

The disadvantage to the manufacturer of structuring the agreement around such an escrow account would be that it would require a large upfront capital commitment, which would have an associated cost. This additional capital cost borne by the manufacturer might require reducing the agreed carbon credit price in the offtake agreement as compared to the appropriate price for a deal structured as a credit purchase guarantee.

2.5.iii) Alternative option – upfront payment or investment

One of the most difficult challenges for many advanced alternative fuels projects is raising the capital necessary to build large capital intensive facilities. One option to structure a credit offtake contract to maximise the value to a project developer trying to raise capital would be to agree either an upfront payment or an upfront investment by the HDV manufacturer

14 The simplest version of this arrangement would be to agree a defined credit price or prices for the duration of the agreement, but it would also be possible to relate the price for credit offtake to some other benchmark (e.g. the reported ETS credit price).

into a project[15]. In return for this upfront payment or investment, the HDV manufacturer would become entitled to the full amount of CO_2 credits generated over the agreed project lifetime, at no additional cost. Such an agreement would have the advantage to the project operator that it would completely remove any risk of future non-payment, but by the same token would load additional risk onto the HDV manufacturer, which may find it difficult to achieve compensation should the decarbonisation project fail. Due to this additional risk for the manufacturer, we would expect that the value of any upfront payment would be discounted as compared to the full value of a credit purchase guarantee with the same project. Such an agreement would therefore likely be of most benefit to project operators who would otherwise struggle to raise project capital.

2.6. Generating and redeeming credits

Once a project is registered, credit generation will be dependent on actual quantities of lower carbon fuels produced. For low-carbon fuel projects, monitoring of credit generation should use parallel mechanisms to existing reporting requirements under the Renewable Energy Directive. For refinery decarbonisation projects, monitoring of credit generation should use parallel mechanisms to reporting requirements under the ETS.

2.6.i) Low carbon fuel projects

For low carbon fuel projects (biomass-to-liquids or electrofuels) the rate of credit generation will depend on the rate of low carbon fuel production. Within the current EU legislative landscape, eligible low carbon fuel projects would produce fuel that would normally be counted towards compliance with renewable energy targets. For projects seeking instead to have fuel counted towards compliance with the heavy duty CO_2 standard, it is suggested that fuel volumes should first be reported and verified under the normal RED processes. This would prevent a duplication of reporting mechanisms, ensure that fuels produced were supplied in the EU and were available in principle for EU heavy duty vehicle fuelling[16], and ensure application of any applicable sustainability requirements.

While reporting the fuel under the RED would streamline the process in terms of using existing monitoring systems, it would create a requirement for the HDV manufacturer and project operator to make an arrangement with a registered fuel supplier under the RED legislation. Once the fuel had been supplied to the market, the fuel producer/supplier/regulated manufacturer should register an application with the appropriate Member State administrator to have the volume of fuel produced by the registered project counted into the manufacturer's average CO_2 emissions instead of towards the fuel supplier's RED obligation. This would therefore require that the fuel sale contract included an agreement for the fuel supplier to agree to the generated credits being retired from RED compliance in this way. In principle, it should be possible for confirmation that a fuel batch originated from a registered fuel decarbonisation

15 The case in which the HDV manufacturer is the owner of the project would be a special case of this.

16 In principle one could imagine a requirement to demonstrate that the produced molecules were supplied only for heavy duty applications rather than personal transport, but in practice such a requirement would be unduly burdensome and deliver no environmental benefit.

project to be added to the information recorded for sustainability monitoring, and thus minimise the need for additional data tracking.

Having identified a fuel batch for transfer from the RED 'account' to the heavy duty CO_2 'account', the total quantity of CO_2 emissions reductions delivered should be calculated as the product of the energy supplied (fuel volume multiplied by volumetric lower heating value) and the reportable carbon saving for the fuel pathway (calculated in accordance with the requirements of Article 28 of the recast Renewable Energy Directive).

Given that the recast Renewable Energy Directive does not anticipate this sort of credit transfer, a legally acceptable mechanism would be necessary. Ideally, given that there would likely be political resistance to amending the Renewable Energy Directive, this would be done through amendment of the proposed heavy duty CO_2 regulation. One approach to the legal framework would be a requirement in the heavy duty standard that any fuels generating credits for the heavy duty CO_2 standard should be disqualified from being counted towards fuel supplier renewable energy in transport targets under the Renewable Energy Directive, based on a formal application by the relevant fuel supplier. This mechanism could then be added to Member State RED implementations, ideally during transposition of the recast Directive. The potential problem with this approach is that it is not explicit in the RED that it is possible for a fuel supplier to ask for fuel to be opted out in this way, and therefore such a requirement could only be placed in the heavy duty standard if the relevant European Commission legal services agreed that it was legally possible without amendment of the RED itself. As an alternative to introducing a cancellation requirement of this sort, one could imagine ta requirement that rather than disqualifying a volume of fuel from being counted towards fuel supplier targets, that the fuel supplier target for renewable energy supply should instead be increased by the relevant amount. Adding a (small) additional target through the heavy duty standard may not require an amendment to the RED, even if creating a credit transfer mechanism would, but again the relevant European Commission legal services would need to agree that this was legally appropriate.

2.6.ii) Refinery decarbonisation projects

For refinery decarbonisation projects, such as green hydrogen or CCS, the rate of credit generation will depend on the avoided CO_2 emission. For CCS, this is the quantity of CO_2 captured and permanently sequestered. For green hydrogen, this is the amount of CO_2 that would normally be released by production of an equivalent amount of hydrogen by steam methane reforming, which could be assessed based on default assumptions in the JEC well-to-wheels analysis (Edwards et al., 2013).

Just as taking advantage of existing alternative fuel supply reporting mechanisms under the RED would minimise additional administrative burden for low carbon fuel projects, so it would be appropriate to take advantage of existing monitoring and verification mechanisms within the ETS for refinery decarbonisation projects. Most EU heavy duty fuel is refined within Europe, but some is imported – here we consider only the case of fuel decarbonisation projects within the EU. As the ETS is already built on a pan-European system of tradable credits, retiring credits from the ETS for use in compliance with the heavy duty standard should be administratively simpler than retiring batches of renewable fuel from compliance with the RED. Refinery operators would be required to retire additional ETS allowances[17] in proportion to the emissions to be considered for transfer into the heavy duty standard.

In general, emissions reduction delivered on refinery operations will result in reduced GHG intensity not only of heavy duty fuels (such as diesel and jet fuel) but also from other fuels produced by the refinery. Within the heavy duty CO_2 standard, it would be appropriate to limit credit generation to the fraction of carbon savings linked to the production of heavy duty fuels. It is therefore suggested that the carbon savings delivered by any refinery project should be divided between heavy-duty and non-heavy duty based on the fraction of eligible heavy duty fuels produced by the process(es) in question, on a lower heating value basis.[18] The savings associated on this basis with non-heavy duty fuels would be eligible to be counted towards the EU ETS as normal.

2.7. Resolving the case that a party to a credit offtake agreement fails to meet its obligations

In some cases, before a credit offtake agreement is concluded one of the parties may find itself unable (or unwilling) to meet its obligations. This could happen on the fuel project operator's side if, for instance, the project failed to generate the expected levels of emissions reductions, went out of business entirely or found that there was an unforeseen commercial advantage in producing a fuel not eligible to contribute to the heavy standard. On the manufacturer side, it could happen in the event that sales of regulated vehicles were lower than expected, if the manufacturer left the EU market entirely, or again if the manufacturer went out of business. In such a case, credit would only be given for demonstrably delivered lifecycle carbon savings from fuels. Legal liability for any resulting non-compliance with regulatory targets would remain with the regulated manufacturer, and that manufacturer would be solely liable for any resulting penalties unless shared financial liability was privately negotiated with the project developer.

To some extent, these risks are simply instances of the types of risks inherent in entering any long-term business agreement, and therefore the primary avenue to manage any such conflict would be robust contracting and, if necessary, the use of the civil courts to resolve disputes. There may, however, be opportunities for the administrators of the heavy duty standard to provide some degree of flexibility to reduce the disruption caused by such contractual issues. This could include enabling a 'secondary market' in credit offtake agreements, such that either by mutual agreement of the parties or following demonstrable failure of one party to meet its commitments the rights to generated CO_2 credits could be transferred from one HDV manufacturer to another.

2.8. Converting CO_2 credits into g/tkm compliance

While carbon reductions delivered by fuel decarbonisation projects will be recorded in tonnes

17 Given that the CO_2 savings from these projects would be taken out of the ETS system, these projects should also be excluded from the calculation of refinery ETS benchmarks (e.g. even if a CCS project delivered one million tCO_2e/year of savings from diesel fuel for the heavy duty standard, the refinery CO_2 benchmark would not be reduced by this amount.

18 Though other allocation approaches could be considered.

of avoided CO_2 emissions, the working unit of the heavy duty CO_2 standard is grams of CO_2e per tonne-kilometre (gCO_2e/tkm or equivalently g/tkm). If fuel credits are to be utilised for compliance with the heavy duty CO_2 standard, it will therefore be necessary to undertake an appropriate conversion. The conversion is rendered relatively simple by the fact that the regulated emissions ratings within the heavy duty CO_2 standard are adjusted using defined payload-mileage assumptions. The contribution to manufacturer compliance of credits from fuel decarbonisation projects may therefore be calculated as follows:

$$\Delta gCO2/tkm = -\frac{CO_2 saving\ in\ tonnes}{no.of\ vehicles \times lifetime} \times 0.6228$$

Where $\Delta gCO_2/tkm$ is the reduction in the manufacturer's average specific CO_2 emissions rating as defined in paragraph 2.7 of Annex I of the proposed heavy duty standard, $no.\ of\ vehicles$ is the number of new regulated HDVs sold in that year by the manufacturer, and $lifetime$ is the typical lifetime in years of a new HDV.

2.9. Duration of projects

The proposed heavy duty CO_2 emissions standard sets targets for 2025 and 2030, but under the draft the efficiency saving delivered in 2030 must be sustained thereafter indefinitely, so that carbon savings from fuel decarbonisation projects would continue to have value to manufacturers. In practice, it might reasonably be expected that further reductions in emissions targets will be set beyond 2030.

The types of investment that will be of most value in accelerating the decarbonisation of EU heavy duty fuel production will in many cases be long term investments with lifetimes of 20 years or longer. There is therefore a clear case to allow eligible fuel decarbonisation projects to generate credits for compliance in the heavy duty standards on a long-term basis, so that regulated manufacturers are able to fully integrate credits from fuel projects into their long-term compliance planning. On the other hand, the political and regulatory environment may change considerably even by 2030, and it would not be realistic to attempt to guarantee permanent recognition of credits from projects.

We suggest that credit generation from eligible projects should be granted for at least 15 years following project approval, in order to provide long-term value and to give manufacturers confidence to enter credit offtake agreements. For a project registered in 2025, this would mean that credits could continue to be generated for heavy duty CO_2 standard compliance until 2040. This would require either that the heavy duty standard is not amended until 2040, which is unlikely, or that the European Institutions should make sure to include the use of fuel decarbonisation credits from existing projects in any recast of the Regulation. It would be poor regulatory practice for good projects registered in good faith to have crediting opportunities removed before the stated crediting end date.

Beyond the end of the crediting period for projects registered under the 2030 Regulation, it might be appropriate depending on the policy landscape in effect at the time for credit generation by these projects to be extended within the heavy duty efficiency standard, but it may also be appropriate for credit generation from continuing projects to be reintegrated into other policy instruments.

3. Additional policy considerations

3.1. Using a registration cut-off date to accelerate investment

Part of the appeal of allowing fuel decarbonisation to be credited under the heavy duty standard is that by creating a more concrete value proposition for fuel decarbonisation projects than is currently available from the RED or ETS, it could accelerate first of a kind commercial scale technology deployment, and thus act as a catalyst for wider development of similar projects outside of the heavy duty CO_2 framework. This role of the framework as a catalyst would be enhanced by projects becoming operational as soon as possible within the regulated period, moving the technologies closer to 'nth of a kind' deployment (cf. Peters, Alberici, Passmore, & Malins, 2016). Fuels Europe (2018b) proposes that, "The option to enter this kind of contract would be time-limited, so as to incentivise early adopters who would establish the first plants and get them running."

In setting a time-limited registration window it would be important to balance the desire to encourage rapid project development with the need to allow adequate time for heavy duty manufacturers to determine their compliance strategies and for projects to be conceived and developed. An initial suggestion would be to close the project registration window in 2025, coinciding with the first year of a binding emission reduction target in the heavy duty standard. This would give six years for projects to be agreed and registered (assuming that the framework is in place by the end of 2019), and allow projects to become operational in advance of 2030. If a system of fuel decarbonisation crediting was successful in contributing to the 2030 targets, it may be possible to open a second project registration window for the following decade if and when 2040 efficiency targets are agreed. While there is a clear case for setting an end date for project registration in this way, such a measure may also limit project development and would reduce the flexibility offered to manufacturers by the system, and should therefore be considered and consulted on before a final decision was made.

3.2. Support for aviation fuel production

Chemically speaking, aviation fuel is composed of similar molecules to road diesel, and indeed the molecules blended to produce aviation fuel could generally be blended into standard compliant road diesel. The technologies available to reduce the lifecycle carbon intensity of aviation fuel production are therefore much the same as those available to reduce the lifecycle carbon intensity of diesel for heavy duty road transport. As noted in the introduction, part of the context for the proposal to allow some fuel decarbonisation projects to contribute to compliance with the heavy duty vehicle efficiency standard is the expectation that demand for heavy duty road fuels can and will not be eliminated entirely by electrification, even in the relatively long term. The same is true, likely on an even longer term basis, for demand from aviation for liquid fuels.

Given that the technologies developed to produce low carbon synthetic diesel fuels are broadly similar to those required to produce low carbon synthetic jet fuels, and that refinery decarbonisation through green hydrogen and CCS will benefit jet fuel production alongside diesel production, and that many Member States see low carbon aviation fuels as a long-term policy priority, it might be considered reasonable to count carbon savings delivered in the jet fuel supply in addition to those delivered in the diesel supply. While this would have the implicit effect of allowing some carbon savings delivered in aviation fuel to be accounted as heavy duty vehicle efficiency gains, which might be considered counter-intuitive, such an approach would certainly be consistent with long-term decarbonisation priorities.

3.3. Taking advantage of EU refining capacity and expertise

Several fuel decarbonisation options discussed in this paper have the potential to utilise existing equipment and infrastructure within the EU refinery industry. This is obvious for the refinery decarbonisation options discussed, but is also relevant for the case of novel low carbon fuels. For example, upgrading paraffinic FT waxes from either electrofuel processes or biomass to liquids processes into blend ready diesel fuels could utilise existing refinery units, either through retrofitting or co-processing. Similarly, several refinery units might be able to co-process pyrolysis oils as renewable feedstock. As demand for liquid fossil fuels reduces due to efficiency improvements and electrification, increasing renewable throughput at existing refineries offers and opportunity to reduce commercialisation costs for advanced renewable fuels by taking advantage of existing assets, while safeguarding high quality EU jobs.

3.4. Flexible opt-in

As discussed above, the types of decarbonisation projects that might be considered for eligibility to count towards heavy duty CO_2 standards would normally generate credit towards compliance with existing incentives, notably the RED and EU ETS. The excess emissions charge under the heavy duty CO_2 standard is equivalent to about 300 €/tCO_2e, which is significantly higher than current or expected CO_2 prices within the ETS, but comparable to the implied carbon price from Member State implementations of the Renewable Energy Directive. Depending on the realised costs of efficiency improvements in the heavy duty fleet, the rate of increase of zero- and low- emission heavy duty vehicle sales and the marginal price of compliance with other legislation, it is plausible that a manufacturer might find that carbon savings from an approved fuel decarbonisation project were no longer necessary for its heavy duty CO_2 standard compliance strategy, and might have more regulatory value within another legislative framework.

In such a case, we see no reason to insist that all credit generated by a registered project must be counted into the heavy duty CO_2 standard if there is mutual agreement between the parties to the credit offtake guarantee contract that those savings could better be recorded within a different policy. For a low carbon electrofuel project, for instance, within the existing legislative framework there would be no reason to insist that the produced fuels be disqualified from the RED and counted instead into the heavy duty CO_2 standard if the contracted parties preferred to have them counted into the RED after all. It should be emphasised though that such a decision must be consensual between the contracted parties – the contractual credit-offtake guarantee should be binding both ways, giving the regulated manufacturer both the obligation and the right to offtake produced credits in line with the contractual terms.

4. Supporting fuel decarbonisation projects

In the introduction, we noted that the implied carbon price of the excess emissions charge under the heavy duty CO_2 standard is 282 €/tCO_2e, assuming that all regulated heavy duty vehicles have a 15 year lifetime. In practice, the value to the manufacturer of engaging in a fuel project will also be limited by the expected cost of the other compliance options available – if manufacturers expect to achieve their targets with investments that are much less costly than the excess emissions charge, they are less likely to commit to costly credit offtake guarantees with fuel projects. Even if fuel decarbonisation crediting is introduced under the heavy duty standard, it would not be guaranteed that fuel producers would be able to access the maximum CO_2 price implied by the excess emissions charge.

A second factor that could limit the willingness of heavy duty vehicle manufacturers to use fuel decarbonisation credits for compliance with the standard is the relationship between vehicle efficiency and vehicle sales price. More efficient vehicles will generally cost more to manufacture, but will also deliver long term cost savings to the vehicle owners. The impact analysis of the proposed regulation for the European Commission (European Commission, 2018b) suggests that in general purchasing more efficient vehicles can be cost negative due to the longer term fuel savings. If the full cost of producing more efficient vehicles could be recouped by manufacturers in increased sales prices, this would reduce the appeal of flexible compliance options for the standard. While it may appear economically rational for heavy duty vehicle purchasers to be willing to pay more for more efficient vehicles, it must also be recognised that there are currently barriers that prevent the market alone from delivering increased efficiency – after all, this is why a standard has been proposed. Work by the ICCT (Sharpe, 2017) highlights four barriers that have previously delayed adoption of efficiency technologies: uncertainty about technology performance; capital restraints; split incentives; and lack of technology availability in specific markets. The first three of these barriers may all reduce the ability of manufacturers to fully recover the cost of improving vehicle efficiency.

The likelihood that fuel decarbonisation credits will be appealing as a compliance option under the heavy duty standard can be explored by considering expected manufacturing costs for more efficient vehicles. The JRC developed heavy duty CO_2 emissions reduction cost curves for various vehicle subgroups as part of the Commission's impact assessment for the standard (Krause & Donati, 2018), and these are taken as the starting point for assessing the potential appeal of fuel decarbonisation credits. The underlying analysis that is the basis for the results discussed in this section is discussed in more detail in Annex B.

Based on the 'typical' cost curves documented in that analysis, delivering full compliance with the 2030 standard for diesel HDVs in any subgroup would have an associated marginal implied carbon price[19] to manufacturers of up to 150 €/tCO_2e (though for moving to LNG fuelled vehicles as a compliance option the marginal implied carbon price is up to 270 €/

19 The 'marginal implied carbon price' refers to the carbon price in €/tCO_2e that would be required to cover the additional manufacturing costs of delivering more efficient vehicles beyond a given point. As the JRC model the cost of emission reductions as a hyperbolic curve, it is expected that the marginal cost of delivering the last few percentage points of emission reductions to meet the Regulation will be higher than the cost of delivering the first few percentage points.

tCO_2e). A 30% efficiency improvement by 2030 compared to a 2016 baseline[20] is achievable for 6 of the 8 vehicle subgroups[21]. If compliance can indeed be delivered by manufacturers for the typical per-vehicle costs detailed by JRC, fuel projects would be unlikely to be attractive at a carbon price of much above 100 €/tCO_2e.

While this is the case for the JRC's typical scenarios, the JRC also provide a high cost scenario, which is described as being closer to cost estimates provided by the manufacturing industry itself. Marginal implied carbon prices in the 2030 high cost scenario from the JRC are above the implied carbon price of the excess emissions charge for all classes of diesel[22] vehicle for further emissions reductions beyond 25%, as shown in Table 1, with a marginal implied carbon price as 800 €/tCO_2e for the final efficiency improvements on class 10-RD vehicles and diesel vehicles in classes 5-LH, 10-LH, 4-LH, 5-RD and 9-LH identified as unable to meet the regulatory requirement. It is clear therefore that if the high cost scenario reflects manufacturers' internal analysis of their compliance options there could be considerable interest in flexible compliance options to meet the final few percentage points of the regulatory requirement.

Table 1. Marginal implied carbon price for emission reductions beyond given percentage in JRC high cost scenario for diesel vehicles in 2030

	20%	22%	24%	26%	28%	30%
Class 4 - RD	€ 148	€ 192	€ 251	€ 331	€ 443	€ 610
Class 5 - LH	€ 188	€ 259	€ 363	€ 524	n/a	n/a
Class 9 - RD	€ 153	€ 197	€ 252	€ 323	€ 419	€ 549
Class 10 - LH	€ 161	€ 221	€ 307	€ 437	€ 650	n/a
Class 4 - LH	€ 159	€ 247	€ 410	€ 767	n/a	n/a
Class 5 - RD	€ 237	€ 298	€ 375	€ 473	€ 601	n/a
Class 9 - LH	€ 110	€ 160	€ 245	€ 400	€ 735	n/a
Class 10 - RD	€ 235	€ 297	€ 375	€ 477	€ 610	€ 792

Pink cells indicate where the marginal implied carbon price is above the implied carbon price of the excess emissions charge. "n/a" indicates that the JRC high cost scenario does not consider it possible to deliver this level of emission reduction for a given vehicle class in 2030.

The values in this table are not adjusted for cost pass through into retail prices (see Annex B for further discussion).

Given the administrative overheads of entering into a credit offtake guarantee agreement we would not expect manufacturers to be willing to enter deals at the full implied carbon

20 Note that the JRC analysis considered a 2016 baseline vehicle whereas the regulation will require improvements compared to measured 2019 heavy duty efficiencies.

21 The other two subgroups are assessed as able to reach a 28% improvement with the technology options assessed. Under the current standard, the remaining obligation could be met by over complying in other vehicle classes.

22 In some cases switching to an LNG fuel supply is identified as the best-value option for full compliance in the high cost scenarios, but we assume that LNG fuelled vehicles will remain a market niche to 2030 and thus do not consider these options in detail in this report.

price of the excess emission charge, but credits offered at anything below 200 €/tCO_2e could offer significant compliance savings to truck manufacturers compared to paying the excess emissions charge. A carbon price of 200 €/tCO_2e is significantly higher than the ETS carbon price, but comparable to the implied carbon prices already available for renewable fuel supply under national implementations of the Renewable Energy Directive.

An implied carbon price for renewable fuel supply can be calculated by consideration of reported prices for renewable fuel supply certificates and the reportable emission savings required for those fuels. For instance, in the Netherlands reported HBE (Dutch renewable fuel supply certificate) prices are consistent with an implied carbon price of around 200 €/tCO_2e. In the UK, reported RTFC (Renewable Transport Fuel Certificate) prices are consistent with an implied carbon price of the order of 150 €/tCO_2e for first generation biofuels. The potential value of advanced biofuel and electrofuel incentives under renewable fuel policy could be even higher. For example, the new 'development fuels' mandate in the UK system (UK Department for Transport, 2018) provides a ring-fenced target and thus an enhanced value signal for specified advanced biofuels and electrofuels. The 'buy-out' price on the development fuel target is effectively £1.60 per litre of fuel. If development credits were traded at just below the buy-out price it would provide an implied carbon price on those fuels of up to 750 €/tCO_2e.

While the nominal value of support for low carbon fuels projects if made creditable under the heavy duty standard may be similar to or below the nominal value under the RED, additional value certainty may make crediting under the heavy duty standard very appealing. As noted above, existing policy under the RED has suffered from an inability to provide long-term value confidence to investors, and so even at a comparable nominal value it is possible that crediting within the heavy duty CO_2 standard may be significantly more appealing for high capital expenditure projects, due to the opportunity to lock in a credit-offtake agreement.

4.1. Potential for a mechanism in the heavy duty standard to drive investment in lower carbon fuels

The potential value of CO_2 emission reductions under the heavy duty CO_2 standard can be compared to available estimates of the cost of specific fuel decarbonisation projects to provide an indication of whether the support mechanism proposed would be likely to be able to drive investments. Table 2 provides low-end values from credible literature for the carbon price required to develop various fuel decarbonisation projects in the near-term. In general, we would expect costs for such projects to fall as we move from the first few projects to *n*th of a kind projects. A comprehensive review of any of these technology costs is beyond the scope of this paper, and thus these numbers should be treated simply as indicative of the possibility of providing support for such projects through the heavy duty CO_2 standard. These are low-end estimates, and for each technology it would be possible to find higher (in some cases much higher) estimates on required carbon price. Note also that the studies quoted do not give high and low cost estimates on a consistent basis, and thus the values quoted from different studies should be directly compared only with caution and with reference to the details of the underlying studies.

Table 2. Indicative carbon price required for project development

Technology		Minimum required carbon price, €/tCO_2e	Source
BtL	Pyrolysis (co-processing)	64	SGAB[a]
	Pyrolysis (standalone)	207	SGAB[a]
	Gasification and FT	222	SGAB[a]
Electrodiesel		330*	Cerulogy[b]
Refinery green hydrogen		190**	IEA[c]
Refinery CCS	SMR	60	IEA[c]
	General	141	IEA GHG[d]

Notes:

**Of the pathways considered, electrofuel production has the widest range on cost estimates, reflecting the high sensitivity to electricity price. The lowest required carbon price estimate from the literature documented by Cerulogy is as low 83 €/tCO_2e, but is not considered credible except for exceptional cases of very ow or negative cost electricity. The value given in the table is derived from the reference case for 2030 with 5 €cent/kWh electricity taken from* Brynolf, Taljegard, Grahn, & Hansson (2017).

** *For electricity price of 10 €cent/kWh.*

a. (Sustainable Transport Forum sub group on advanced biofuels, 2017)

b. (Malins, 2017)

c. (Körner et al., 2015)

d. (IEA GHG, 2017)

Notwithstanding the inevitable uncertainty relating to the carbon price required to drive novel projects, the positive take away from the table is that for most of the project types considered the quoted required-carbon-price is around 200 €/tCO_2e or lower. This suggests that the value signal from the heavy duty CO_2 standard could be enough to drive investment in projects of this sort. Only the value quoted for electrodiesel is above the carbon value of the excess emissions charge. This suggests that it may be unlikely for electrodiesel projects to be funded through the proposed mechanism. It should be noted however that the range on cost estimates for electrofuel projects in the literature is very wide indeed, and highly sensitive to electricity price. If electricity could be obtained at low price by an electrofuel project (e.g. by avoiding curtailment at a grid bottleneck) it may be possible for a small number of projects to be developed much more cheaply. In particular, whereas wholesale EU electricity prices are significantly above the level at which electrofuels could be competitive, it may be possible to develop solar electricity projects in parts of the tropics with lower levelised renewable electricity generation costs (due in part to higher insolation) but where it is challenging to connect into existing electricity markets, and where electrofuel production and export would therefore be particularly appealing (Schmidt, Zittel, Weindorf, & Raksha, 2016).

4.2. Project examples

In this section, we provide simple worked examples of two cases in which fuel decarbonisation projects could be appealing as compliance strategies for part of a manufacturer's CO_2 emission reduction obligation, based on estimates from the literature of the cost of the projects and cases from the JRC heavy duty vehicle emission reduction cost curves (Krause & Donati, 2018) for the cost of compliance through efficiency improvements. The examples given in the analysis are simplified by assuming that manufacturers produce only certain classes of vehicle, and therefore ignoring the potential to over-comply with some vehicle classes to compensate for more difficult to decarbonise classes. The examples should therefore only be treated as illustrations of how a business case for a fuel decarbonisation project could emerge at the manufacture level, rather than as predictions of actual manufacturer-level outcomes. The analysis also does not address the potential cost of ZLEV manufacture as a compliance strategy, and assumes that the sales price of HDVs is insensitive to the CO_2 emissions rating. Additional research with input from the truck manufacturer, refining and advanced alternative fuels industries would be useful to confirm (or refute) the validity of these examples.

The examples are based on the analytical framework described further in Annex B, including the assumptions detailed on the ability of manufacturers to pass through increased costs in retail vehicle prices. The potential to support fuel decarbonisation projects in these examples is expressed through the carbon price – where we show that a truck manufacturer may be willing to guarantee credit offtake at a price around or above the carbon price reported in the literature as necessary to support a fuel decarbonisation project, we assume that such a credit offtake agreement could support development of a project. The examples also do not explicitly consider the temporal relationship between an increasing supply of fuel decarbonisation credits and the increasingly stringent regulatory requirements on heavy duty manufacturers, assuming that where credits have a clear value in 2030 they will also have value in meeting interim targets and ongoing targets. A more sophisticated model could be developed to try to take these temporal dynamics better into account, but given the many uncertainties involved in such an assessment we do not believe that it would affect the core conclusion – that there are likely to be some truck manufacturers who would see value in fuel decarbonisation credits, but that the truck manufacturers themselves will be best placed to assess the precise value to them of such credits given other details of their regulatory compliance strategies.

4.2.i) Example 1: Class 5 HDV manufacturer and BtL FT diesel project

In this example, consider a manufacturer of diesel powertrain Class 5 heavy duty vehicles whose expected costs to deliver CO_2 emissions reduction for new vehicles match the 'high' cost scenario as presented by Krause & Donati (2018). For long haul class 5 vehicles (5-LH), the 'high' JRC diesel cost curves show a maximum potential emission reduction of 26%, at a cost of 32,000 € per vehicle. For regional delivery Class 5 vehicles (5-RD), the maximum achievable emission reduction is given as 28%, at 34,000 € per vehicle.

For both of these classes, the marginal additional cost of delivering further emissions improvements rises above the cost of the excess emissions charge (minus assumed cost pass-through) before the 2030 target would be achieved. This is true for additional emissions savings beyond 24%. This hypothetical manufacturer may therefore see a business case to use fuel decarbonisation credits to meet the remainder of the requirement for both vehicle classes, provided they were priced appropriately.

For a manufacturer with 1,800 annual Class 5 sales, split evenly between 5-LH and 5-RD, closing this emissions gap would require 250,000 tonnes a year of CO_2 reduction credits. This level of carbon savings from substitute diesel fuels could be generated by a 110 million litre a year BtL Ft facility producing 75% of output as diesel and working at full capacity. Given that the heavy duty vehicle manufacturer takes on some administrative overheads and a degree of risk by relying on credits from future fuel production by a new facility, we would expect that any credit offtake contract would be based on a lower agreed carbon price than the implied carbon price of the excess emissions charge, for example 200 or 150 €/tCO_2e. For a contracted carbon price of 200 €/tCO_2e, around the level considered necessary to bring these projects to market, a commitment to offtake the full number of CO_2 reduction credits would be worth €50 million a year when at full capacity, equivalent to 62 €cent per litre of renewable diesel produced. The heavy duty manufacturer could save up to €20 million a year by using credits at this price instead of paying an excess emissions charge.

Assuming that full capacity is reached after five years of operations, over a 15 year period this would represent a €500 million financial commitment. The present value of the commitment to the fuel producer calculated on a discounted cash flow basis with a 10% discount rate[23] and assuming three years to build the facility after contract agreement and five years to reach nameplate capacity would be around €230 million. This compliance value is in addition to the value of actually selling the produced fuel. Peters et al. (2016) put the capital requirement for an FT facility of this size at around €400 million. Such a significant and contractually guaranteed additional income stream from delivered carbon savings on top of the value of the fuel itself would therefore provide a strong signal in favour of project development, and would be expected to have considerable value in attracting investment. The carbon price of 200 €/tCO_2e is somewhat below the maximum potential value signal under an advanced biofuel target, but having a confirmed carbon price locked in over 15 years is likely to make this framework more valuable on a net present value basis to project developers than a future market for renewable fuel credits with a potentially higher price but much lower price certainty.

4.2.ii) Example 2: Class 10 diesel vehicle manufacturer and refinery CCS project

For the second example, consider a manufacturer of Class 4 and Class 10 HDVs whose expected costs to deliver CO_2 emissions reduction for new vehicles again match the 'high' cost scenario as presented by Krause & Donati (2018). The marginal cost of delivering emissions reductions beyond about 20%[24] for these vehicles is higher, however, than the estimated carbon price required for refinery CCS projects detailed in Table 2 (141 €/tCO_2e).[25] There may therefore be interest from truck manufacturers in utilising the flexibility of a fuel decarbonisation crediting option through refinery CCS to reduce compliance costs.

23 The appropriate discount rate for a given fuel decarbonisation project will depend on the financial characteristics of the operators, 10% is used here as an example to illustrate the potential benefit of a firm credit offtake agreement for project balance sheets.

24 Specifically, beyond 21% for class 4-RD, beyond 20% for classes 10-LH and 4-LH, and beyond 18% for 10-RD.

25 Also for Class 4-LH, Class 5-RD and Class 5-LH.

IEA GHG (2017) present a range of refinery CCS cases, varying in refinery size and complexity and in the set of refinery units for which CCS is assumed. The largest projects could deliver up to 2 $MtCO_2e$ of emission reduction per annum. Here we consider a smaller project as an example, the installation of CCS for the power plant of a medium complexity refinery, delivering about 460,000 tCO_2e of emissions reductions per year (a bit over 20% of total refinery CO_2 emissions), at a carbon price of 150 €/tCO_2e, requiring about €350 million of capital expenditure (comparable to but less than the capital requirement for the BtL FT facility discussed above).

The 460,000 tCO_2e savings from this CCS project would be sufficient to cover the last 10 percentage points of the CO_2 emissions reduction requirement for a manufacturer selling 3,600 HDVs annually split evenly across classes 10-RD, 10-LH, 4-RD and 4-LH. Such a credit offtake agreement would be worth about €70 million a year to the refiner.

4.3. Is there a case for differentiated support?

Two of the cost estimates quoted in Table 2 are significantly below the others – those for pyrolysis diesel via co-processing, and for CO_2 capture from the steam methane reformer (SMR). Recognising that hierarchy, while also noting the caveats about uncertainty and data comparability given above, it is reasonable to consider whether there is a case for differentiated levels of support depending on project type. Within biomass to liquids projects, the expected environmental performance of pyrolysis and FT diesel production are comparable. From a technology development point of view, however, the FT fuel synthesis technology requires further development and commercialisation (at the scale appropriate to gasification plants, at least), whereas by definition co-processing pyrolysis oils uses existing refinery units with and well commercialised technologies (although there remain metallurgical challenges and risks in handling acidic pyrolysis oils in existing facilities that must not be overlooked). FT synthesis technologies have a potential long term role in both biomass to liquids and electrofuels, and there are potential applications for small scale FT synthesis in reducing natural gas venting and flaring. One could therefore make a case that the gasification and FT pathway has a larger co-benefit from technology commercialisation, and that enhanced support would be justified as compared to the pyrolysis pathway.

Within refinery decarbonisation projects, the lowest quoted required carbon price is for carbon capture at the SMR unit (SMR-CCS). Green hydrogen from electrolysis is a technology that is arguably in competition with SMR-CCS as two alternative pathways for decarbonising hydrogen production. Increasing hydrogen production from electrolysis has the potential to have knock on benefits for technology development in electrolysis and the hydrogen economy more generally, and is potentially a zero carbon technology as against SMR-CCS as a low carbon technology[26]. Installing SMR-CCS, however, could have knock on benefits for development of CCS technology more broadly. If a high level of priority is placed upon developing electrolysis as the primary building block of an enlarged the hydrogen economy, then a case could be made that enhanced support would be justified for green hydrogen from electrolysis as compared to installing SMR-CCS.

26 It is not practical to capture 100% of CO_2.

5. Role of fuel decarbonisation investments in the longer term EU climate strategy

Above, it is noted that several technologies in need of development for the implementation of the fuel decarbonisation projects discussed may have a large role in the long-term decarbonisation of the EU economy, and that therefore accelerating the development of those technologies may have significant co-benefits for EU decarbonisation. In particular, deployment of the technologies discussed will be dramatically accelerated once there are a number (say a dozen or so) commercially operational and successful projects in each group for investors to refer to. If fuel decarbonisation crediting under the HDV standard could help catalyse some of these first of a kind successes, the knock on benefits could be much greater than the carbon savings delivered by the first of a kind projects themselves.

Here, we link those technology developments directly to the EU strategic long-term vision for a decarbonised economy (European Commission, 2018a). The strategy identifies seven 'building blocks' for action; of these the technologies discussed here are relevant to:

> *Building block 2: Maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply*
>
> *Building block 3. Embrace clean, safe and connected mobility*
>
> *Building block 4. A competitive EU industry and the circular economy as a key enabler to reduce greenhouse gas emissions*
>
> *Building block 6. Reap the full benefits of bio-economy and create essential carbon sinks*
>
> *Building block 7. Tackle remaining CO_2 emissions with carbon capture and storage*

5.1. Building block 2: Maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply

Under this building block, the strategy states that,

> *"The competitive deployment of renewable electricity also provides a major opportunity for the decarbonisation of other sectors such as heating, transport and industry, either through direct use of electricity or indirectly through the production of e-fuels through electrolysis (e.g. e-hydrogen), when direct use of electricity or sustainable bio-energy is not possible."*

The development of electrolysis technology using renewable electricity, whether for green hydrogen use at the refinery, directly for electrofuel production, or as an energy storage solution, has a clear role to play in delivering this goal. The strategy also identifies "natural gas steam reforming using Carbon Capture and Storage" as a potential hydrogen source for the decarbonised economy.

5.2. Building block 3. Embrace clean, safe and connected mobility

Reinforcing the points made in the introduction to this report, the strategy notes that,

> *"Electrification using renewables alone will not be the single silver bullet for all transport modes. Batteries have so far a low energy density, and for now their high weight makes the technology ill-suited for aviation and long distance shipping. Also for long-haul trucks and coaches it is currently unclear whether batteries will reach the required cost and performance level. … Until we see emerge new technologies that will allow to electrify more modes than today, alternative fuels will be important."*

The development of low carbon biomass to liquids fuels and electrofuels fits clearly within this building block, while the strategy notes that, "Aviation must see a shift to advanced biofuels and carbon-free e-fuels", which supports the suggestion above that it might be appropriate to allow the production of low carbon aviation fuels to be used to generate credits.

5.3. Building block 4. A competitive EU industry and the circular economy as a key enabler to reduce greenhouse gas emissions

The strategy notes that,

> *"Becoming greenhouse gas emissions free will often mean significantly modernising existing installations or completely replacing them. This investment will constitute part of the next industrial revolution."*

As noted above, several of the fuel decarbonisation options discussed in this report provide the potential to take advantage of existing refining installations and the expertise and jobs associated with them. The strategy notes that, "Instead of fossil fuels, both renewable hydrogen and sustainable biomass can be a feedstock for a number of industrial processes, such as steel production and certain chemicals." The development of fuel synthesis from hydrogen (whether from biomass gasification or electrolysis) can support the development of renewable chemicals, building on existing complementarity between the refining and chemicals industries.

5.4. Building block 6. Reap the full benefits of bio-economy and create essential carbon sinks

The strategy recognises the tension between the opportunity for increased biomass use and the limited supply of biomass,

> *"A biomass-based transition is limited by the availability of land. Depending on the biogenic material from which the biomass is produced, the impacts on land use, the EU natural sink, biodiversity and water resources can differ substantially. The transition of our economy will always have to be careful how to make best use of scarce land*

> *and other natural resources and ensure that biomass is only used in the most efficient and sustainable way."*

The development of biomass to liquids technologies using waste and residual biomass provides an opportunity to increase the use efficiency of the EU's existing biomass production (cf. Harrison et al., 2014). Developing CCS technologies is also a necessary precondition to successful future deployment of bioenergy with CCS as a power generation and carbon sequestration option.

5.5. Building block 7. Tackle remaining CO_2 emissions with carbon capture and storage

The strategy acknowledges that CCS has a major role dealing with CO_2 emissions that would otherwise be difficult to eliminate,

> *"CCS deployment is still necessary, especially in energy intensive industries and – in the transitional phase - for the production of carbon-free hydrogen. CCS will also be required if CO_2 emissions from biomass-based energy and industrial plants are to be captured and stored to create negative emissions. Together with the land use sink, it could compensate for remaining greenhouse gas emissions in our economy."*

However,

> *"CCS has not yet reached the commercialisation stage, hampered by lack of demonstration of the technology and economic viability."*

Deploying CCS at the refinery as a fuel decarbonisation option could support the broader commercialisation of the technology, accelerating deployment in other applications.

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Annex A. Estimation of the implied carbon price in the heavy duty CO_2 standard

The targets in the heavy duty CO_2 standard are set at the manufacturer level in terms of grams of carbon dioxide per tonne kilometre (gCO_2/tkm) per vehicle. The target reportable emissions reductions by year are detailed in Table A, leading up to a 30% emissions reduction by 2030.

Table A. Rated emissions reduction requirements by year

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Emissions reduction	0%	3%	5%	8%	10%	13%	15%	18%	21%	24%	27%	30%

From 2019 to 2024, manufacturers are able to earn emissions credits for use against their 15% 2025 emissions reduction requirement by achieving emissions below the annual targets detailed in the table, but there is no penalty for exceeding the stated trajectory in those years. In 2025, the 15% target must be met, including counting any emissions credits earned in the preceding years (these early credits may not be used beyond 2025). In the years 2025 to 2028 it is possible to acquire either credits or debts, depending on whether emissions are below or above the target trajectory. The 2029 target must be met, using credits if there are credits available, and the 2030 target must be met absolutely with no use of credits. The Regulation proposes a set excess emissions charge of 6800 € per gCO_2/tkm per vehicle to be imposed on manufacturers failing to meet targets in 2025, 2029 or 2030, or exceeding a maximum emissions debt in the years 2026 to 2028.

Given that the targets and associated excess emissions charges are expressed in terms of gCO_2/tkm per vehicle, on first glance it may appear difficult to integrate into the standard crediting for emissions reductions measured in absolute tCO_2 terms. This unit inconsistency can be overcome, however, by consideration of the default assumptions given in the Regulation for the average kilometres travelled and tonnage for each category of vehicle, and by making a reasonable assumption about the lifetime of a new heavy duty vehicle.

Consider the case of a manufacturer producing only vehicles in the category 5-LH (long – haul tractors with a 4x2 axle configuration). In practice manufacturers will generally produce vehicles across several categories, but for illustrative purposes we use a simplified example. The JRC report (Tansini & Zacharof, 2018) an estimated average baseline emissions value for these vehicles of 66 gCO_2e/tkm[27]. The Regulation states gives an assumed average tkm per 5-LH vehicle of 1,605,672, and so each of these vehicles is expected to emit 105 tonnes of CO_2 per year. A 30% emission reduction for these vehicles would require reducing the

27 While we include this estimated baseline for the illustration, and the calculated 2019 baseline for vehicles of this type is likely to be slightly different, note that the carbon price implied by the excess emissions charge is insensitive to the calculated baseline emissions values.

emissions intensity to 46 gCO_2/tkm, and thereby reducing expected emissions by 32 tCO_2 per vehicle. Over a vehicle lifetime of 15 years (as used in the cost analysis by the JRC in Krause & Donati, 2018), that gives 474 tCO_2 reductions delivered by an emissions intensity reduction by 20 tCO_2e/tkm.

If, however, these emissions reduction were not achieved, the manufacturer would be liable to an excess emissions charge of €134,000 per vehicle sold. This gives an implied carbon price, given the assumptions made about lifetime and activity, of 282 €/tCO_2.

This carbon price emerges from consideration of a fleet made solely of 5-LH vehicles, but what about other vehicle categories? The Directive includes a set of mileage and payload weighting factors relative to the 5-LH vehicles[28] that are used to adjust the reportable emissions intensity values for other categories, and these weighting factors compensate for the differences in activity profiles such that the implied carbon price comes out the same for all vehicle categories, provided the lifetimes are the same. This is shown in Table B.

Table B. Emissions reductions and implied carbon price for regulated vehicle categories

	Estimated baseline CO_2 emissions	Mileage and payload weighting factor	Adjusted CO_2 emissions	2030 target (for adjusted CO_2 emissions)	tkm per vehicle	tCO_2 reduction per vehicle	Cost of non-compliance per vehicle	Implied carbon price (€/tCO_2)
4-UD	254	0.10	25.2	17.6	159000	178	€ 51,368	282.3
4-RD	209	0.15	32.2	22.6	248040	146	€ 65,782	282.3
4-LH	128	0.45	57.9	40.6	727160	90	€ 118,184	282.3
5-RD	87	0.50	43.4	30.4	800124	61	€ 88,574	282.3
5-LH	66	1.00	65.7	46.0	1605672	46	€ 133,951	282.3
9-RD	116	0.29	33.0	23.1	458440	81	€ 67,343	282.3
9-LH	77	0.90	69.0	48.3	1447200	54	€ 140,699	282.3
10-RD	90	0.43	39.2	27.5	697544	63	€ 80,035	282.3
10-LH	68	0.92	62.7	43.9	1481094	48	€ 127,950	282.3

The calculation used above to calculate the equivalent carbon price to the excess emissions charge set by the Regulation can be reversed to convert an absolute CO_2 reduction into an equivalent reduction in adjusted CO_2 emissions per vehicle using the following formula:

28 The values are normalised to the 5-LH category because 5-LH vehicles have the highest expected tkm activity.

$$Fuel\ credit\ \left(\frac{\Delta gCO2}{tkm}\right) = -\frac{CO_2 saving\ in\ tonnes \times 1000000}{no.of\ vehicles \times lifetime \times tkm\ per\ 5LH\ vehicle}$$
$$= -\frac{CO_2 saving\ in\ tonnes}{no.of\ vehicles \times lifetime} \times 0.6228$$

which reduces assuming a 15 year vehicle lifetime to

$$Fuel\ credit\ \left(\frac{\Delta gCO2}{tkm}\right) = \frac{CO_2 saving\ in\ tonnes}{no.of\ vehicles} \times 0.04152$$

In this way, it would be possible to convert a carbon reduction credit from a fuel project into a defined contribution to a manufacturer heavy duty CO_2 target. Note again that this credit should be applied to the mileage and payload adjusted CO_2 emissions result (which is the value regulated) rather than the actual CO_2 emissions value for any single vehicle category (excepting 5-LH for which the actual and adjusted emissions ratings are identical).

It should be noted that compliance with the heavy duty CO_2 standard can be aided by the generation of 'super credits', awarded to manufacturers for sales of very low or zero emissions vehicles (ZLEVs). The super credits provide multiple counting of the emissions values for ZLEVs into the manufacturer averages, giving these vehicles extra compliance value. Manufacturers of zero and low emissions vehicles may also apply a ZLEV factor to their adjusted average emissions value, calculated as the ratio of the number of vehicles without super credits divided by the number of vehicles counting super credits (this value is limited between 0.97 and 1). In order to avoid implied multiple counting of carbon reductions delivered from fuel decarbonisation projects, we proposed that any adjustment to manufacturer average emissions from fuel decarbonisation credits should be made before application of the ZLEV factor, so that the equation in Article 2.7 of Annex 1 of the Regulation would become:

$$CO\_2[g/tkm] = ZLEV \times \left(\left[\sum\nolimits_{sg} share_{sg} \times MPW_{sg} \times avgCO2_{sg}\right] - Fuel\ credit\right)$$

Annex B. Analysis of JRC cost curves

The JRC (Krause & Donati, 2018) present cost curves for improving the efficiency of vehicles across 8 class/payload combination with both diesel and LNG as fuel, for 'typical', 'medium' and 'high' cost cases in 2025 and 2030. The cost curves are derived from curve fitting to estimated cost of specific technology additions, with the functional form:

$$Cost = C + {}^{c}/_{(x - x_0)} + bx$$

Where C, c, x_0 and b are constants. The curve is asymptotic at x_0, which is the maximum efficiency improvement identified as achievable in each case.

For example, Table C shows the additional manufacturing costs from the cost curve for the typical case for diesel vehicles in 2030. Per vehicle costs range from €6,000 to €15,000.

Table C. Cost of delivering efficiency improvements against 2016 baseline for typical case for diesel vehicles In 2030

	2%	6%	10%	14%	18%	22%	26%	30%
Class 4 - RD	€ 17	-€ 87	-€ 52	€ 264	€ 660	€ 1,543	€ 3,042	€ 5,587
Class 5 - LH	€ 36	-€ 83	€ 34	€ 691	€ 1,515	€ 3,468	€ 7,227	€ 15,213
Class 9 - RD	€ 10	-€ 88	-€ 22	€ 379	€ 854	€ 1,884	€ 3,586	€ 6,385
Class 10 - LH	€ 26	-€ 30	€ 121	€ 756	€ 1,505	€ 3,221	€ 6,403	€ 12,831
Class 4 - LH	n/a	-€ 40	€ 26	€ 441	€ 982	€ 2,325	€ 5,113	€ 11,975
Class 5 - RD	-€ 3	-€ 10	€ 263	€ 1,167	€ 2,146	€ 4,228	€ 7,721	€ 13,777
Class 9 - LH	n/a	-€ 29	€ 67	€ 521	€ 1,076	€ 2,387	€ 4,929	€ 10,456
Class 10 - RD	-€ 3	-€ 29	€ 209	€ 1,037	€ 1,940	€ 3,861	€ 7,067	€ 12,556

While the cost curves estimate the total cost per vehicle of delivering efficiency improvements, here we are more interested in the marginal cost of delivering the last few percentage points of emissions reductions required to meet the standard. The marginal cost of additional savings can be calculated as the derivative of the cost curve, divided here by 100 to identify the additional cost of a further percentage point of efficiency improvement:

$$Marginal\ cost = \frac{\left(b - {}^{c}/_{(x - x_0)^2}\right)}{100}$$

By cross referencing the per vehicle marginal costs with the assumed vehicle payloads and annual mileage, it is possible to go further and calculate the marginal cost of delivering each additional 1 gCO_2e/tkm efficiency improvement, or the mileage-payload adjusted[29] efficiency improvements regulated in the standard. If these latter adjusted marginal gCO_2e/tkm costs are above €6,800 then it may be preferable for a manufacturer to pay the excess emissions charge than to deliver the efficiency improvement (depending on the value added to the sales price of the vehicle). Table D and Table E show these adjusted marginal costs for the typical and high cost case in 2030.

Table D. Marginal cost of additional gCO_2e/tkm adjusted efficiency improvements in 2030 for typical case (diesel vehicles)

	2%	6%	10%	14%	18%	22%	26%	30%
Class 4 - RD	-€ 179	-€ 46	€ 131	€ 377	€ 730	€ 1,265	€ 2,130	€ 3,667
Class 5 - LH	-€ 115	-€ 8	€ 145	€ 379	€ 759	€ 1,438	€ 2,839	€ 6,519
Class 9 - RD	-€ 179	-€ 25	€ 178	€ 455	€ 846	€ 1,424	€ 2,331	€ 3,872
Class 10 - LH	-€ 79	€ 20	€ 161	€ 373	€ 712	€ 1,301	€ 2,470	€ 5,330
Class 4 - LH	n/a	-€ 11	€ 100	€ 275	€ 574	€ 1,151	€ 2,501	€ 7,009
Class 5 - RD	-€ 99	€ 98	€ 365	€ 744	€ 1,306	€ 2,191	€ 3,702	€ 6,608
Class 9 - LH	n/a	€ 5	€ 100	€ 246	€ 485	€ 920	€ 1,840	€ 4,370
Class 10 - RD	-€ 122	€ 84	€ 364	€ 757	€ 1,335	€ 2,234	€ 3,743	€ 6,575

29 Remembering that the regulated efficiency values in the standard are adjusted by applying a weighting factor between 0 and 1, with lower weights for vehicle types with lower expected annual payload-mileage. .

Table E. Marginal cost of additional gCO_2e/tkm adjusted efficiency improvements in 2030 for high case (diesel vehicles)

	2%	6%	10%	14%	18%	22%	26%	30%
Class 4 - RD	-€ 181	€ 215	€ 762	€ 1,545	€ 2,725	€ 4,622	€ 7,961	€ 14,681
Class 5 - LH	-€ 295	€ 131	€ 754	€ 1,714	€ 3,309	€ 6,249	€ 12,621	n/a
Class 9 - RD	-€ 361	€ 107	€ 734	€ 1,601	€ 2,848	€ 4,736	€ 7,791	€ 13,222
Class 10 - LH	-€ 243	€ 130	€ 671	€ 1,498	€ 2,856	€ 5,322	€ 10,533	n/a
Class 4 - LH	n/a	€ 92	€ 490	€ 1,183	€ 2,561	€ 5,943	€ 18,479	n/a
Class 5 - RD	-€ 219	€ 486	€ 1,421	€ 2,697	€ 4,504	€ 7,182	€ 11,395	n/a
Class 9 - LH	n/a	€ 110	€ 414	€ 920	€ 1,850	€ 3,863	€ 9,623	n/a
Class 10 - RD	-€ 168	€ 512	€ 1,420	€ 2,671	€ 4,462	€ 7,156	€ 11,478	€ 19,064

It can be seen that in the typical case one would expect manufacturers to avoid paying the excess emissions charge, except possibly to a small extent for Class 4 LH vehicles. For the high cost case, in contrast, manufacturers might consider paying the excess emissions charge to achieve the last few percentage points towards compliance with the standard for all assessed classes. Manufacturers expecting the cost of delivering emissions reductions to be similar to the published high cost values from JRC would therefore be potentially interested in engaging in fuel decarbonisation credit offtake agreements if that flexibility were introduced into the standard.

While this analysis helps identify cases in which a manufacturer would potentially be interested in flexible compliance options, it does not take into account the contribution of efficiency improvements to increasing sales price. This is difficult to predict for the coming decade, as the introduction of harmonised efficiency assessment and reporting may improve the capacity of manufacturers to pass through efficiency related costs[30] as compared to the current market situation. For the purposes of this paper, we have developed a simple model of cost pass through that assumes that:

1. The ability to pass through the cost of emissions reductions will be constrained by the performance of cost efficient manufacturers (i.e. manufacturers matching the 'typical' cost curve); and
2. The value to the vehicle purchaser of the last percentage point of efficiency improvement over the baseline is the same as the value of the first percentage point of improvement.

Based on these two hypotheses, we implement a modelling assumption that the sales price of a vehicle delivering an additional one percentage point emission reduction will increase by the average cost of delivering a percentage point emission reduction based on the typical

30 It is to be expected that all or almost all costs of manufacturing more efficient vehicles will be passed on to vehicle purchasers across the market as a whole, here we address directly the question of how much price differential the market will support between otherwise similar vehicles with different emissions ratings.

cost curve. For example, Table C reports a total cost of €12,000 to deliver a 30% emission reduction for a Class 4 LH diesel vehicle. It is therefore assumed in the analysis in this paper that each percentage point emission reduction for a Class 4 LH vehicle allows the sales price of that vehicle to be increased by €400 (equivalent to a price increase of €1000 per adjusted gCO_2e/tkm). Looking at Table D and Table E, it is apparent that when a cost pass through is included on that basis the marginal cost of full compliance for a Class 4 LH vehicle in the typical cost case would no longer be above the excess emission charge. In the high cost case, however, the marginal cost above 26% would indeed be well above the €6,800 excess emission charge even including €1,000 of cost pass through.

It should be emphasised that this cost pass through assumption is highly simplified, and that it has not been truthed against observed market behaviours – rather, it should be treated as indicative of the type of pricing dynamic that could affect compliance choices, and is included partly as a placeholder because it is clear that it would not be appropriate to ignore this cost pass through effect. If the cost pass through is greater, then the business case for taking advantage of flexibility mechanisms such as fuel decarbonisation credits would be weaker. If market barriers prevent even this level of cost pass through, the case for taking advantage of fuel decarbonisation crediting would be proportionately stronger.

Given this assumption on the ability of manufacturers to recoup manufacturing costs in sales prices, the marginal cost data derived from the JRC cost curves as described above, and an assumption that the lifetime of all regulated trucks is 15 years, it is possible to derive the implied marginal carbon price for manufacturers to deliver additional emission reductions. This carbon price can be compared to the potential carbon price required to support fuel decarbonisation projects, as discussed in the main body of the report. For example, Table F details the implied carbon prices arising from the high cost curves for 2030 diesel vehicles. It is apparent that for all vehicle classes, under the assumptions discussed carbon credits at a price of 200 €/tCO_2e would be potentially appealing to manufacturers in meeting the final percentage point requirements of the standard.

Table F. Implied marginal carbon price from high cost case for diesel vehicles in 2030

	2%	6%	10%	14%	18%	22%	26%	30%
Class 4 - RD	-€ 42	-€ 25	-€ 3	€ 30	€ 79	€ 158	€ 296	€ 575
Class 5 - LH	-€ 58	-€ 40	-€ 15	€ 25	€ 92	€ 214	€ 478	n/a
Class 9 - RD	-€ 53	-€ 34	-€ 8	€ 28	€ 80	€ 158	€ 285	€ 511
Class 10 - LH	-€ 51	-€ 35	-€ 13	€ 22	€ 78	€ 181	€ 397	n/a
Class 4 - LH	n/a	-€ 37	-€ 21	€ 8	€ 65	€ 206	€ 726	n/a
Class 5 - RD	-€ 72	-€ 43	-€ 4	€ 49	€ 124	€ 235	€ 410	n/a
Class 9 - LH	n/a	-€ 25	-€ 13	€ 8	€ 47	€ 130	€ 370	n/a
Class 10 - RD	-€ 70	-€ 42	-€ 4	€ 48	€ 122	€ 234	€ 413	€ 728