# Whitepaper

# Analysis of cost of ownership and the policy support required to enable industrialisation of fuel cell trucks

## Executive Summary

Green hydrogen, made from renewable electricity, can be used as part of a sustainable energy system to provide grid balancing services and to decarbonise a wide range of 'hard to reach' end uses. Once such end-use is the long-haul, heavy-duty trucking sector, where hydrogen fuel cell vehicles are able to provide the long range and fast refuelling required by end users. The deployment of hydrogen trucking must start now and ramp-up quickly if the ambitious emissions reductions targets of net-zero by 2050 are to be achieved. This will allow the sector to scale-up green hydrogen and truck production volumes, and cost reductions to be realised.

The H2Accelerate collaboration has been formed by hydrogen infrastructure players Linde, OMV, Shell, and TotalEnergies, and hydrogen truck OEMs Daimler Truck, IVECO, and Volvo Group, to promote the use of hydrogen to decarbonise long-haul, heavy-duty trucking across Europe.

Today, fuel cell trucks are significantly more expensive to operate compared to the incumbent diesel vehicles. These costs will fall through time as the industry scales up whilst developing and deploying new lower cost technologies.

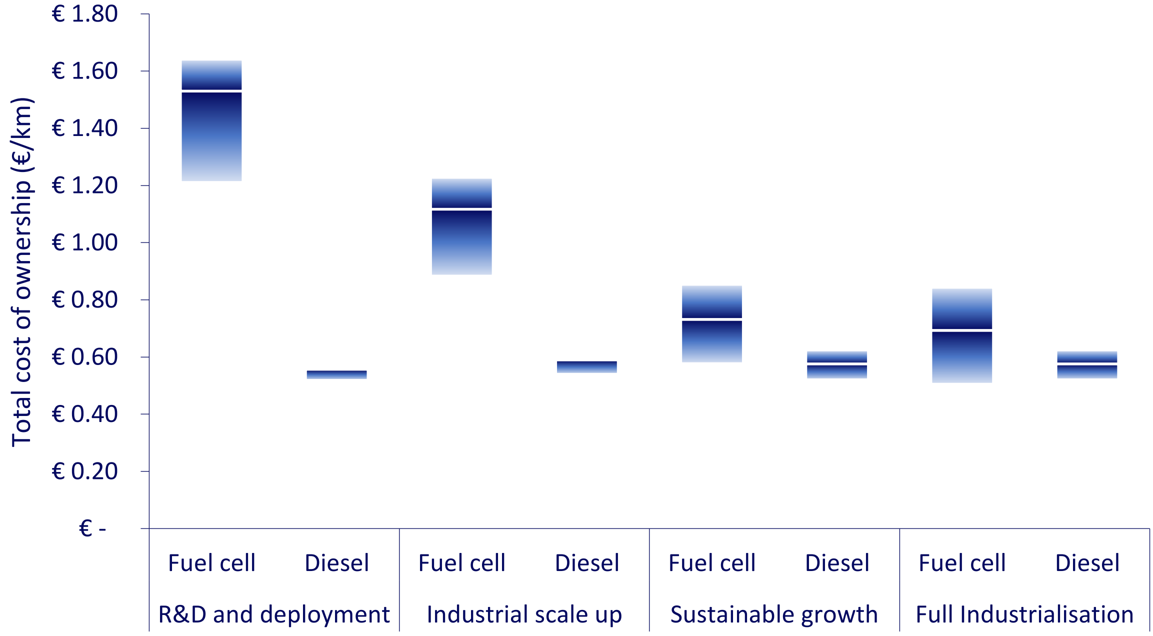
In order to secure the volume-related reductions in cost, it will be necessary to ensure that demand for trucks builds through time. Members of the H2Accelerate collaboration are clear that creating this demand will require state support. The companies expect that this will be best achieved through a partnership where the private sector makes major investments in R&D, production facilities, and infrastructure for green hydrogen and fuel cell trucks, whilst the public sector creates the conditions to stimulate the deployment of the trucks at a progressively increasing scale.

This paper seeks to articulate the likely evolution of the cost base for fuel cells trucks through time, and then uses this to define the policy support which will be required to underpin the transition to an economically viable fuel cell trucking system for Europe.

As secretariat to the H2Accelerate collaboration, independent zero carbon consultancy Element Energy has assessed the expected total cost of ownership (TCO) of operating a fuel cell and diesel truck through time. This has led to a central case forecast for the ownership costs, together with upper and lower bounds based on the plausible technology pathways seen by the companies today. These results are shown below. The graphic illustrates how the cost of operating a fuel cell truck will tend towards that of operating the equivalent diesel truck as the industry scales up. The analysis envisages a transition through a first 'R&D and deployment' phase pre-2025, when low hundreds of trucks are deployed at a relatively high cost (due to low volumes) through a series of expansions producing 1,000s and then 10,000s of trucks per year to a 'full industrialisation' phase, when only a slight cost increase is observed for the central case. The analysis suggests the prospect of lower ownership costs compared to diesel depending on the relative cost of diesel and hydrogen fuel and trucks.

The following analysis was performed in Autumn and Winter of 2021 and does not take into account the recent changes to the market environment at the time of publication (September 2022).

Range of possible total cost of ownership for fuel cell and diesel articulated trucks in progressive deployment phases, based on capex and fuel costs only




To bridge the gap between incumbent diesel vehicles and the hydrogen fuelled options, policy support will be required. The policy response will need to coincide with the phases of the roll-out.

In the **early years** when deployment volumes are low, but the cost differential is high, the study sees a requirement for capital subsidies for hydrogen trucks and early hydrogen refuelling stations. These can be deployed through 'Project' type funding as is already available from European institutions and member state industrial development programs, such as state aid through designation as an Important Project of Common European Interest (IPCEI), the Connecting Europe Facility Alternative Fuels Infrastructure Facility (CEF AFIF) funding, and Clean Hydrogen Partnership funding. It is expected that a larger scale of programme will be required than is typical for these schemes today - based on certain assumptions, this analysis shows that around €240m of project-type support to trucks and refuelling stations is expected to be needed to enable the required deployment in the first 'R&D and deployment' phase[1].

As the costs come down in the scale-up phases, this project-based support can give way to support for individual vehicle purchase (similar to the current German scheme to fund 80% of the cost gap between a fuel cell vehicle and a conventional vehicle) and an increasing reliance on policy measures which help to encourage uptake of the hydrogen truck option. Through time, the cost gap closes so that only the policy measures are required and the requirement for direct subsidy is removed.

Element Energy has analysed how a combination of policy measures can be used to achieve parity between hydrogen and diesel trucks. The following measures (if implemented together) will create the conditions for a thriving hydrogen truck market in Europe:

- Member state implementation of a favourable RED II framework for hydrogen is essential. In addition, within the RED III proposals, a long term and appropriately ambitious transport sub-target for renewable fuels of non-biological origin (RFNBOs) (which will treat green hydrogen in the same way 'advanced biofuels' are already treated) will help create and sustain the business case for green hydrogen production and the associated hydrogen refuelling stations.
- Introduction of differential road tolls to favour hydrogen and other zero emission options over fossil fuel-based vehicles. The modelling suggests road tolls of €0.40/km for diesel vehicles and €0.10/km for zero emission vehicles would help to create demand for hydrogen trucks.
- Taxation of fuels which recognises the changing landscape towards more decarbonised and zero carbon fuels and zero emission vehicles, which does not disadvantage hydrogen and other sustainable fuels until their business case is established.
- A carbon tax on diesel starting at a minimum of €30/tonne $CO_2$ and increasing through time to a minimum of €60/tonne (based on proposed prices in the German carbon pricing scheme for transport and buildings), in addition to the tax currently applied on diesel today.

In order to ensure that hydrogen trucking rolls out uniformly across Europe (and therefore delivers the continent-wide zero emission trucking which is required by freight operators), it will also be important that these policy measures are applied harmoniously, at a similar level and time across all European member states, as well as the U.K.

[1] Assuming 25 refuelling stations with €3m funding required per station, and 500 trucks with an average funding requirement of €330k per truck.

The overall policy approach is summarised in the diagram below, which also provides indicative dates for each phase. These dates are deliberately indicative as they are dependent on creating the conditions for the roll-out required by each phase.

| R&D and Deployment (2023 – 2026) | Industrial Scale-up (2026 – 2028) | Sustainable Growth (2028 – 2030) | Full Industrialisation (2030 onwards) |
|---|---|---|---|
| • First 100s of trucks in the hands of customers<br>• Limited (but high reliability) refuelling network in clusters<br>• Learning about customer attitudes and interactions with the trucks | • First series produced vehicles emerge<br>• Networks start to expand<br>• High capex/risk<br>• Vehicles still carry a cost premium | • Series produced vehicles available from many manufacturers<br>• Pan-European network on major corridors<br>• Vehicles trending towards an affordable cost base | • Supply chains for trucks and green hydrogen have fully matured<br>• Fuel cell trucks sales make up >20% of heavy-duty vehicle sales<br>• Cost of operating fuel cell trucks minimised |
| **Support required in each phase:** | | | |
| • Mainly **capital support for whole projects** through IPCEI, CH JU, the EU's TEN-T program, and other member state budgets<br>• Policies to promote green hydrogen such as RED II/III, CO2 taxes and road tolls need to be developed | • Ongoing **vehicle purchase support** schemes<br>• Increased reliance on regulations and ongoing policies including CO2 taxation, differential road tolls, and RED II/III credits | • **Market driven by regulatory/policy forces**<br>• Policies include CO2 taxation, differential road tolls, and RED II credits<br>• Increasing use of mandates/bans and soft incentives to support zero emission vehicles | • Policy support measures for hydrogen may be reduced / tax on hydrogen implemented<br>• **Regulatory measures** implemented to phase out diesel vehicles |

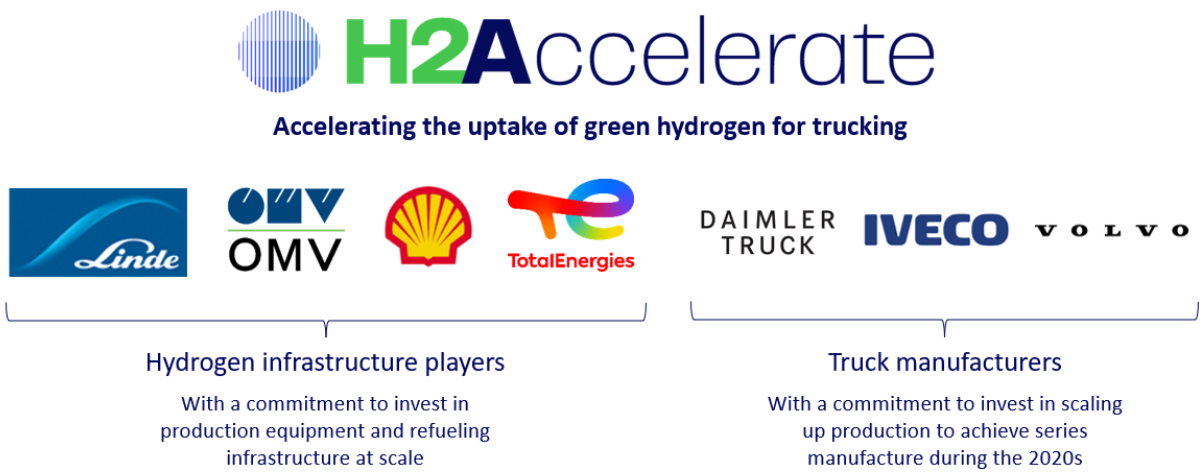
This paper is published by the H2Accelerate Collaboration in September 2022 as a milestone whitepaper in a series of whitepapers in support of the use of hydrogen in long-haul trucking. Other whitepapers from the H2Accelerate Collaboration are available at the H2Accelerate website.

# Contents

# The H2Accelerate Collaboration

Hydrogen fuel cell and battery trucks are the only zero emission technology options to decarbonise the trucking sector, which currently causes 6%[2] of total European $CO_2$ emissions. Both technological solutions will be required to meet the needs of different truck use cases. The long range and fast refuelling capabilities of hydrogen fuel cell vehicles make them the only zero emission technology option able to meet end user operational needs in the longest-haul, heavy-duty trucking sector. The deployment of a hydrogen trucking system in Europe is therefore necessary to decarbonise the long-haul, heavy-duty trucking sector, with medium- and heavy-duty trucks responsible for 60% of road freight emissions[3].

The H2Accelerate collaboration has been formed between Daimler Truck, IVECO, Linde, OMV, Shell, TotalEnergies, and Volvo Group to work collaboratively to develop the evidence base and public funding programmes which can help move Europe towards a commercially viable hydrogen trucking system. Each of these major industrial companies, from both the refuelling and trucking sectors, have made their own organisational commitments to achieving net zero in line with Europe's ambitious decarbonisation targets under the Paris climate agreements.




The H2Accelerate members are planning to initiate the first deployment of hydrogen fuel cell trucks and infrastructure in Europe in the first half of the decade, with hundreds of trucks and tens of high-capacity refuelling stations deployed in clusters along freight corridors which connect multiple countries. These will be deployed alongside new green hydrogen production facilities to supply a fully zero carbon fuel to the refuelling network. The success of this first phase is expected to lead to increasing scales of deployment, resulting in as many as 60,000 fuel cell trucks and 400 refuelling stations, supplied by over 2GW of green hydrogen production, by 2030[4].

[2] European Commission (2019) *Reducing $CO_2$ emissions from heavy-duty vehicles*
[3] Shell International B.V. (2021) *Decarbonising road freight: Getting into gear*
[4] Conservatively assuming hydrogen demand per truck of 20 kg/day, electrolyser efficiency of 50 kWh/kg, and 100% load factor, over 2GW of electrolysis capacity is needed to meet demand. .

Achieving these targets will require significant investment on the part of truck manufacturers in research and development and scaling up fuel cell truck manufacturing facilities, and from infrastructure players to scale up the green hydrogen supply chain and invest in the first high-capacity hydrogen stations. These investments will need to occur in advance of demand for hydrogen fuel and trucks from customers, resulting in significant financial risk for both truck OEMs and infrastructure players. While the H2Accelerate members are fully ready and willing to commit to scaling up the hydrogen trucking sector, support from the state will be necessary to mitigate the risk associated with developing a new sector and unlock the levels of investment required to achieve a rapid and sustainable scale-up. This will include both capital funding during the high-risk early stage and policy/regulatory support for the subsequent expansion.

To support national and European policymakers to define and quantify the policy mechanisms needed to enable the roll-out of fuel cell trucks, H2Accelerate secretariat Element Energy has analysed the expected total cost of ownership (TCO) for operating fuel cell electric and diesel trucks over time, as the sector moves through different phases of industrialisation. This analysis is used as a basis to define recommendations for policy mechanisms and the levels of support needed to enable hydrogen trucks to become cost competitive with existing vehicles in each of the deployment phases.

It is expected that commitments from truck OEMs, infrastructure players, and national and European government will allow development of a mature zero-emission trucking system that can meet end user needs in the coming ten years. Members of the H2Accelerate collaboration are prepared to work with government to facilitate this transition.

# Scaling up the deployment of hydrogen trucking in Europe

The central objective of the H2Accelerate collaboration is to create awareness of the benefits of the use of green hydrogen for trucking, and the challenges in scaling-up the sector up to and beyond 2030. Achieving the mass-market roll-out of hydrogen trucks in Europe is reliant on the rapid, but sustainable, scale-up of refuelling infrastructure, truck manufacturing facilities, and the associated supply chains. For the hydrogen truck option to mature by 2030, scale-up must start today. Early deployment projects will need to occur in parallel with R&D activities to refine the trucks and associated sub-components, as well as the fuelling and operational proposition to the truck customers. Customer views are expected to determine the approach to refuelling technology preferences (350 bar, 700 bar, or liquid hydrogen), which will be defined in the first phase of deployment.

As presented in a previous whitepaper on 'Expectations for the fuel cell truck market', the H2Accelerate members envision the deployment of hydrogen trucks up to 2030 occurring in phases. The deployment in each of these phases progressively increases in scale, with economies of scale, new learnings, and technological improvements leading to reduced costs of operating the trucks over time. These phases span the period from today, when very few hydrogen trucks have been deployed in limited demonstration projects and come at a significant cost premium compared to diesel alternatives, to the post-2030 world where hydrogen trucks become ubiquitous throughout Europe.

The envisioned deployment phases are:

- **A first 'R&D and deployment' phase from 2021 to 2025** where the first hundreds of trucks are placed in the hands of customers, using a relatively limited (but high reliability) refuelling network. In this phase the hydrogen trucking industry will learn about customer attitudes to, and interactions with, the trucks, as well as developing new refuelling stations for high-capacity truck refuelling and standardising around preferred refuelling and vehicle field service solutions. During this phase, the trucks will still be in a developmental phase and not yet comparable to series products. The vehicles will require a support network capable of servicing the vehicles - a regional repair and maintenance network will therefore be established. During this phase, volumes are low and costs will be high due to a lack of economies of scale, therefore significant state support will be required to make an acceptable business case proposition for end users. This will be required in addition to substantial investments in capacity build up which will be made by hydrogen providers and vehicle manufacturers.
- **A second 'industrial scale up' phase from 2025 to 2028** where the first series production of trucks will occur, and vehicles will be deployed in the thousands. In this phase, the refuelling network will grow across Europe, along key transport corridors. Customer technology preferences (for 350 bar, 700 bar, or liquid hydrogen) defined in the first phase of deployment will be used to inform the roll-out of infrastructure. This will be the phase with the highest investment required and also the highest risk, which leads to the need for the greatest financial support. Policy support measures during

this period are expected to start to transition from capital subsidy for trucks and infrastructure to more sustainable measures, for example in the form of differential road tolls, carbon taxes, etc.

- **A third 'sustainable growth' phase from 2028 to the early 2030s** where economies of scale have helped to reduce prices across the supply chain and public funding support can be progressively withdrawn in favour of supportive sustainable policy measures.
- **This will lead to a mature industrialised sector in the 'full industrialisation' phase**, with high volume series manufacture starting around 2030. Once the manufacturing and associated supply chains have scaled up and matured, the technology is expected to have a similar cost base to the incumbent diesel vehicles today.


It should be noted that the timescales here are indicative and achieving the next scale of deployment is reliant both on scaling up from the preceding phase and having sufficient policy support in place to allow an acceptable ownership cost proposition for customers going forward. Members of the H2Accelerate collaboration are not bound by the scope or timing of these phases.

The following section assesses the likely development of the ownership costs for hydrogen fuel cell trucks in these phases. Subsequent sections explore the implications of this analysis for policy makers.

# Total Cost of Ownership of fuel cell and diesel trucks

An analysis of the Total Cost of Ownership (TCO) for fuel cell and diesel trucks over time has been performed by Element Energy, an independent zero-carbon energy consultancy that acts as secretariat to the H2Accelerate collaboration. A literature review allowed Element Energy to collect a number of published data points on the expected cost and performance of fuel cell trucks and infrastructure through time. Appropriate input values to the model were then selected from public sources through interviews with H2Accelerate members, and Element Energy's own analysis. The specific data sources used in this analysis are available in the below tables. This analysis does not commit H2Accelerate members to attaining the predicted results, in relation to their future individual strategies, nor reflects their position via-à-vis the TCO elements, nor does it provide information on them.

Hydrogen trucks are expected to be a needed complement to battery electric vehicles to decarbonise the trucking sector. Hydrogen trucks are expected to fulfil the demand of long range and fast refuelling in long-haul and other heavy-duty applications, where battery trucks are operationally challenging. Therefore, a purely cost-based comparison with battery vehicles cannot be made.

This analysis only considers the comparison between fuel cell and diesel vehicles, for large rigid and articulated truck types.

## Calculation of Total Cost of Ownership (TCO)

The TCO analysis focusses on the two elements of TCO that significantly differ between fuel cell and diesel vehicles: capital cost depreciation and fuel costs. TCO is then the sum of these two components, calculated on a 'per km' basis. Each component of TCO is calculated as follows:

- **Capital cost depreciation,** calculated by finding the annual capital cost that must be depreciated over the first user lifetime, given a residual value for the vehicle at the end of its first user lifetime and an assumed 5% cost of capital. The annual capital cost depreciation was then divided by the annual truck mileage, which was assumed to be 120,000 km.
- **Fuel cost,** based on product of the price per unit of fuel (kg $H_2$, l diesel) and the fuel consumption of the vehicle.

Since little data is currently available on the long-term maintenance costs of fuel cell vehicles, this is assumed to be equal between vehicle types. This is a conservative assumption, as fuel cell vehicles have few moving parts and are therefore expected to have reduced maintenance costs compared to the equivalent diesel vehicles. All TCO components that would be equal between fuel cell and diesel vehicles, such as driver costs and insurance, have been excluded from this analysis.

A number of key uncertainties in the calculation of hydrogen truck TCO through time currently exist. To address this uncertainty, the analysis presents lower bound, upper bound, and probable case scenarios for truck TCO in each phase, based on sensitivity to key uncertainties. The key uncertainties for the purpose of this analysis are:

- **Truck capital cost** - uncertainties on the magnitude of fuel cell truck capital cost are caused by the challenge of predicting technology development and truck manufacturing volumes over time, and the impact of these factors on capital cost.
- **Fuel cost** - the magnitude of reduction in hydrogen price is dependent on the development of technology in the green hydrogen supply chain, the rate at which green hydrogen production scales up, and whether hydrogen can be transported by pipeline rather than road (which is not shown in this analysis but could lead to further cost reductions by the full industrialisation phase).
- **Fuel consumption** - for both diesel and fuel cell vehicles, research and development is expected to lead to improving fuel consumption over time. Exact fuel consumption in each phase will be dependent on the development of truck drivetrain technology and the impact of emissions regulations for diesel vehicles.
- **Vehicle first user lifetime and residual value** - fuel cell vehicles may be able to be used for longer if they can be demonstrated to have lower maintenance requirements than diesel vehicles. Conversely, the phasing out of diesel vehicles is leads to uncertainty in their residual value at the end of their first user lifetime.

A key uncertainty at the current stage of market development is the refuelling technology that will be used for trucks, with 350 bar, 700 bar, liquid, and cryo-compressed hydrogen all considered viable technology options[5]. The below analysis does not refer to any single refuelling technology, and the impact of changing between each of these technology options on truck capital cost and hydrogen price is covered by the lower and upper bound assumptions.

The values used for each of these parameters in the lower bound, upper bound, and probable case scenario, for each vehicle type and phase of deployment, is detailed below.

## Truck capital cost

The high capital cost of fuel cell trucks today is expected to significantly decrease through time. In the first three phases of deployment, this will be largely due to technology developments and the transition to series manufacturing. The scale of manufacturing in the sustainable growth and full industrialisation phases will enable production lines, automated manufacturing, and procurement at scale to bring down the cost of components and truck construction. When transitioning from the sustainable growth phase to the full industrialisation phase, the majority of the truck capital cost reduction is expected to come from maturation of the supply chain, leading to reductions in the cost of truck components.

[5] H2 Mobility (2021) *Overview: hydrogen refuelling for heavy duty vehicles*

Diesel truck capital costs are expected to be constant through time due to the technology having reached maturity and manufacturing already occurring with the benefits of high-volume series production.

It is possible that by the full industrialisation phase, sales of fuel cell trucks will exceed 50,000 vehicles per year, making up 20% of the sales of medium and heavy commercial vehicles (based on 300,000 vehicles sold in 2019[6]). In this case, the capital cost of the vehicles could fall to be a third of their price in the early stages of deployment. The costs of the fuel tanks (liquid or compressed, which both have significant materials requirements) and the relative unit cost of fuel cells compared with existing engine technology are expected to mean there is always a premium over diesel vehicles even in the most optimistic scenarios for volume and technology improvements. However, an upper bound scenario where fuel cell truck manufacturing volumes remain modest will lead to significantly higher capital costs.

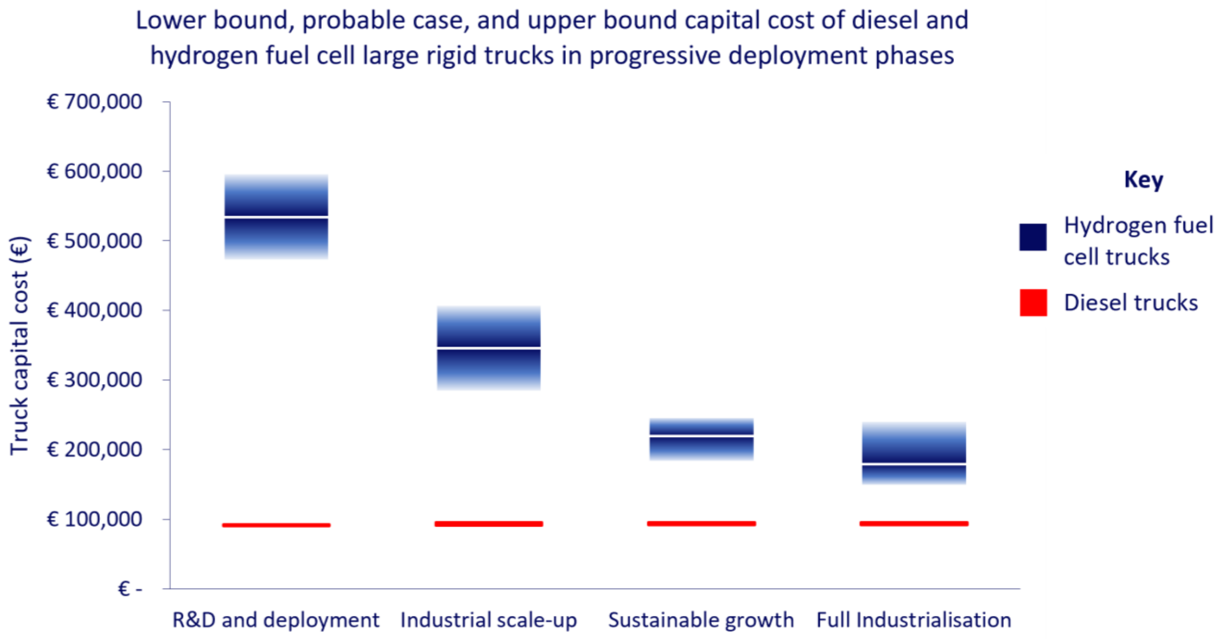
The tables and charts below show the results of the study on expected lower bound, probable case, and upper bound scenarios for large rigid and articulated fuel cell and diesel vehicles in each deployment phase - R&D and Deployment (R&DD), Industrial Scale Up (ISU), Sustainable Growth (SG), and Full Industrialisation (FI).

**Hypothetical Price of Large Rigid Vehicles**

| Truck type | Unit | Scenario | R&DD | ISU | SG | FI |
|---|---|---|---|---|---|---|
| Fuel cell 700 bar | k€ | Lower | 471 [1] | 283 [4] | 182 [7] | 148 [10] |
| | | Probable case | 534 [2] | 346 [5] | 220 [8] | 179 [11] |
| | | Upper | 597 [3] | 409 [6] | 247 [9] | 242 [12] |
| Diesel | k€ | Lower | 90 [13] | 91 [14] | 92 [15] | 92 [15] |
| | | Probable case and upper | 93 [16] | 96 [17] | 96 [18] | 96 [19] |

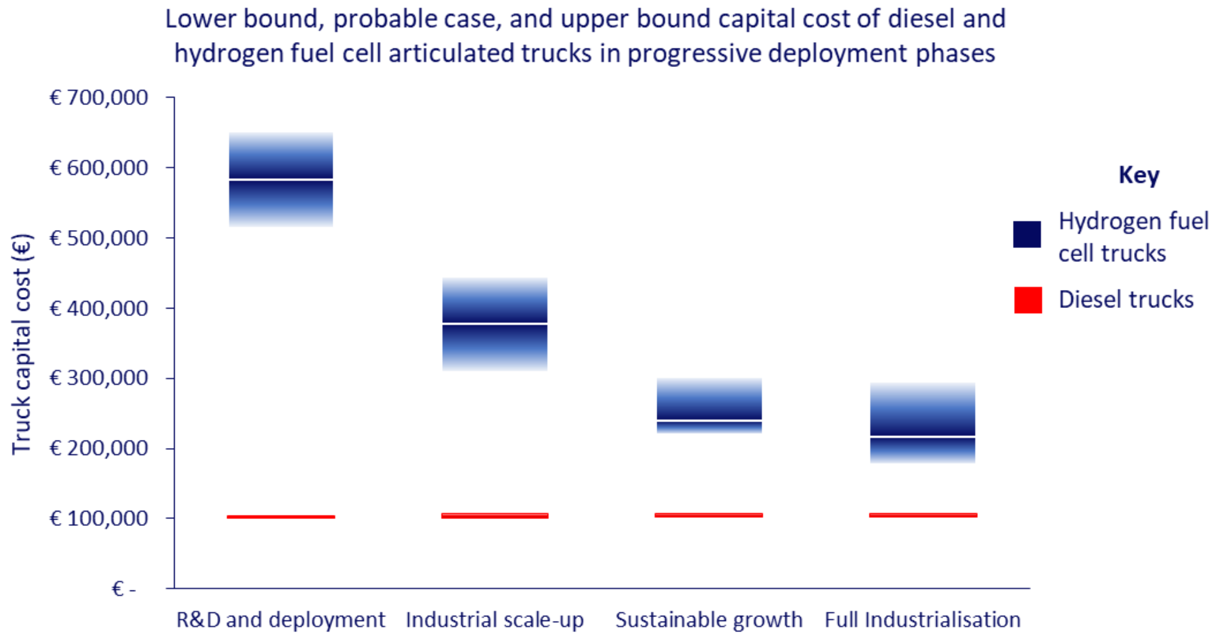
*Data sources:*
**National Platform for Mobility H2-BZ >20 <SZM:** [1] in 2023 [2] in 2022 [3] in 2021 [4] in 2026 [5] in 2025 [6] in 2024 [8] in 2030
**Roland Berger 270 kW H2 fuel cell truck:** [7] 'rather niche' case in 2030 [9] 'niche' case in 2030 [10] 'rather mass' case in 2035 [11] 'rather niche' case in 2035 [12] 'niche' case in 2035
**National Platform for Mobility diesel truck >20 <SZM:** [13] in 2022 [14] in 2025 [15] in 2030
**Roland Berger 270 kW diesel truck:** [16] in 2023 [17] in 2025 [18] in 2030 [19] in 2035

[6] Statista (2021) *Medium and heavy commercial vehicle market in Europe – statistics & facts*




| Hypothetical Price of Articulated Vehicles | | | | | | |
|---|---|---|---|---|---|---|
| **Truck type** | **Unit** | **Scenario** | **R&DD** | **ISU** | **SG** | **FI** |
| Fuel cell 700 bar | k€ | Lower | 514 [1] | 309 [4] | 221 [7] | 177 [10] |
| | | Probable case | 583 [2] | 377 [5] | 240 [8] | 216 [11] |
| | | Upper | 651 [3] | 446 [6] | 301 [9] | 295 [12] |
| Diesel | k€ | Lower | 101 [13] | 101 [14] | 102 [15] | 102 [15] |
| | | Probable case and upper | 104 [16] | 107 [17] | 107 [18] | 107 [19] |

*Data sources:*
**National Platform for Mobility SZM:** [1] in 2023 [2] in 2022 [3] in 2021 [4] in 2026 [5] in 2025 [6] in 2024 [8] in 2030
**Roland Berger 330 kW H2 fuel cell truck:** [7] 'rather niche' case in 2030 [9] 'niche' case in 2030 [10] 'rather mass' case in 2035 [11] 'rather niche' case in 2035 [12] 'niche' case in 2035
**National Platform for Mobility diesel truck SZM:** [13] in 2022 [14] in 2025 [15] in 2030
**Roland Berger 330 kW diesel truck:** [16] in 2023 [17] in 2025 [18] in 2030 [19] in 2035




## Fuel price

Infrastructure players within H2Accelerate are ready and willing to invest in scaling up the supply chain to support a pan-European hydrogen trucking system. The price of hydrogen will subsequently decrease significantly over time due to increasing scale of both production sites and refuelling stations, increasing maturity of the technologies involved in the hydrogen supply chain, and decreasing costs of accessing renewable electricity for the green hydrogen production. These improvements will lead to reduced equipment capital and operating costs as the production of green hydrogen becomes increasingly industrialised to achieve the EU target of 40GW of electrolyser capacity by 2030[7].

The deployment of large-scale green hydrogen production facilities and refuelling stations will be subject to the availability of capital support in the early years. Funding support for infrastructure has already been made available through national IPCEI programmes and the CEF Alternative Fuels Infrastructure Fund. Capital support for programmes such as these will need to continue until the sector reaches maturity.

Another component of the ability to reduce costs for green hydrogen will be RED II/III credits for green hydrogen. The 'Fit for 55' package proposed an updated target for 2.6% renewable fuels of non-biological origin (i.e. hydrogen and e-fuels) to be used in road transport by 2030, allowing green hydrogen credits to be traded, raising additional revenue for producers and reducing the price 'at the pump'. Increasing targets for the use of hydrogen in transport are expected to support the cost reduction path for green hydrogen by not only providing additional revenue for producers, but also by supporting the scale-up of the sector. The impact of the RED II target is to make green hydrogen affordable relative to more carbon intensive options such as hydrogen generated from fossil fuels (with or without carbon abatement). As a result, it will be important that the principles of Fit for 55 are implemented

[7] European Commission (2020) *A hydrogen strategy for a climate-neutral Europe*

in favour of hydrogen use in mobility across all member states. The impact of these regulatory changes is included in the price estimates below.

A further assumption is that a tax will be applied to diesel fuel, but not to hydrogen throughout all deployment phases. Tax on fuel is taken from the Study on Hydrogen Fuel Cells Trucks[8] and assumes €0.60/l for diesel and is included in the below fuel cost values. This tax is assumed to be an excise duty separate from CO2 tax on road transport emissions (which is not yet in place across Europe).

| **Hypothetical Fuel Prices[9]** | | | | | | |
|---|---|---|---|---|---|---|
| **Truck type** | **Unit** | **Scenario** | **R&DD** | **ISU** | **SG** | **FI** |
| Hydrogen 700 bar | €/kg | Lower | 7.30 [1] | 6.47 [2] | 4.50 [3] | 4.50 [5] |
| | | Probable case and upper | 7.30 [1] | 6.47 [2] | 4.80 [4] | 4.80 [6] |
| Diesel | €/l | Probable case | 1.26 [8] | 1.37 [9] | 1.37 [9] | 1.37 [9] |

*Data sources:*
**Roland Berger 700 bar $H_2$ price** [1] in 2023 [2] in 2025 [4] in 2030 [6] in 2035
**Roland Berger 350 bar $H_2$ price** [3] in 2030 [5] in 2035
**Roland Berger diesel price** [8] in 2023 [9] in 2025

# Fuel consumption

Research and development is expected to lead to incremental improvements in the fuel efficiency of both fuel cell and diesel drivetrains. These improvements lead to lower fuel costs for both vehicle types through time.

By the sustainable growth phase, it is assumed that fuel consumption has reached a plateau and significant improvements to fuel efficiency in subsequent phases are not expected. A lower bound fuel consumption is presented to demonstrate the uncertainty in the progression of technology development.

| **Hypothetical Fuel Consumption of Large Rigid Vehicles** | | | | | | |
|---|---|---|---|---|---|---|
| **Truck type** | **Unit** | **Scenario** | **R&DD** | **ISU** | **SG** | **FI** |
| Fuel cell 700 bar | kg/km | Lower | 0.070 [1] | 0.069 [3] | 0.068 [4] | 0.068 [4] |
| | | Probable case and Upper | 0.071 [2] | 0.070 [1] | 0.070 [1] | 0.070 [1] |
| Diesel | l/km | Lower | 0.265 [5] | 0.257 [6] | 0.243 [7] | 0.243 [7] |
| | | Probable case and Upper | 0.288 [8] | 0.284 [9] | 0.275 [10] | 0.275 [10] |

*Data sources:*
**National Platform for Mobility H2-BZ hydrogen fuel consumption >20 <=SZM** [1] in 2023-2035
**Roland Berger 270 kW hydrogen truck fuel consumption** [2] in 2023 [3] in 2026 [4] in 2030
**National Platform for Mobility analysis diesel fuel consumption >20 <SZM** [5] in 2022 [6] in 2025 [7] in 2030
**Roland Berger 270 kW diesel truck fuel consumption** [8] in 2022 [9] in 2025 [10] in 2030

[8] Roland Berger (2020) Study on fuel cells hydrogen trucks
[9] The assumed diesel prices do not account for the increases in prices of diesel due to the Russian invasion of Ukraine, which began 24 February 2022

| Hypothetical Fuel Consumption of Articulated Vehicles | | | | | | |
|---|---|---|---|---|---|---|
| **Truck type** | **Unit** | **Scenario** | **R&DD** | **ISU** | **SG** | **SG** |
| Fuel cell 700 bar | kg/km | Lower | 0.075 [1] | 0.075 [1] | 0.075 [1] | 0.075 [1] |
| | | Probable case and Upper | 0.080 [2] | 0.078 [3] | 0.076 [4] | 0.076 [4] |
| Diesel | l/km | Lower | 0.294 [5] | 0.285 [6] | 0.270 [7] | 0.270 [7] |
| | | Probable case and Upper | 0.320 [8] | 0.315 [9] | 0.305 [10] | 0.305 [10] |

*Data sources:*
**National Platform for Mobility H2-BZ hydrogen fuel consumption in SZM** [1] in 2022-2030
**Roland Berger 330 kW hydrogen truck fuel consumption** [2] in 2023 [3] in 2025 [4] in 2030
**National Platform for Mobility diesel fuel consumption in SZM** [5] in 2022 [6] in 2025 [7] in 2030
**Roland Berger 330 kW diesel truck fuel consumption** [8] in 2022 [9] in 2025 [10] in 2030

# Vehicle first user lifetime and residual value

Currently, diesel trucks are often moved into alternative, less heavy-duty cycle applications after the first five years of operation. This is because an increasing frequency of maintenance issues after five years of operation start to cause operational challenges for end users. A residual value of 30% of the purchase price is assumed for diesel trucks after this first uses lifetime, based on current market conditions.

In the probable case, it is assumed that all truck types have a first user lifetime of 5 years and retain a residual value of either 20% (fuel cell vehicles) and 30% (diesel vehicles) at the end of this period. The reduced residual value for fuel cell trucks reflects the current uncertainty in the second-user market for these vehicles, which has not yet been developed.

It has been previously noted that the fewer number of moving parts within a fuel cell drivetrain are expected to lead to fewer maintenance issues for fuel cell trucks. If this can be proven under real world conditions during the R&D and deployment and industrial scale-up phases, the first user lifetime of fuel cell trucks could be extended to 8 years in the sustainable growth and full industrialisation phases. It is assumed that in this scenario, the residual value of the fuel cell truck would be zero as insufficient information on the aftermarket value of fuel cell trucks following extended periods of operation is available. However, if this market is developed it could further improve the TCO of fuel cell trucks in the sustainable growth phase.

The upper bound for diesel vehicles in the sustainable growth and full industrialisation phases assumes that diesel trucks have no residual value, due to the improved customer proposition of zero emissions vehicles and the implementation of regulations restricting the use of diesel vehicles.

The below table sets out the values of first user lifetime and residual value used in the TCO analysis.

| First user lifetime | | | | | |
|---|---|---|---|---|---|
| **Truck type** | **Unit** | **Scenario** | **R&DD** | **ISU** | **SG** |
| Fuel cell 700 bar | years | Lower | 8 [1] | 8 [1] | 8 [1] |
| | | Probable case and Upper | 5 [2] | 5 [2] | 5 [2] |

| First user lifetime | | | | | |
|---|---|---|---|---|---|
| **Truck type** | **Unit** | **Scenario** | **R&DD** | **ISU** | **SG** |
| Diesel | years | All | 5 [3] | 5 [3] | 5 [3] |

*Data sources:*

[1] Assumption based on longer fuel cell vehicle lifespan with zero residual value
[2] Roland Berger assumption for fuel cell vehicles
[3] Roland Berger assumption for diesel vehicles

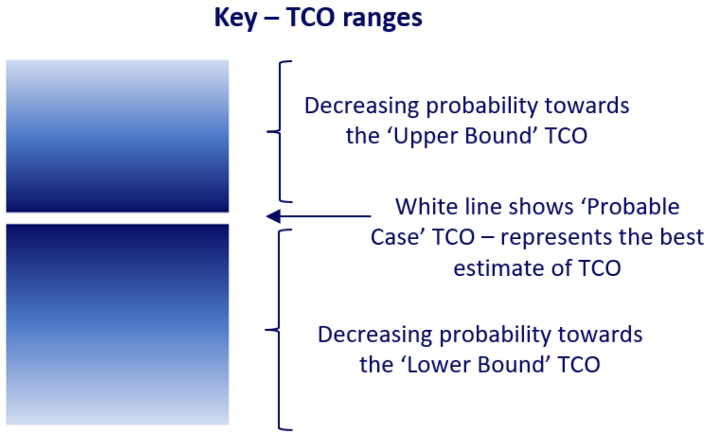
| Residual value at the end of first user lifetime, as a percentage of capital cost | | | | | |
|---|---|---|---|---|---|
| **Truck type** | **Unit** | **Scenario** | **R&DD** | **ISU** | **SG** |
| Fuel cell 700 bar | % of capex | Lower | 0% [1] | 0% [1] | 0% [1] |
| | | Probable case and Upper | 20% [2] | 20% [2] | 20% [2] |
| Diesel | % of capex | Lower and Probable case | 30% [3] | 30% [3] | 30% [3] |
| | | Upper | 30% [3] | 30% [3] | 0% [4] |

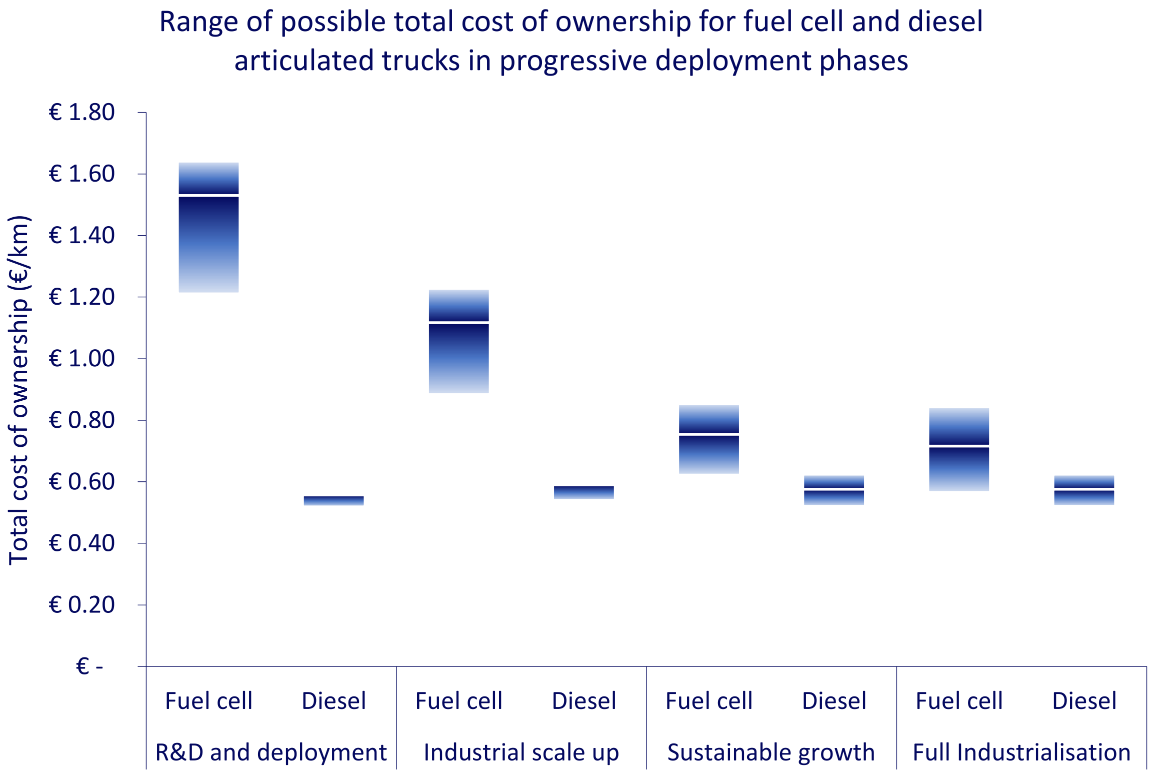
*Data sources:*

[1] Assumption based on longer fuel cell vehicle lifespan with zero residual value
[2] Assumed values based on residual value of current trucks at end of first user lifetime
[3] Assumed values based on residual value of current diesel trucks at end of first user lifetime
[4] Assumption based on phase-out of diesel vehicles resulting in zero residual value

## TCO results

The above methodology and input parameters can be used to calculate the possible range of truck TCO in each deployment phase. These ranges are shown on the graph below for articulated diesel and fuel cell trucks. The chart for large rigid trucks is shown in the Annex.




This chart shows that in the first two phases of deployment, fuel cell trucks are not able to compete with the incumbent diesel vehicles on a pure ownership cost basis under only the policy mechanisms available today (RED II credits and excise tax on diesel). During these phases, it is therefore expected that policy and regulatory support for zero emission trucks will be required to enable these vehicles to compete with diesel alternatives. This support will further allow the sector to scale up and achieve the TCO shown in the sustainable growth and full industrialisation phases.

While in the sustainable growth and full industrialisation phases, the probable case TCO for fuel cell trucks is still higher than the probable case for diesel trucks, the lower bound scenario for fuel cell vehicles is lower than the diesel probable case. This demonstrates that if ambitious scale and technological improvements to the hydrogen trucking sector are achieved in the coming years, these vehicles can offer customers a preferable TCO over diesel vehicles.

Fuel cell trucks exhibit much greater uncertainty in their TCO over the coming years than diesel trucks. This is due to the relative immaturity of the sector, leading to high variations in the upper and lower bound input parameters for these trucks. As the technology matures and the sector scales up, it is expected that the ranges shown here will become smaller. This will allow the required policy support to be refined based on updated input parameters.

The calculations presented here do not assign a financial value to the economic, environmental, and health benefits associated with zero emission vehicles, as these do not directly affect the TCO for end users. Nevertheless, the roll-out of these solutions are expected to result in significant environmental, health, and economic benefits which justify the need for policy support.

## Achieving lower bound TCO for fuel cell trucks

In the sustainable growth and full industrialisation phases, achieving the lower bound TCO for fuel cell trucks will allow them to offer improved costs over diesel vehicles with no policy support beyond RED II credits and diesel tax. Achieving this lower bound will require the sector to achieve a significant market share, resulting in high volumes of fuel and vehicles being delivered. Technology developments will also be needed to allow the lower bounds to be reached.

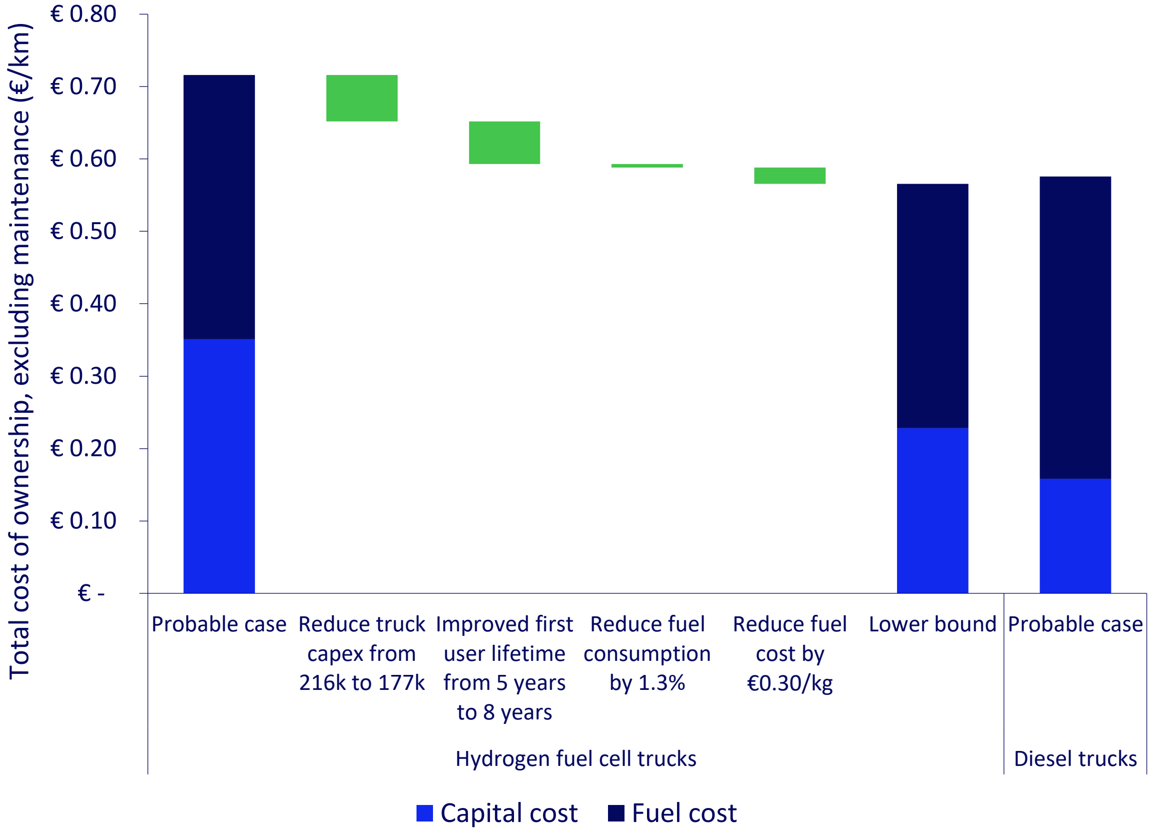
The lower bound for fuel cell truck capital cost assumes that trucks have reached mass market production volumes. In the full industrialisation phase, it is expected that over 50,000 fuel cells are being produced per year if lower bound prices are to be achieved. For comparison, the European market for medium and heavy commercial vehicles was 300,000 in 2019[10]; fuel cell trucks are therefore expected to take up 20% of the market in this scenario. The scale of manufacturing will enable production lines, automated manufacturing, and procurement at scale to bring down the cost of truck and infrastructure components and construction.

Research and development will also be required to achieve the lower bound assumptions, by improving the performance of hydrogen production and refuelling, and fuel cell technology, and reducing the cost of components across the hydrogen supply chain. R&D improvements contribute to the lower bounds of all key uncertainties, by allowing the price of green hydrogen and fuel cell trucks to be reduced, fuel cell truck lifetime to be increased, and fuel consumption improvements.

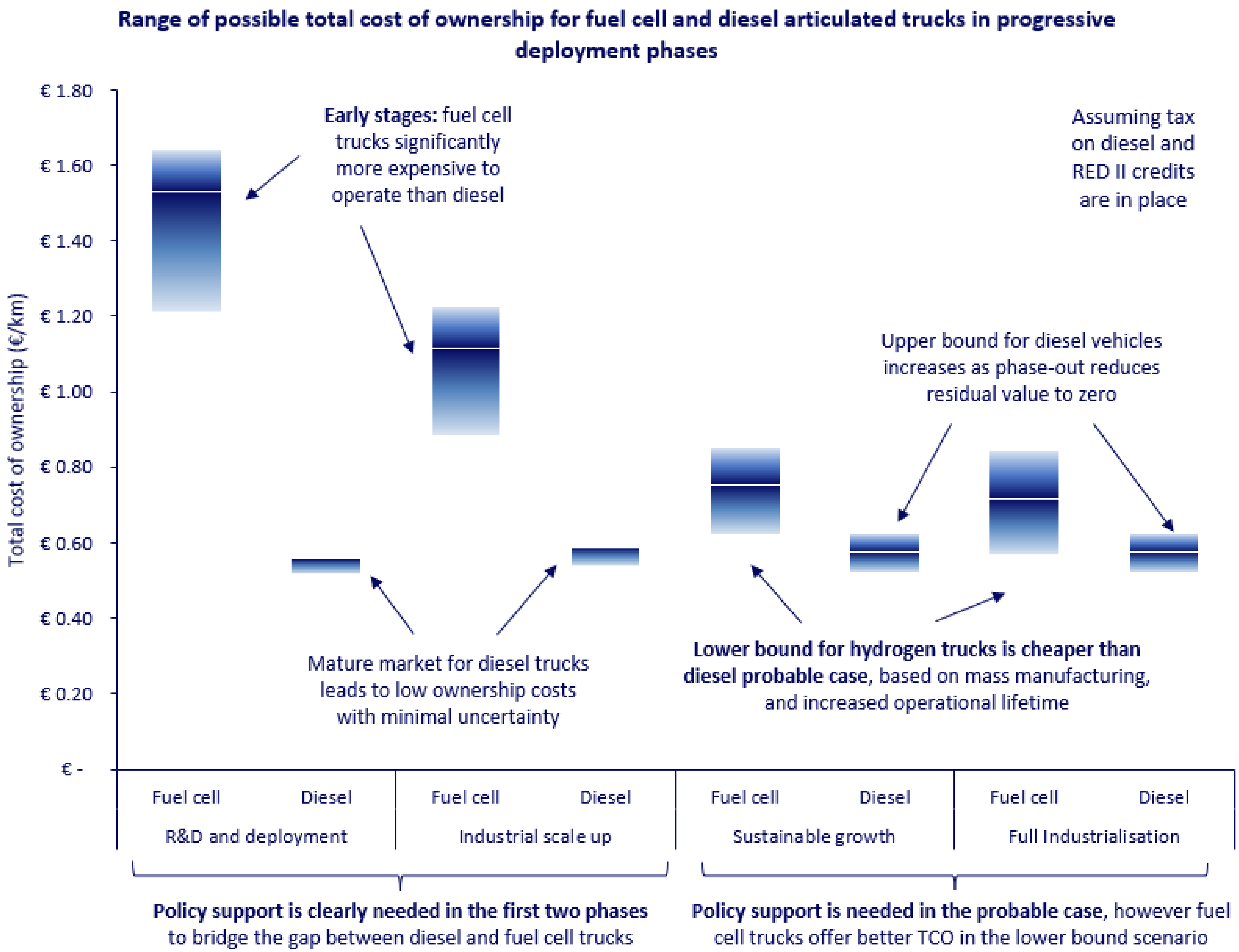
The below chart shows the impact of moving from the probable case to the lower bound assumptions on the TCO for fuel cell trucks in the full industrialisation phase.

[10] Statista (2021) Medium and heavy commercial vehicle market in Europe – statistics & facts

Impact of moving from probable case to lower bound assumptions for articulated fuel cell vehicles in the full industrialisation phase




It is clear that some combination of these movements towards the lower bound will be required in the long term if fuel cells trucks are to offer an improved TCO over diesel vehicles in the absence of policy intervention beyond RED II credits and diesel excise duty.



Range of possible total cost of ownership for fuel cell and diesel articulated trucks in progressive deployment phases
Total cost of ownership (€/km)
€ 1.80
€ 1.60
€ 1.40
€ 1.20
€ 1.00
€ 0.80
€ 0.60
€ 0.40
€ 0.20
€ -
Early stages: fuel cell trucks significantly more expensive to operate than diesel
Assuming tax on diesel and RED II credits are in place
Upper bound for diesel vehicles increases as phase-out reduces residual value to zero
Mature market for diesel trucks leads to low ownership costs with minimal uncertainty
Lower bound for hydrogen trucks is cheaper than diesel probable case, based on mass manufacturing, and increased operational lifetime
Fuel cell
Diesel
R&D and deployment
Industrial scale up
Sustainable growth
Full Industrialisation
Policy support is clearly needed in the first two phases to bridge the gap between diesel and fuel cell trucks
Policy support is needed in the probable case, however fuel cell trucks offer better TCO in the lower bound scenario

# Policy support is needed to scale-up the hydrogen trucking sector

Analysis of fuel cell and diesel trucks ownership costs shows that in the first two phases of deployment, policy support is clearly needed to allow an acceptable TCO for customers and to enable the industry to reach the next scale of deployment. In the sustainable growth and full industrialisation phases, fuel cell trucks will achieve lower TCO than diesel vehicles under lower bound assumptions, but the probable case still sees fuel cell trucks as more expensive than diesel vehicles for end users to operate. In the probable case, policy support from government (beyond the RED II credits and diesel excise duty already included in this analysis) will therefore be required to enable the deployment of fuel cell trucks in all phases.

Element Energy has reviewed the policy options which are being considered across Europe as well as the measures most likely to support each phase of the roll-out. The following sections explore the policy mechanisms that could be used to support fuel cell trucks in reaching parity with diesel vehicles in the first three deployment phases. The below graphic shows the **types of support** that will be needed in each phase.

| R&D and Deployment (2023 – 2026) | Industrial Scale-up (2026 – 2028) | Sustainable Growth (2028 – 2030) | Full Industrialisation (2030 onwards) |
|---|---|---|---|
| • First 100s of trucks in the hands of customers<br>• Limited (but high reliability) refuelling network in clusters<br>• Learning about customer attitudes and interactions with the trucks | • First series produced vehicles emerge<br>• Networks start to expand<br>• High capex/risk<br>• Vehicles still carry a cost premium | • Series produced vehicles available from many manufacturers<br>• Pan-European network on major corridors<br>• Vehicles trending towards an affordable cost base | • Supply chains for trucks and green hydrogen have fully matured<br>• Fuel cell trucks sales make up >20% of heavy-duty vehicle sales<br>• Cost of operating fuel cell trucks minimised |
| **Support required in each phase:** | | | |
| • Mainly **capital support for whole projects** through IPCEI, CH JU, the EU's TEN-T program, and other member state budgets<br>• Policies to promote green hydrogen such as RED II/III, CO2 taxes and road tolls need to be developed | • Ongoing **vehicle purchase support** schemes<br>• Increased reliance on regulations and ongoing policies including CO2 taxation, differential road tolls, and RED II/III credits | • **Market driven by regulatory/policy forces**<br>• Policies include CO2 taxation, differential road tolls, and RED II credits<br>• Increasing use of mandates/bans and soft incentives to support zero emission vehicles | • Policy support measures for hydrogen may be reduced / tax on hydrogen implemented<br>• **Regulatory measures** implemented to phase out diesel vehicles |

Many policy and regulatory options are available to government to support the roll-out of zero emission vehicles. The policy incentives for clean transportation can be broadly split into four categories:

- **Capital subsidies** for trucks and refuelling infrastructure. These can be further divided into:
    - 'Project based' schemes aimed at accelerating the emerging hydrogen sector, where typically both hydrogen trucks and refuelling stations can be funded under the same or related programs. These programs, such as the EU's CEF, Clean Hydrogen Partnership, and the Innovation Fund can provide substantial levels of support per station and per vehicle. Grants are typically

administered based on competitive project applications. A number of member states are considering similar programs, which will be endorsed via the EU's Important Project of Common European Interest (IPCEI) platform.

- Per vehicle support schemes - many national funding programmes currently exist to provide capital grant funding for trucks. However, the review concluded that often the level of support provided through these schemes (typically below €50,000 per truck) is insufficient to make a business case for fuel cell trucks in the current, early stages of deployment where trucks are significantly more expensive than diesel vehicles. The exception to this is in Germany, where a commitment to fund 80% of the cost difference between a zero emission and diesel truck is in place[11]. The German support scheme is seen across the industry as a very useful tool to support early sales.

- **Operating cost support** to reduce fuel cost or road tolls for zero emission vehicles or increase the cost of fuel and road tolls for diesel vehicles. Fuel cost reductions are expected to be achieved through the use of RED II credits for green fuels, while the Eurovignette directive will require member states to implement differential road tolls for zero emission heavy-duty vehicles in the early 2020s (however implementation is expected to be complex and may take longer). The EU already sets a minimum excise duty on diesel of €0.33/l through the Energy Tax Directive, which effectively increases the cost of diesel and therefore the cost of operating diesel vehicles[12]. The price of diesel fuel is also increased by the use of $CO_2$ tax, which is applied through a number of national schemes[13]. Under Fit for 55 the European Commission has proposed that an updated version of the Emissions Trading System, which will cap and trade emissions from road transport, effectively increasing the cost of diesel[14].
- **Soft incentives** which do not provide direct financial support but improve operational conditions for zero emission vehicles through road access, parking, curfews, etc. A number of large European cities are proposing zero emission zones as early as 2025, which can be expected to create a considerable driver for zero emission vehicles of all types. In addition, the creation of zero emission corridors on motorways could have a significant impact on logistics operator technology choice.
- **Mandates** for zero emission vehicles and the associated infrastructure could support a robust and aligned rollout of hydrogen vehicles. Should a member state ban heavy-duty diesel engines, they should have a clear plan in place to enable the cost-effective transition to hydrogen vehicles. Europe has already implemented regulation to reduce the emissions from heavy-duty vehicles in 2019, which requires manufacturers to reduce the average emissions from their fleets by 15% from 2025 and 30% from 2030, compared to a 2019 - 2020 reference period[15]. The

[11] NOW GmbH (2021) *EU approves new funding guideline for commercial vehicles with alternative drive systems – funding guideline and funding call published*
[12] European Commission (2003) *Excise duty on energy*
[13] Tax Foundation (2021) *Carbon taxes in Europe*
[14] European Commission (2021) *Questions and Answers - Emissions Trading – Putting a Price on carbon*
[15] European Commission (2019) *Reducing CO2 emissions from heavy-duty vehicles*

Fit for 55 package, published June 2021, included a revision of the Alternative Fuels Infrastructure Directive (AFID), now a proposed Regulation, to include a target of hydrogen refuelling stations every 150km on TEN-T networks. Within their National Policy Frameworks, member states should be required to demonstrate demand is aligned with these targets and when installations are anticipatory of demand member states should offer funding or support for those sites which may be underutilised initially.

The Element Energy analysis has assessed the impact of a selection of plausible policies on achieving TCO parity between fuel cell and diesel trucks, based on policies that may be implemented across the EU in the coming years. This analysis has been used to develop concrete recommendations for the policies that will need to be implemented in each phase if ownership cost parity is to be achieved. This was calculated by adding policy support to either increase (shown in red) or decrease (shown in green) a probable case TCO for fuel cell and diesel trucks. Baskets of policy measures which can enable TCO parity have then been demonstrated to show how these measures can lead to cost parity and quantify the scale of policy intervention needed.

In addition to the excise duty on diesel and RED II credits, the Element Energy study shows that the following policy measures are the most plausible way that cost parity can be reached in each phase:

**Policy and funding to support hydrogen price**

Members of H2Accelerate are prepared to invest in the development of a pan-European infrastructure to support hydrogen trucking, and believe that the hydrogen prices stated in the TCO analysis can be achieved subject to:

- Funding support for production facilities and stations as part of the support package for early projects.
- RED II credits being available for green hydrogen across all deployment phases, under the same treatment that is currently made available for advanced biofuels.

This support is assumed to be in place for the stated hydrogen prices to be achieved and is not quantified in the below policy analysis.

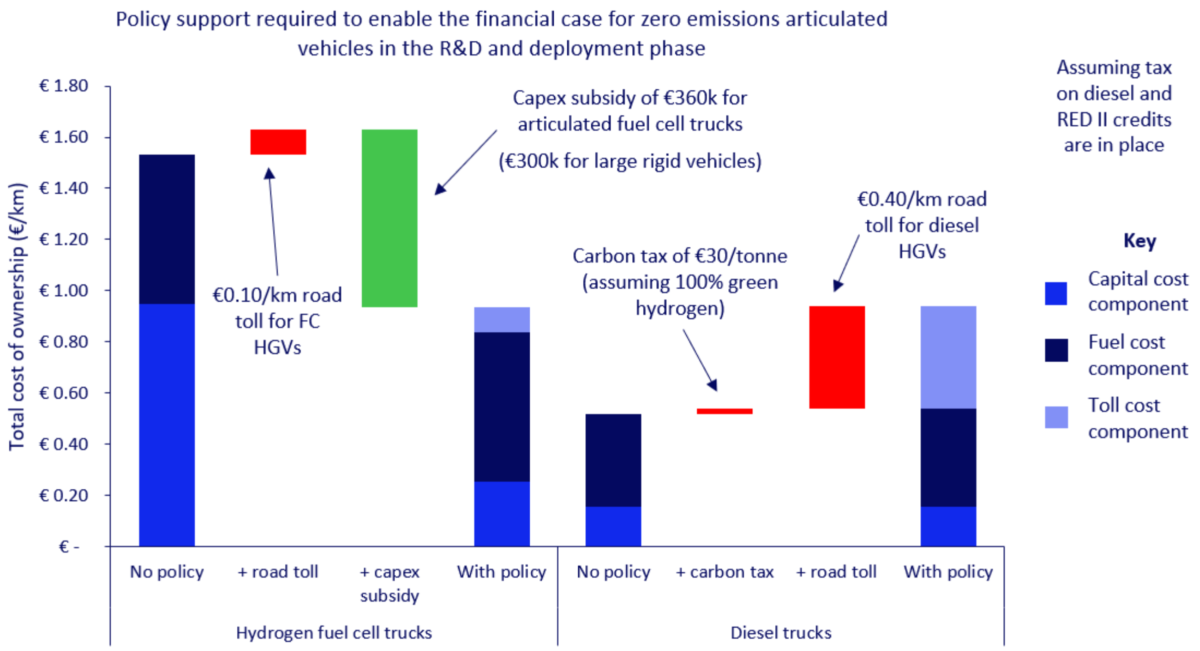
- **Capital subsidy for the early years**: applied as a direct reduction to the capital cost of the vehicle to allow cost parity between fuel cell and diesel vehicles after other policy measures are applied. The level of capital subsidy will be reduced through time, and this policy measure is expected to be unnecessary by the sustainable growth phase. The expectation is that in the early years the 'project based' subsidy schemes will be used to enable linked support between truck and refuelling station roll-out. As costs decrease this can evolve to a more generic per vehicle support scheme (with a lower per vehicle grant), without requiring the creation of specific projects to fund individual purchases.
- **Differential road tolls:** calculated a per km driven basis. The analysis below suggests a rate of €0.40/km for diesel vehicles, and fuel cell vehicles receiving a 75% discount to €0.10/km will help to create parity for zero emission vehicles. This is consistent with the road toll charging methodology in the Eurovignette directive.
- **Carbon tax:** applied as an increase to the cost of diesel, and calculating by multiplying a carbon price (in €/tonne) by the carbon intensity of diesel, based on stochiometric combustion $CO_2$ emissions of $2.62 \times 10^{-3}$ tonne $CO_2$/l. While the carbon price in the

new emissions trading system for road fuels proposed in the Fit for 55 package is not yet known, Germany has proposed an emissions trading system for transport and heating which was used to model $CO_2$ prices through time in this study. The scheme will place a $CO_2$ price of €30/tonne on road fuels in 2022 (R&D and deployment phase), increasing to €55/tonne in 2025 (industrial scale-up phase), and €55-€65/tonne in 2026 (modelled as €60/tonne in the sustainable growth phase, with prices determined by the market in 2027 and beyond[16]. The magnitude of $CO_2$ tax can be expected to grow over time, giving increased flexibility to reduce the magnitude of other policy support mechanisms for hydrogen or introduce a tax on hydrogen in the 2030s. The hydrogen is assumed to be produced from renewable electricity, and therefore hydrogen price is unaffected by a carbon tax.

The below analysis shows how a combination of these policy measures allow fuel cell trucks to reach cost parity with diesel in the R&D and deployment, industrial scale-up, and sustainable growth phases.

## Funding first fuel cell trucks in the 'R&D and deployment' phase

In the first stages of fuel cell truck deployment, a significant gap exists between the TCO of fuel cell and diesel vehicles due to limited manufacturing volumes and relative immaturity of the hydrogen and fuel cell truck supply chain. The implementation of differential road rolls of €0.40/km for diesel and €0.10/km for zero emission trucks, and a €30/tonne $CO_2$ tax improves the business case for fuel cell trucks. Even with these interventions, a significant capital subsidy of €360k for articulated and €300k for large rigid trucks is expected to be required for trucks to achieve cost parity, as shown in the below chart. The equivalent charts for large rigid vehicles are shown in the Annex.




[16] Clean Energy Wire (2021) Germany's carbon pricing system for transport and buildings

Note that the above differential road tolls, $CO_2$ tax, and truck capital subsidy are applied in addition to the support already assumed in the probable case - tax on diesel and RED II credits for green hydrogen.

This early stage will be used to gather learnings for truck OEMs on the performance of fuel cell trucks under normal operating conditions, therefore trucks should be driven as many miles as the equivalent diesel vehicles. Further, ensuring fuel cell trucks drive at least as many miles as diesel vehicles will lead to a guaranteed level of hydrogen demand, which creates a more secure business case for infrastructure operators, encouraging further roll out.

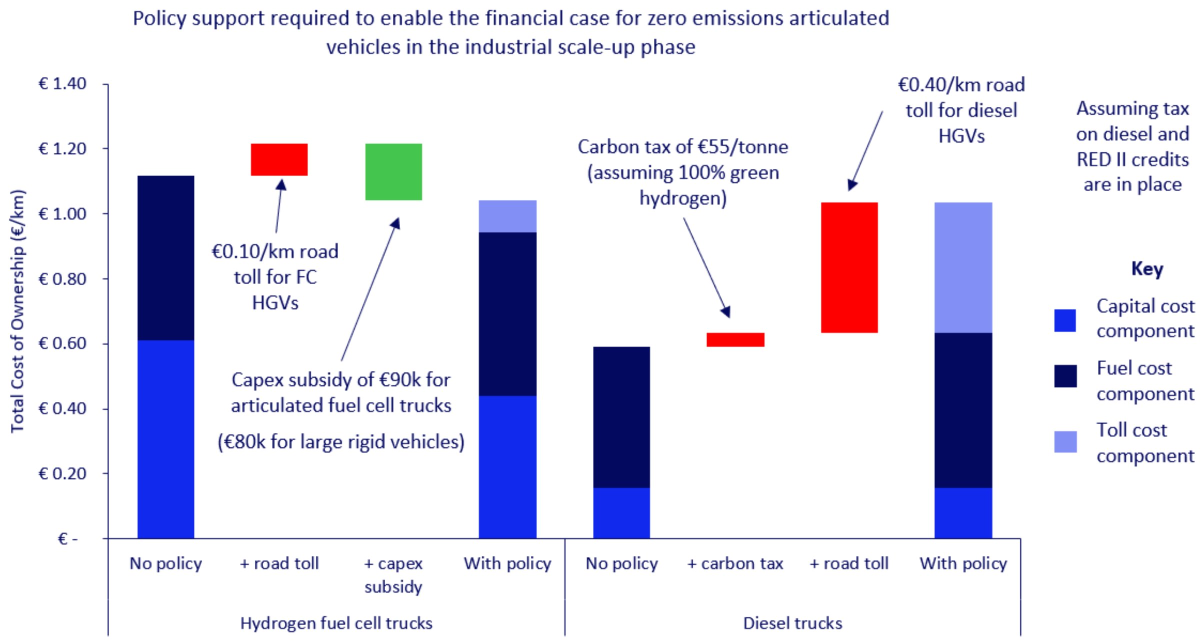
Maximising the miles driven by trucks in the early stages can present a challenge, as refuelling networks will be limited to a small number of high-capacity stations along key corridors. It is therefore clear that any deployments in the R&D and deployment phase need to be structured in defined projects, where trucks and infrastructure are deployed simultaneously, and end users are obliged to drive the trucks for a set minimum number of miles per year in order to justify the required capital grants for vehicles.

A first estimate for the funding requirement in the R&D and deployment phase can be calculated from the above policy support requirement, plus a level of support for hydrogen refuelling stations. Assuming an average of €3m of funding is required to support the deployment of a hydrogen truck refuelling station, and that this phase of deployment will require ~25 refuelling stations and ~500 trucks, a total funding amount of ~€240m will be required. While this is only an order of magnitude calculation, it demonstrates the significant commitment to hydrogen truck deployments required to enable the completion of this first phase.

## Reducing funding levels during the 'Industrial scale-up' phase

Following the first deployments in the R&D and deployment phase, new learnings and increasing manufacturing volumes allow the TCO of fuel cell trucks to be significantly reduced. Even so, these vehicles remain more expensive to operate than their diesel equivalents.

It is in this phase that a European carbon tax on road fuel emissions can be expected, in addition to existing policy support from RED II credits, differential road tolls, and diesel excise tax. This combination of operating cost support will enable the required capital grant to be reduced to €90k for articulated fuel cell trucks, and €80k for large rigid trucks, as shown in the below graphic.



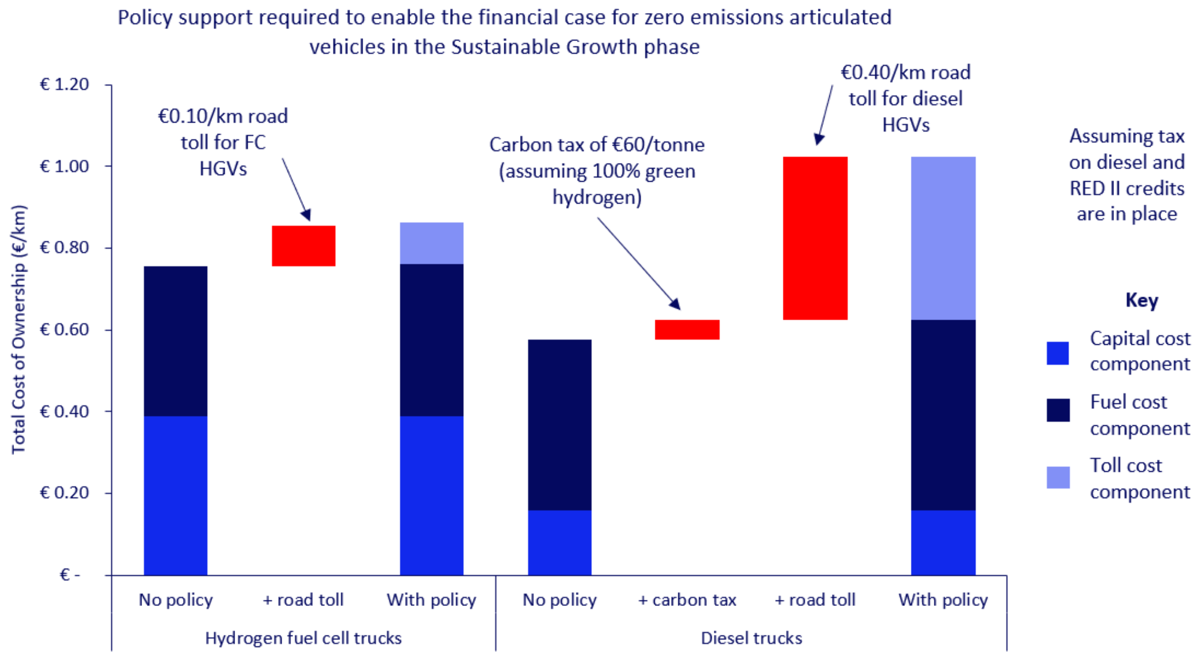

In addition to policy support the above recommendations, other policy mechanisms that do not provide direct financial support to the industry are expected to start to be implemented by this stage. For example, specific zero emissions zones or corridors where diesel vehicles are not permitted to operate (or are charged a fee to do so). Low emission zones are currently in operation across a number of European countries (including Germany, Italy, the Netherlands, France and the UK)[17], with several zero emission zones planned in urban areas over the coming years (e.g., in 14 cities across the Netherlands from 2025, in Paris from 2030)[18]. Zero emission zones could be increasingly deployed on freight corridors that have good access to zero emissions infrastructure to increase demand for hydrogen vehicles (hydrogen refuelling stations and charge points). These schemes will naturally create clusters with higher density of deployment of fuel cell vehicles compared to locations who have not implemented these measures.

# Transitioning to long-term policy support in the 'Sustainable Growth' phase

While it is possible that the TCO of fuel cell trucks will be lower than that of diesel vehicles in the sustainable growth phase if lower bound parameters can be achieved, under the more probable case assumptions zero emissions trucks will still require policy support in this phase of deployment.

In the sustainable growth phase, the cost of operating fuel cell vehicles has decreased sufficiently so that a combination of RED II credits, diesel excise tax, additional carbon tax on road fuels, and differential road tolls can be used to improve the TCO of fuel cell trucks beyond that of diesel trucks, as shown in the below chart.

[17] Urban Access Regulations in Europe (2021)
[18] electrive.com (2021) *Dutch Municipalities to set up zero emission zones by 2025*




Under this policy regime, the TCO of fuel cell trucks is significantly better than the TCO of diesel vehicles, encouraging the rapid uptake of zero emission vehicles by operators across Europe, implying thousands to tens of thousands of vehicle sales per year. This will create a self-sustaining mass market for fuel cell trucks.

Only during the sustainable growth phase, once the market for zero emission trucks is fully developed and able to meet end user needs, and sustainable policy support can be used to achieve cost parity between diesel and zero emission vehicles, should the European Commission consider implementing restrictions on the sale of new diesel vehicles. Implementation of this regulation following attainment of cost parity and market scale-up will prevent a step-change in the cost of operating heavy-duty vehicles and therefore the cost of freight services for end users.

## Summary of the policy support needed to enable a hydrogen trucking system at scale in Europe

It is clear that additional policy support to that already in place today will be required to enable the deployment of fuel cell trucks and subsequent scale-up of the hydrogen truck market. The below table summarises the recommendations for policy support across the first three phases of fuel cell truck deployment.

| Policy measure | Unit | R&DD | ISU | SG | Value used in analysis |
|---|---|---|---|---|---|
| Diesel excise tax | €/l | | | | €0.60/l<br>Included in diesel price |
| RED II renewable hydrogen credits | €/kg | | | | Dependent on market<br>Included in hydrogen price |
| Capital support through CEF, FCH JU, Innovation Fund, IPCEI, etc. | € | | | | Dependent on phase and truck type - see below |

| Policy measure | Unit | R&DD | ISU | SG | Value used in analysis |
|---|---|---|---|---|---|
| Differential road toll | €/km | | | | €0.10/km for zero-emission trucks<br>€0.40 for diesel trucks |
| Carbon tax on road fuels | €/tonne | €30 /tonne | €55 /tonne | €60 /tonne | €30, €55, and €60/tonne in subsequent phases<br>Additional to diesel excise tax |

**Key**

R&DD – R&D and Deployment ISU – Industrial Scale-up SG – Sustainable Growth

■ Expected in this phase ☐ Not expected in this phase

| Expected capital support required per truck | | |
|---|---|---|
| **Vehicle type** | **R&D and deployment phase** | **Industrial scale-up phase** |
| Large rigid | €300k | €80k |
| Articulated | €360k | €90k |

Note that whilst the policy measures are expected to decrease the level of intervention through time, it will be important that they are 'grandfathered'. This means that a measure designed to influence the TCO for a purchase in, for example, 2025, remains in place for the expected life of that vehicle and is not reduced as newer models arrive. This grandfathering will be an important part of policy design and will increase the confidence of customers committing to purchase in a given year and against a given set of policy interventions.

Beyond the sustainable growth phase, policy measures to support fuel cell trucks may not be required if certain technological and scale improvements to ownership cost can be achieved. The level of ongoing policy support required for new vehicles sold in the mid-2030s will be strongly dependent on the speed at which the sector can scale up in the preceding decade. This can be accelerated by a strong signal from government in favour of zero emission freight.

In addition to policy support that directly financially supports fuel cell trucks, other policy mechanisms that do not provide direct financial support to the industry could also increase the uptake of fuel cell trucks. These could include the implementation of zero emission zones, increasingly stringent vehicle $CO_2$ standards (as implemented in 2019 and to be reviewed in 2022), mandates for zero emission trucks and refuelling infrastructure (through the alternative fuels infrastructure directive, updated through the Fit for 55 proposal), and bans on diesel vehicles.

While each of these policy mechanisms have the benefit of stimulating the zero-emission truck market without needing significant financial intervention from government, they are unlikely to allow the fuel cell truck market to reach mass deployment alone. H2Accelerate members consider that a well-selected number of non-financial incentives for zero emission trucks could be complimentary to the financial policy measures discussed.

# Support for fuel cell trucks during scale-up may enable parity in the next decade

While the expected costs of operating of fuel cell trucks face large uncertainties, it is clear that policy support will be needed to allow end users to achieve a TCO comparable with that of diesel trucks in the near- and mid-term. By providing support in the form of capital grants in the first two phases of deployment (in addition to green hydrogen support, differential road tolls, and carbon tax plus the already in place excise duty on diesel), the state will enable the development of technology and demonstration of its viability. If fully mature series manufacturing of trucks and low-cost hydrogen refuelling can be achieved, policy support measures will be able to be progressively removed as hydrogen becomes increasingly cost competitive with diesel. This is dependent on several of the following 'lower bound' assumptions occurring:

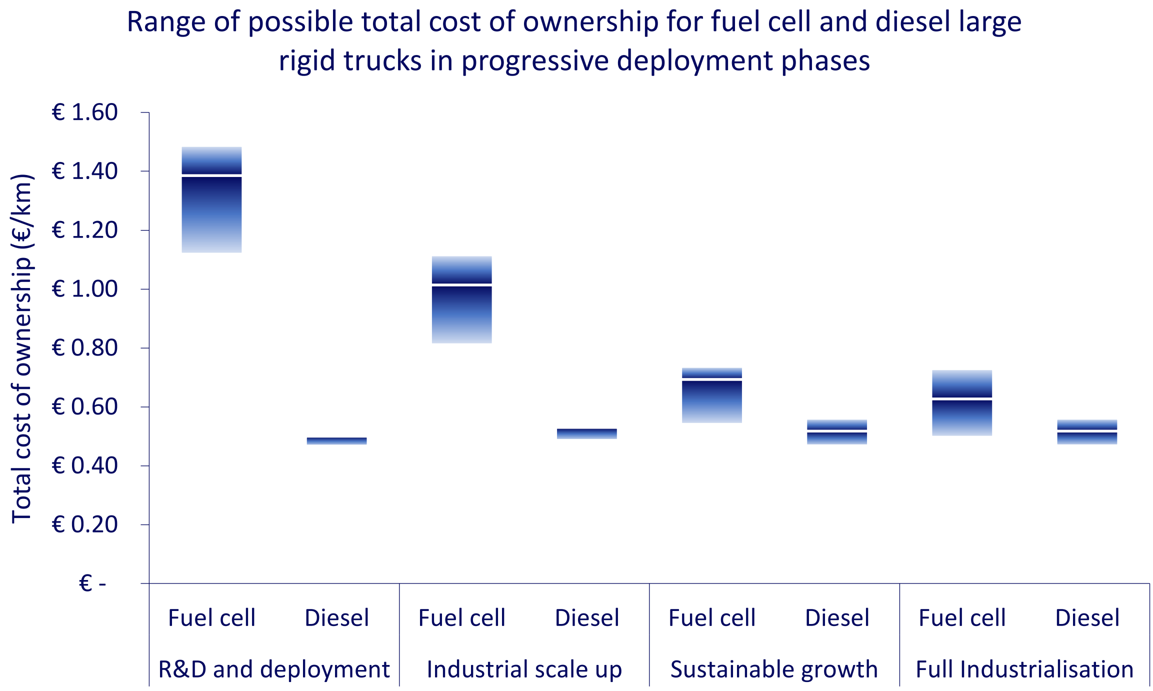
- Fuel cell truck manufacturing scaling up to >50,000 units per year
- R&D leading to reduced manufacturing costs of on-board hydrogen storage tanks and fuel cells
- Fuel cell trucks requiring sufficiently low maintenance that their first user lifetime can be extended from 5 to 8 years
- Regulatory support to allow electrolyser operators to access low-cost renewable electricity
- R&D leading to improved electrolyser and fuel cell efficiency
- Developing the supply chains and transitioning to mass manufacturing for both electrolysers and hydrogen refuelling station components
- Sufficient market demand to allow large-scale (>5,000kg/day) stations to be highly utilised

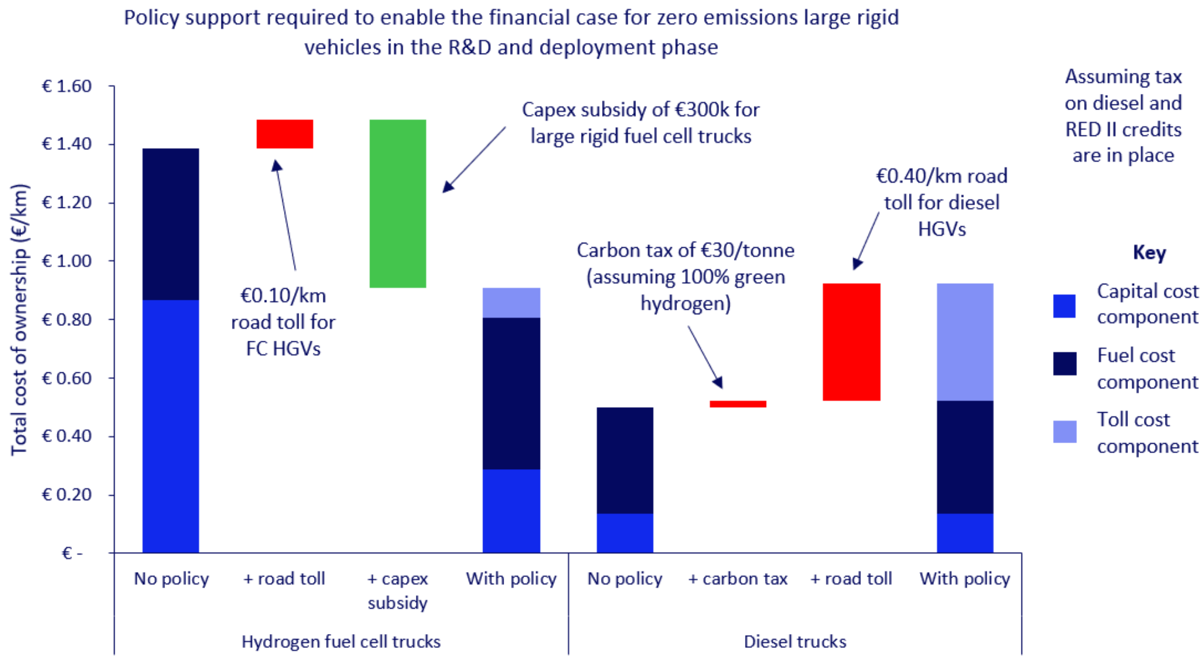
If the lower bound values cannot be achieved by the sustainable growth phase, it is expected that policy support in the form of a carbon tax of €60/tonne and differential road tolls (€0.10/km for zero emission trucks and €0.40/km for diesel trucks) can allow fuel cell trucks to achieve a lower TCO than diesel trucks.

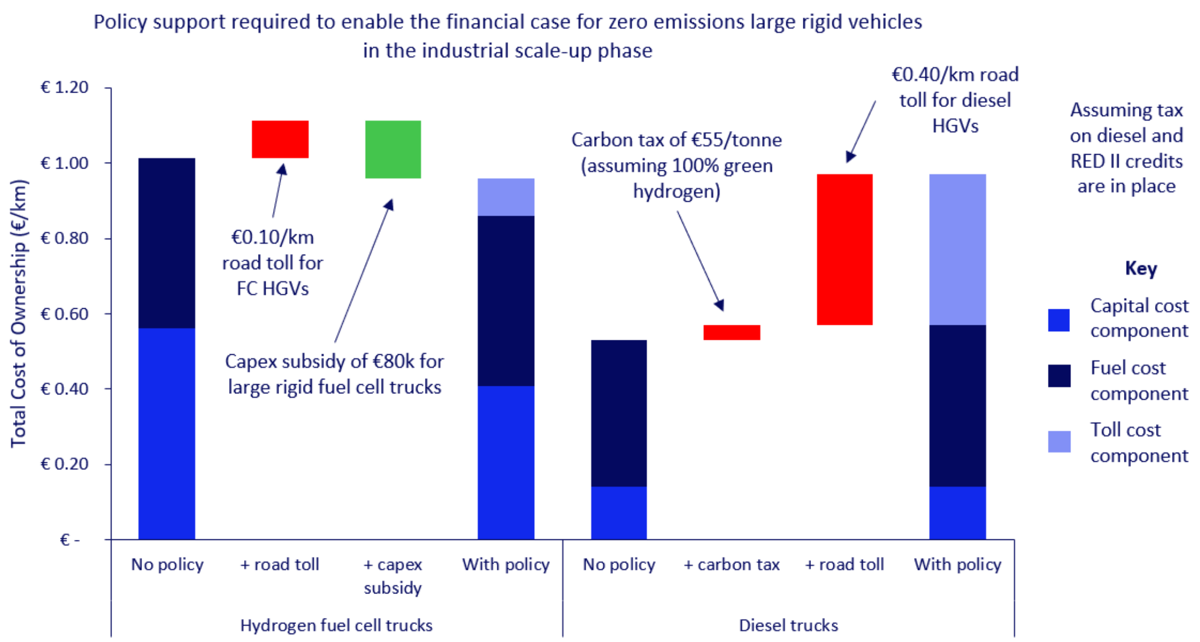
The success of the sustainable growth phase is expected to lead to a full industrialisation phase, with fuel cell truck manufacturing scaling up to >50,000 units per year. This will allow the supply chains for trucks and hydrogen value chain components to mature, leading to further cost reductions. In addition, the level of hydrogen demand could support the development of a national hydrogen pipeline network that can be accessed by hydrogen stations, leading to significant reductions in the cost of hydrogen at the pump.

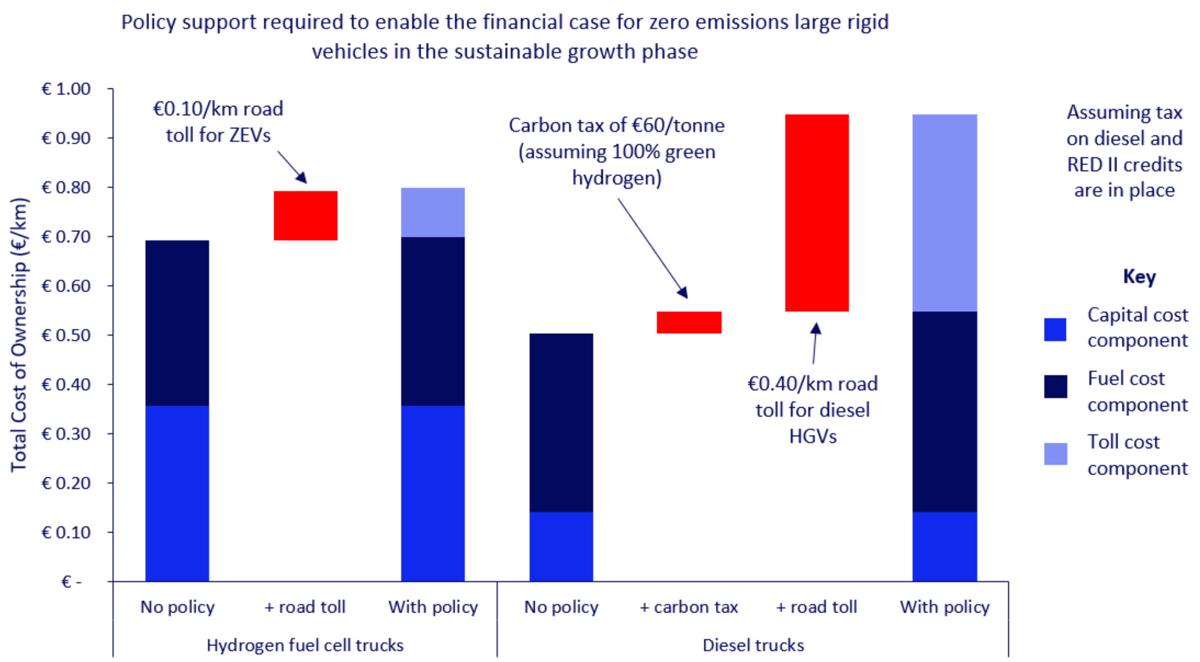
The member companies of the H2Accelerate collaboration: Daimler Truck AG, IVECO, Linde, OMV, Shell, TotalEnergies, and Volvo Group, are fully ready and willing to both support policymakers to develop the required policy measures to unlock the fuel cell truck market, and to invest in the scale-up of infrastructure to reach mass manufacturing in the coming decade.

# Annex: TCO and policy support for large rigid vehicles




Policy support required to enable the financial case for zero emissions large rigid vehicles in the industrial scale-up phase
Total Cost of Ownership (€/km)
€ 1.20
€ 1.00
€ 0.80
€ 0.60
€ 0.40
€ 0.20
€ -
€0.10/km road toll for FC HGVs
Capex subsidy of €80k for large rigid fuel cell trucks
Carbon tax of €55/tonne (assuming 100% green hydrogen)
€0.40/km road toll for diesel HGVs
Assuming tax on diesel and RED II credits are in place
No policy
+ road toll
+ capex subsidy
With policy
No policy
+ carbon tax
+ road toll
With policy
Hydrogen fuel cell trucks
Diesel trucks
Key
Capital cost component
Fuel cost component
Toll cost component


Policy support required to enable the financial case for zero emissions large rigid vehicles in the sustainable growth phase
Total Cost of Ownership (€/km)
€ 1.00
€ 0.90
€ 0.80
€ 0.70
€ 0.60
€ 0.50
€ 0.40
€ 0.30
€ 0.20
€ 0.10
€ -
€0.10/km road toll for ZEVs
Carbon tax of €60/tonne (assuming 100% green hydrogen)
€0.40/km road toll for diesel HGVs
Assuming tax on diesel and RED II credits are in place
No policy
+ road toll
With policy
No policy
+ carbon tax
+ road toll
With policy
Hydrogen fuel cell trucks
Diesel trucks
Key
Capital cost component
Fuel cost component
Toll cost component