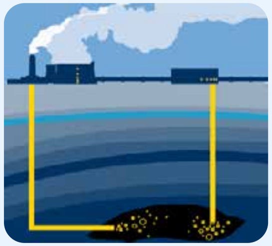

Economic Case for Hydrogen Buses in Europe

This is a summary of a report commissioned by Ballard Power Systems

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BALLARD®

May 2017

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This document sets out a high-level analysis of the European impact of fuel cell bus deployment in Europe

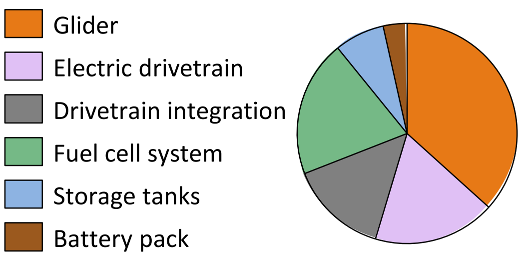
Overview of the analysis

- This analysis was commissioned by Ballard Power Systems (a provider of fuel cells for hydrogen fuelled buses)
- This analysis aims to assess the economic impact for Europe due to the deployment of fuel cell buses vs their two main competitors, diesel and battery electric buses
- The report is based on a simple, first principles analysis of the economic value, using unbiased assumptions about the source of components and fuel
- It is not a comprehensive economic modelling analysis, but uses quantitative data to point to some of the main drivers of economic value which we would expect to see in a modelling exercise of that complexity
- It is important to bear in mind that the analysis here is fairly high level, and is subject to a series of uncertainties, such as projecting future trade flows for technologies only emerging today, and cost down projections
- We developed a simple model of the overall lifetime ownership cost of the three technologies both today and in 2025, each of the components of this ownership cost will either add value to Europe or export it
- The model assigns a percentage of European value and exported value to each TCO component for vehicle capital costs, operating costs of the vehicle and the fuel supply
- These percentages are either derived from standard European estimates of the indigenous vs imported share of the main components, or based on assumptions regarding their sourcing
- Sourcing of fuel cells and battery packs are based on European estimates but have also been treated as sensitivities

The model consists of 3 successive steps: cost breakdown, European value estimates and a lifetime value creation analysis

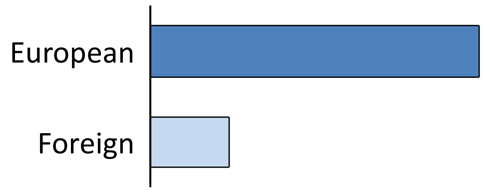
Value Creation from bus CAPEX and OPEX

The capital and operational costs of the buses from 2017 - 2030 are estimated & broken down to the component level



Cost breakdown on FC bus in 2020 (based on Ballard estimates)

The proportion of European value for each bus component is estimated



FC bus CAPEX value creation by geography in Thousand Euros (2020)

Value creation from fuel production and retailing

The different cost components of producing and dispensing fuel are estimated. We consider

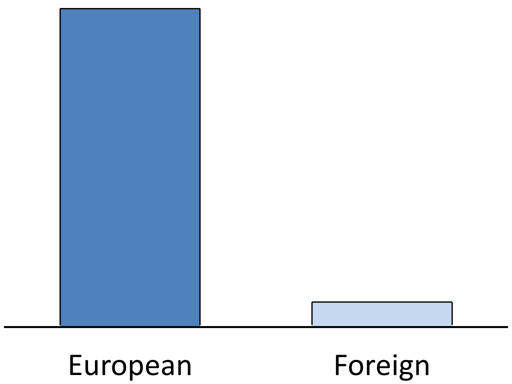
- Grid electricity
- Diesel
- Electrolytic and SMR hydrogen

European value proportions are used to estimate the relative share and value creation for each fuel. This includes:

- Fuel costs (e.g. natural gas, crude oil)
- and equipment costs (e.g. electrolysers, power generation)

Lifetime value creation analysis

Via a series of operational and technical assumptions, the lifetime value creation in Europe and abroad is estimated for each bus type.



Total FC bus value creation by geography in Thousand Euros (2020)

These value creation estimates are projected forwards using an estimate of bus uptake to illustrate a total value created for the European economy

The majority of European value assumptions for buses are based on trade flows for Europe from 2015 in the Eurostat PRODCOM database

Bus costs and operation

- Assumptions regarding overall bus component costs are based on bilateral discussions between Element Energy and European bus OEMs
- For the 2020 fuel cell bus, costs are based on Ballard, *Fuel Cell Electric Buses: An attractive value proposition for zero-emission buses in the United Kingdom.*
- Other costs are based on discussions with manufacturers, and the data collected in Roland Berger Strategy Consultants for the FCH JU: Fuel Cell Electric Buses – Potential for Sustainable Transport in Europe (2015) and McKinsey & Company for the FCH JU: Urban Buses, alternative powertrains for Europe (2012)
- Operational assumptions are based on the findings of the NewBusFuel project and can be found in the annex

European value proportions

- Most value estimates are based 2015 entries in the Eurostat *PRODCOM* database
- This provides breakdowns of European import, export and production values for different commodities
- The proportion of value created by these components in Europe is based on the following equation:

(Production – Exports) / (Production – Export + Import) = Proportion of European value

- Some other components (e.g. battery value and fuel cell value proportions) are based on discussions with suppliers. In the case of battery packs, these are estimated for the dominant supplier of current European battery buses (BYD) pack, and fuel cell proportions are based on Ballard products

*Please note, that in some cases, due to inconsistencies within the database, this approach can lead to value proportions greater than 100%, where this is the case 100% European value is assumed

A summary of all assumptions is set out in the annex of this pack

Overview of assumptions

To interpret the outputs, the assumptions made on European value shares are critical and these are summarised in the annex (slide 41 onwards) as well as in the annex of the main report. At a high level the main assumptions made are:

- **Oil, gas, coal and nuclear fuels:** given Europe’s dependence on imported fuels, it is assumed that any consumption of these fuels increase reliance on imports of fuel.
- **Bus chassis:** are primarily sourced in Europe.
- **Electric and diesel drivetrain components:** are primarily sourced from Europe and based on labour in Europe for all bus types.
- **Batteries and charging infrastructure:** based on existing electric buses in Europe, it is assumed that cells are sourced from outside Europe, but packs are assembled in Europe. It is also assumed that the charging infrastructure is produced outside of Europe. The sensitivity to fully European cell manufacture is also considered.
- **Fuel cells stacks and balance of plant:** are assumed to result in predominantly foreign value, as the two main fuel cell manufacturers are currently outside of Europe – the sensitivity to on-shoring and offshoring this manufacture is also considered.
- **Hydrogen production and dispensing equipment:** are assumed to be produced in Europe, given manufacture of the hydrogen fuelling systems, electrolysers and steam methane reformation plants in Europe today are dominated by European companies, and in a few cases foreign companies with a significant European manufacturing base.
- **Hydrogen tanks and piping:** in expectation of success from the ongoing development of 350 bar tanks systems in Europe, we assume the majority sourcing of tanks from Europe.

Introduction

Bus CAPEX and OPEX supply chain

Fuel supply chain

Overall results

Sensitivity results

Additional benefits of zero emission buses

Annex

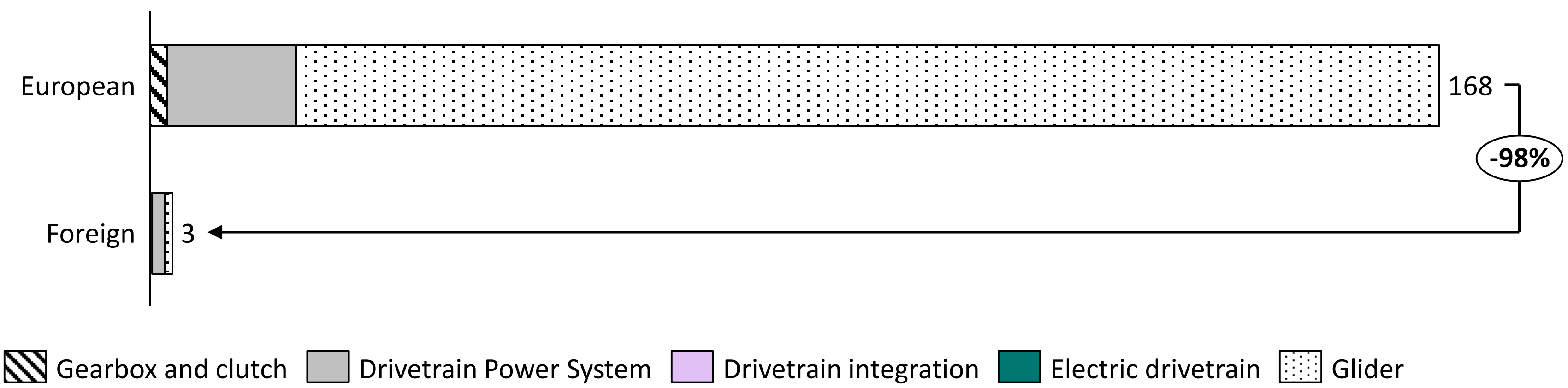
The CAPEX of a diesel bus is assumed to result in almost entirely European value

State of the European bus market

- Europe has a strong value chain with respect to motor engines, large passenger vehicle chassis and their auxiliary components.
- Thus, the value generated by the capital costs of a diesel bus is assumed to be almost exclusively European.
- This analysis assumes that the cost, and supply chain value of diesel buses will remain stable up to 2030 .
- All the operational and maintenance value for diesel buses (excluding fuel costs) have been assumed European, aside for one system overhaul over the buses lifetime, which is assumed to have the same ratio of European to foreign value as above*

Diesel bus CAPEX

Thousand € / bus



Based on estimates from http://appsso.eurostat.ec.europa.eu/nui/show.do

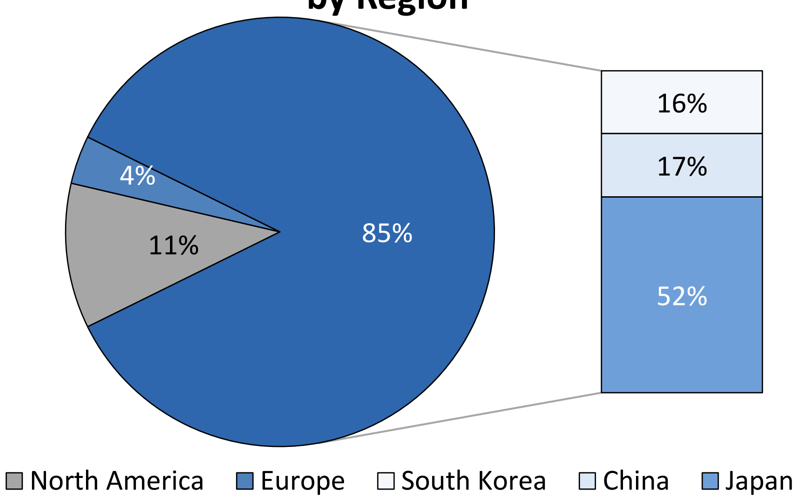
* this overhaul is assumed for all bus types and is included as an OPEX item in the overall analysis

European OEMs have strong capability in electric drivetrain integration, but cell manufacture is dominated by Asian companies

European market for battery electric drivetrains

- Electric drivetrain systems underlie both fuel cell and battery electric buses
- European bus OEMs usually procure electric drivetrain systems from other European companies such as BAE, Siemens, Vossloh, ZF and Voith[1]. An exception to this is Volvo which manufactures its own drivetrains[2].
- Thus, Europe has a strong manufacturing capacity with respect to electric drivetrains
- Conversely, the automotive battery market is dominated by Asian manufacturers, many of which are Japanese and Korean. The estimated market shares of different regions are presented below
- Many of these manufacturers are focussed on producing batteries for smaller vehicles, and hence the of the dominant player in the European bus market is BYD
- In this arrangement, the vehicles are manufactured by Alexander Dennis, and BYD supply the core drivetrain technology including the battery
- Thus, the European supply chain for automotive batteries is relatively weak

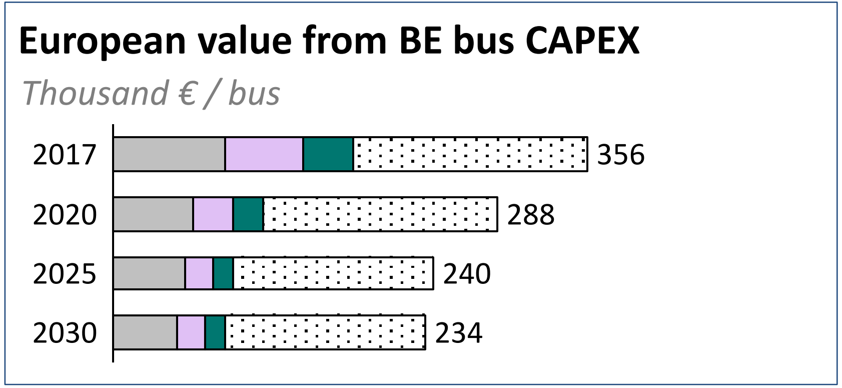
Proportion of global Automotive Cell Manufacture by Region[3]

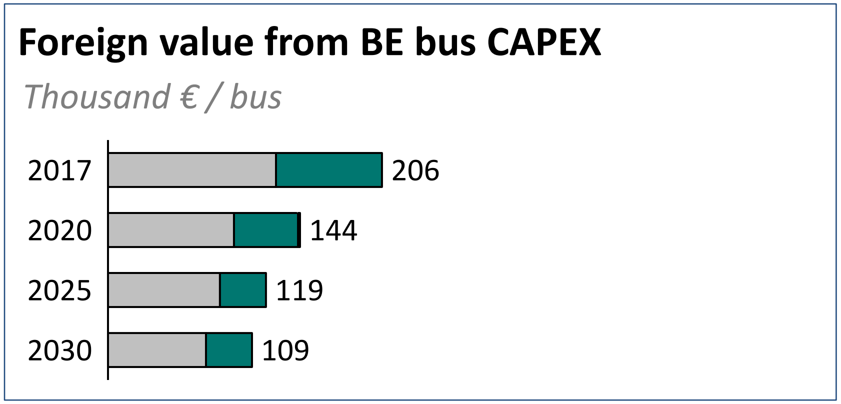


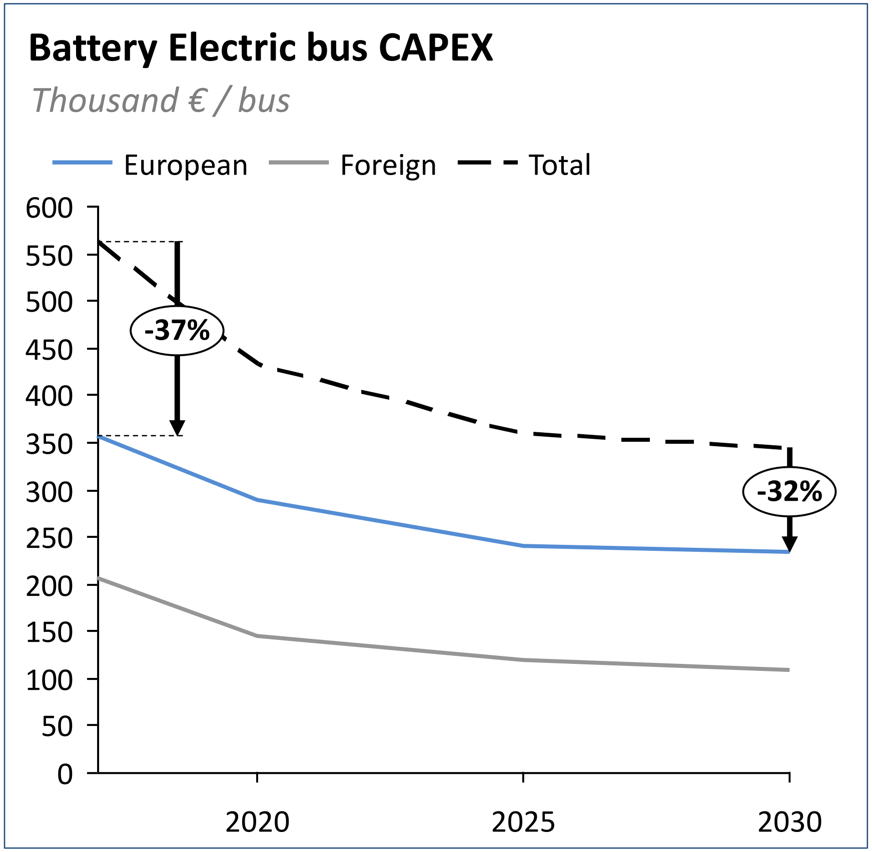
1: Frost and Sullivan (2013)
2: Fraunhofer MOEZ: *Techview Report Electric Buses*
3: Based on Roland Berger for FKA (Forschungsgesellschaft Kraftfahrwesen mbH Aachen): *E-Mobility Index Q3 201*

60-70% of the value generated by a battery electric bus is assumed to remain in Europe

Analysis of the value creation in Europe from the production of a battery electric (BE) bus, suggests that 60-70% of the value generated by the CAPEX remains in Europe







The fuel cells and batteries used in Europe's fuel cell buses are largely sourced from outside Europe

Sourcing of fuel cell components and hydrogen production equipment

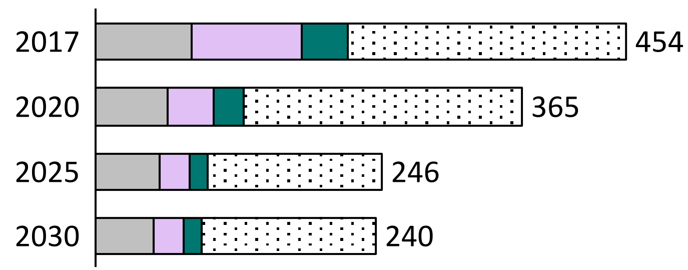
- As is the case with battery electric buses, chassis and drivetrains are largely produced in Europe, however, the -relatively small- batteries used in fuel cell buses are largely sourced from Asia
- The major manufacturers and providers of large fuel cell stacks to Europe are Ballard and Hydrogenics, which are both based outside of Europe
- Europe is a leader in the manufacture of hydrogen production, dispensing and distribution equipment. More specifically:
  - **Electrolysers:** much of the value created by this retailing is likely to be retained in Europe, as a number of leading hydrogen production equipment companies are European including Siemens, McPhy, ITM Power and NEL. The exception to this is Hydrogenics, which is a Canadian company, but has significant manufacturing within Europe.
  - **Steam Methane Reformers:** major European manufacturers for road fuel production include Johnson Matthey , Linde and HyGEAR.
  - **Hydrogen refuelling infrastructure:** a number of European companies have been responsible for the development of hydrogen refuelling equipment, including Linde (via ATZ), H2Logic, Air Liquide, McPhy and Attawey. In addition to this, the earliest forecourt operators, such as Shell, are European companies.
- Like battery electric buses, fuel cell electric buses are expected to undergo significant cost reductions over the next decade

Roughly 70% of the value generated by a fuel cell bus is expected to remain in Europe

Overall, the assumptions underlying this analysis (see annex) suggest that roughly 70% of the value creation resulting from a fuel cell bus's CAPEX results in European value.

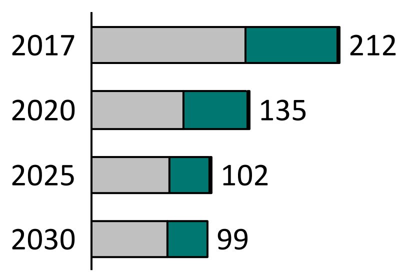
European value from FC bus CAPEX

Thousand € / bus



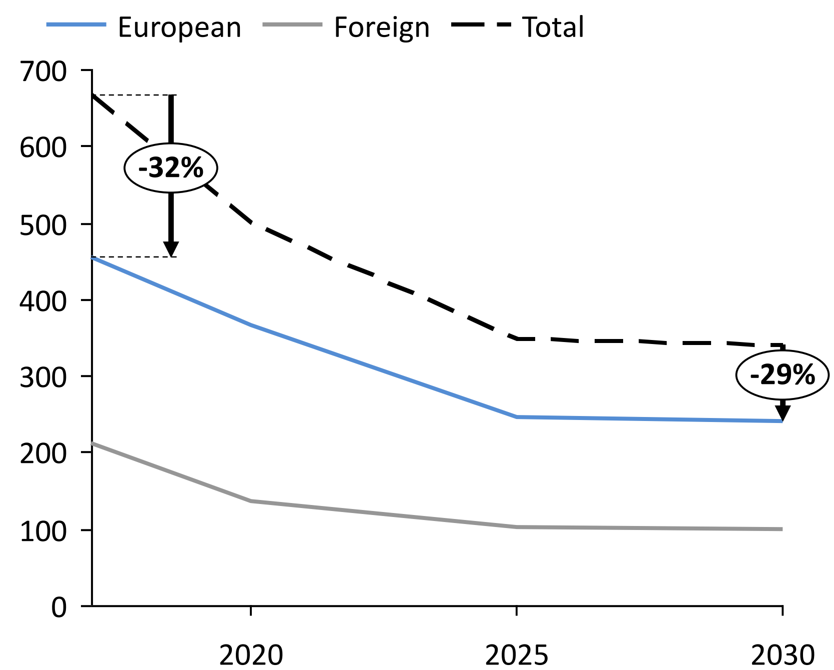
Foreign value from FC bus CAPEX

Thousand € / bus



Fuel cell bus CAPEX

Thousand € / bus



Gearbox and clutch | Drivetrain Power System | Drivetrain integration | Electric drivetrain | Glider

Introduction

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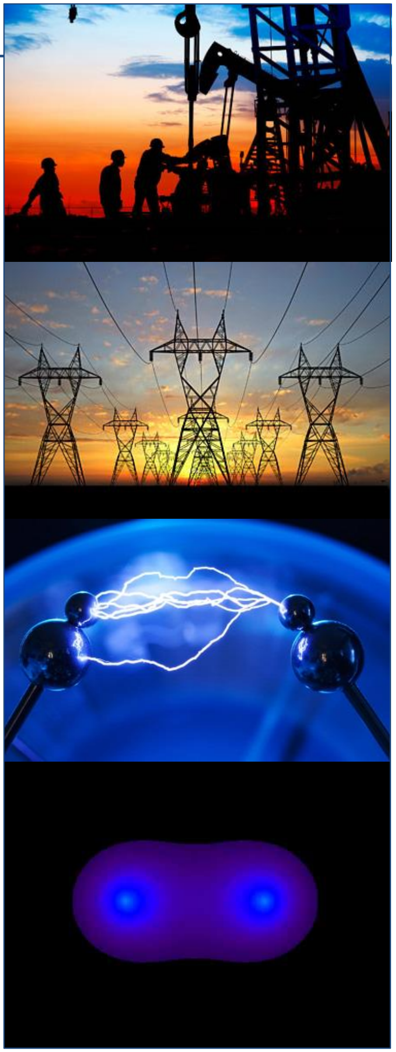
Each bus type inherently relies on a different fuel, each with a different supply

Fuel types for different buses

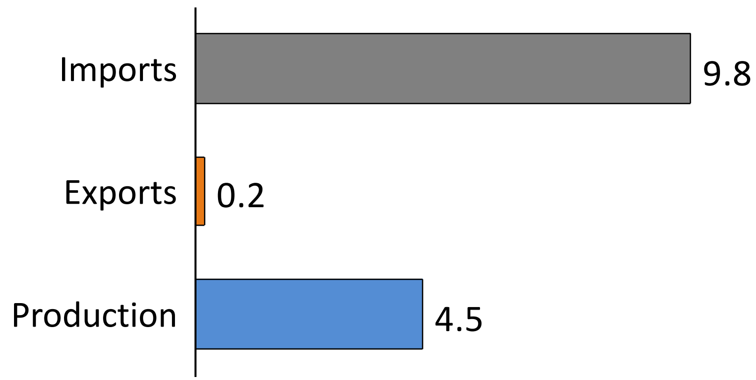
- Each bus type considered here relies on a different energy vector, in the case of fuel cell buses this is hydrogen, for diesel buses this is diesel fuel derived from crude oil, and grid electricity for battery electric buses.
- These not only have significantly different value chains today, but as the future electricity generation mix shifts away from fossil fuel based generators, and towards renewable and nuclear power generation, are expected to undergo significant changes, leading to a shifting value chain.
- This section sets out key aspects of the analysis, showing the overall value creation from:
  - **Diesel fuel:** this considers the retailing, commodity costs, refining and taxation as aspects of the diesel value chain
  - **Grid electricity:** this accounts for generation and distribution of grid electricity, as well as levies and charges applied
  - **Hydrogen:** here, the value creation from Steam Methane Reformation and Electrolytic hydrogen production are assessed, along with fuel distribution to refuelling stations, as well as the fuel retailing value chain.
- This section describes the analysis of the value chain for each fuel.
- It is assumed throughout this analysis that the operation of a battery or fuel cell bus directly offsets the equivalent amount of diesel required to operate a diesel bus



Europe has significant refining capacity, but most of its crude oil is imported from outside of the continent

European crude oil imports and exports

Million barrels per day

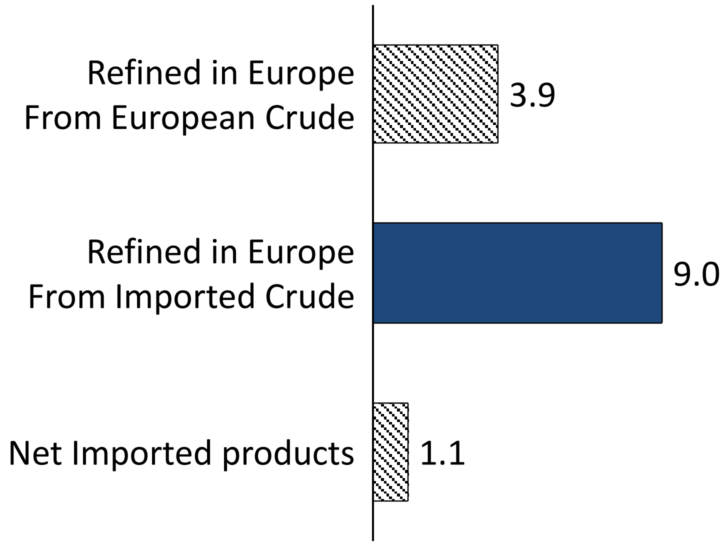


Petroleum product supply and demand

Million barrels per day

European consumption by source

Million barrels per day



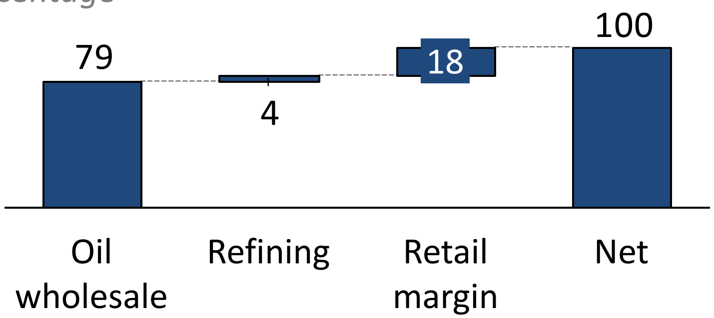
- This analysis suggests that the majority of European diesel results from the refining of imported crude
- Therefore, we assume that any uptake of fuel cell and battery electric buses displaces products derived from imported crude oil refined in Europe

1: Based on 2015 data from BP: *Statistical review of World Energy 2016*

Aside from fuel duty, almost the entirety of the value creation of diesel fuel is accrued outside of Europe

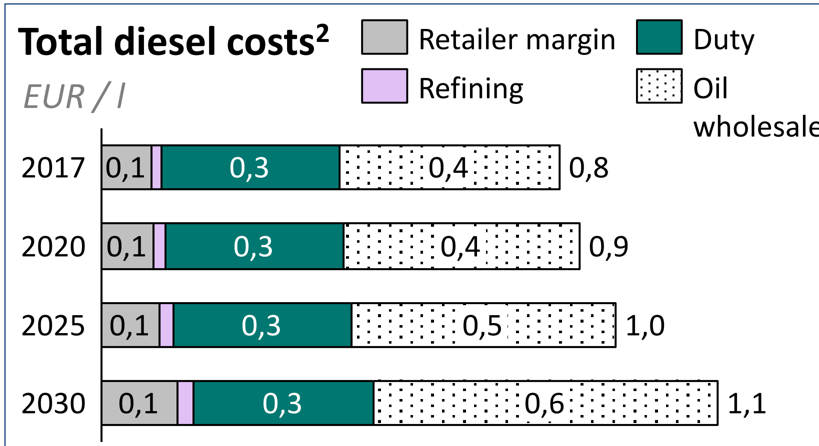
Diesel wholesale cost breakdown[1]

Percentage



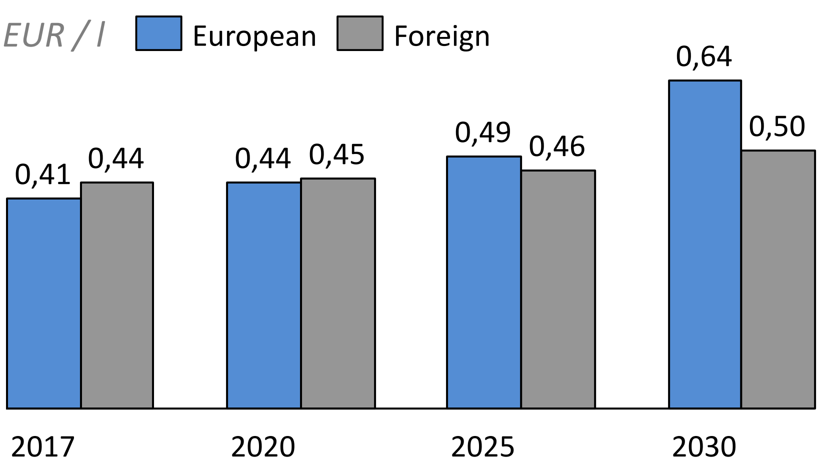
Total diesel costs[2]

EUR / l



Diesel value chain breakdown

EUR / l



This analysis assumes the following:

- The diesel is refined in Europe, but derived from imported crude oil, so all oil wholesale results in foreign value
- Only duty, retailing and refining result in value for Europe

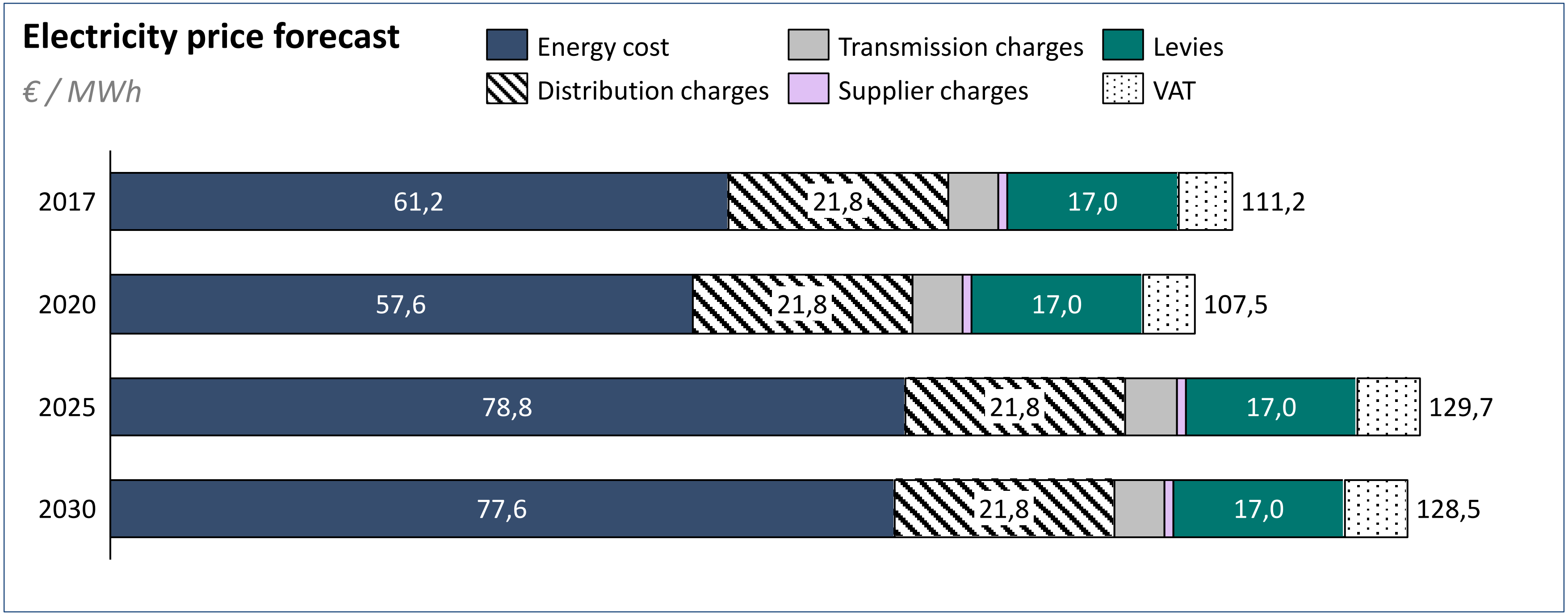
1: Based around Deloitte: *Study of the UK petroleum retail market,* Rusinga: *Value Chain analysis along the Petroleum Supply Chain*, and McKinsey and Company: *UKH_2Mobility Phase 1 Report*

2: Duty based on (http://ec.europa.eu/taxation_customs/business/excise-duties-alcohol-tobacco-energy/excise-duties-energy/excise-duties-energy-tax-rates_en), wholesale costs evolution based on DECC annex M

The projected cost of electricity generation used here increases between 2017 and 2030

Electricity cost components

- Projections for the value and supply chain of electricity produced and transmitted in Europe have been derived (see the annex for detailed assumptions).
- This starts with a projection of the overall major components of electricity costs for Europe which are shown below
- This includes estimates of levies, transmission, distribution and supplier charges , VAT , and electricity generation costs



The analysis makes a series of assumptions regarding the value creation of electricity generation and other components

Value creation from electricity

The value creation in the electricity mix has been split into two parts:

- **Distribution, taxes and levies:** The value of tariffs, levies and distribution and transmission charges for electricity has been assumed to result purely in European value, as these charges and levies are reinvested either in local distribution networks, or national transmission and electricity generation systems. These are also assumed constant over time
- **Electricity generation:** Thus, the foreign value contribution from electricity shown in Figure 7 results only from the generation of electricity. This generation cost is broken down into different LCOE components. In turn, each of these are segmented based on estimates of their relative European value. Specifically:
  - **Power station CAPEX:** These are defined for each power station type on the basis of the value shares presented in the annex
  - **Fixed OPEX:** Plant fixed OPEX contributions are assumed to result in 100% European value
  - **Fuel costs:** For non-renewable generation, the fuel used in the production of electricity are assigned value shares based on estimates for European imports[1]. The value shares assumed are 34% for natural gas, 60% for nuclear fuels, and 58% for coal and other solid fuels.
  - **Decommissioning costs:** This is a relatively small component of the overall cost of electricity and is assumed to result entirely in European value

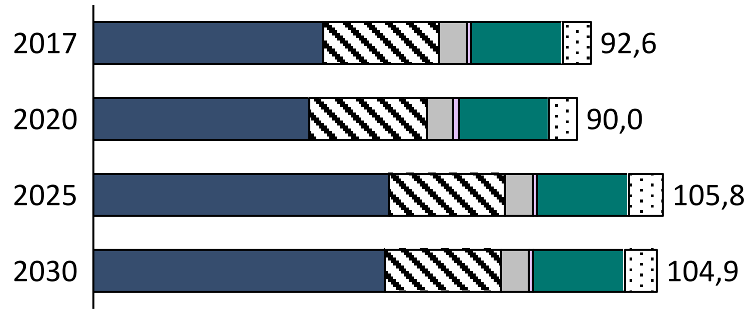
These are averaged over the generation mix to estimate the overall European and foreign value creation. The full set of assumptions underlying this can be found in the annex.

1: https://ec.europa.eu/energy/en/topics/imports-and-secure-supplies

This analysis suggests that over 80% of the value creation from electricity remains in Europe

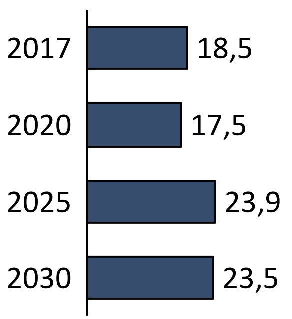
Estimated European value from electricity

€ / MWh

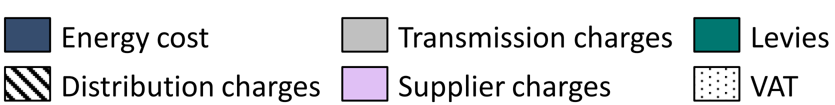


Estimated Foreign value from electricity

€ / MWh

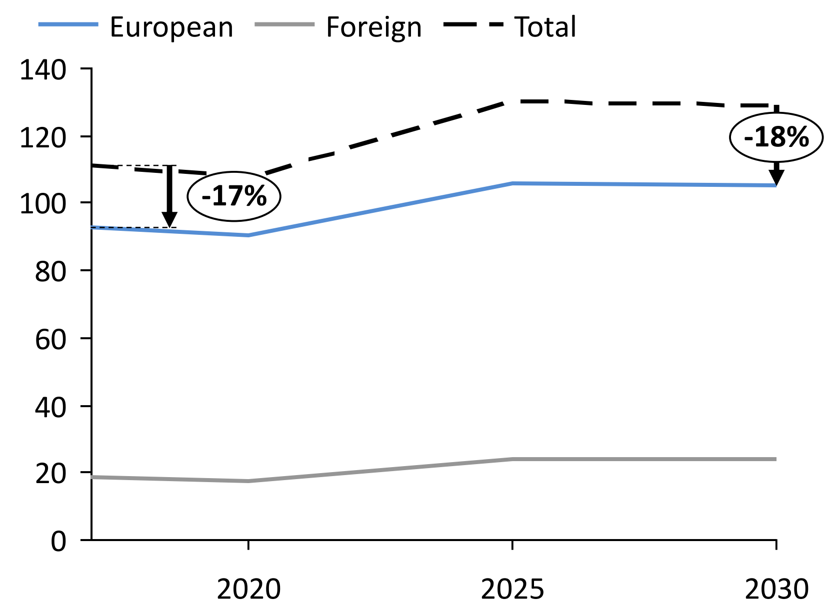


Distribution, transmission and supplier chargers, along with levies and VAT are assumed to result solely in European value



Overall electricity value chain

€ / MWh



- Transmission, supplier and distribution charges have all been assumed constant over time, so the cost increases are driven by a projected rise in the wholesale cost of electricity
- Overall, the estimated value from electricity use for Europe is roughly 80%

Three hydrogen fuel production pathways are considered in this analysis

Hydrogen production pathways

Three production pathways for hydrogen fuel have been considered which reflect the long-term value chain:

- **Steam Methane Reformation (SMR):** Here steam and methane are reacted to produce hydrogen. Most of the capital and operational costs are anticipated to result in European value, though significant amounts of natural gas (66%) are assumed imported.
- **Polymer Electrolyte Membrane (PEM) and Alkaline Electrolysis:** Hydrogen can also be produced via electrolysis of water. Before 2030, the dominant options for electrolytic hydrogen generation are anticipated to be PEM and alkaline electrolysis.

There are several key aspects to the economics of hydrogen fuel production:

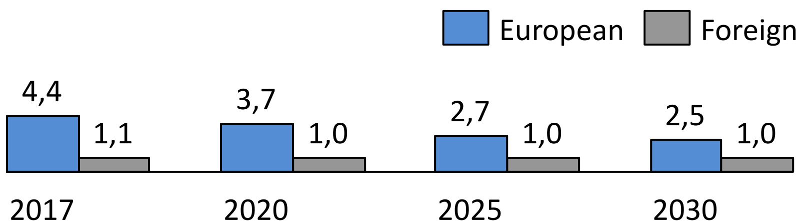
- **Distribution:** electrolysis is assumed to occur onsite and result in no distribution costs, whereas SMR is assumed to happen at a centralised plant and be distrusted
- **Dispensing:** all the costs and value creation figures shown below include the costs of building dedicated hydrogen refuelling infrastructure to dispense the fuel
- **Utilisation:** The utilisation of all assets is assumed to increase from 40% in 2017 to 90% in the 2030s
- **Electricity costs:** The cost reductions shown here are aggressive, and assume that electrolysers have access to relatively cheap bulk electricity (e.g. €0.07 per kWh). In the long term this will likely only be possible should electrolysers participate in flexibility markets to achieve lower electricity prices, directly couple hydrogen production behind the meter to renewable generators, or provide balancing services to electricity networks

Under these assumptions, roughly 80 – 90% of the value created by hydrogen fuel is retained in Europe

SMR Value Chain

€/kg H_2

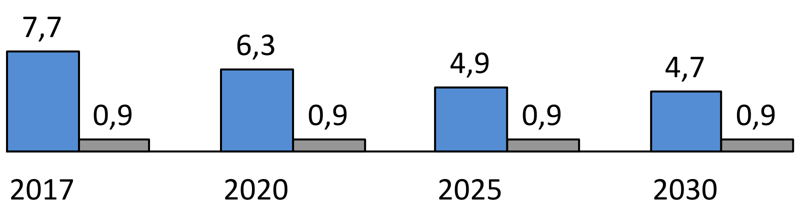
Assumed 50% of hydrogen production



PEM Value Chain

€/kg H_2

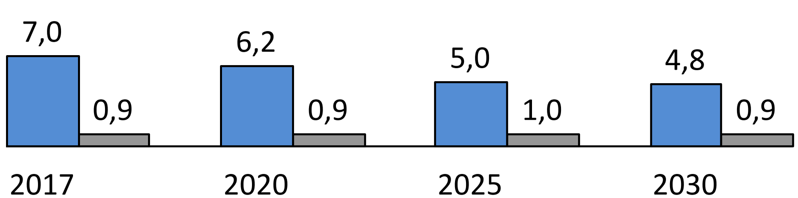
Assumed 25% of hydrogen production



Alkaline Value Chain

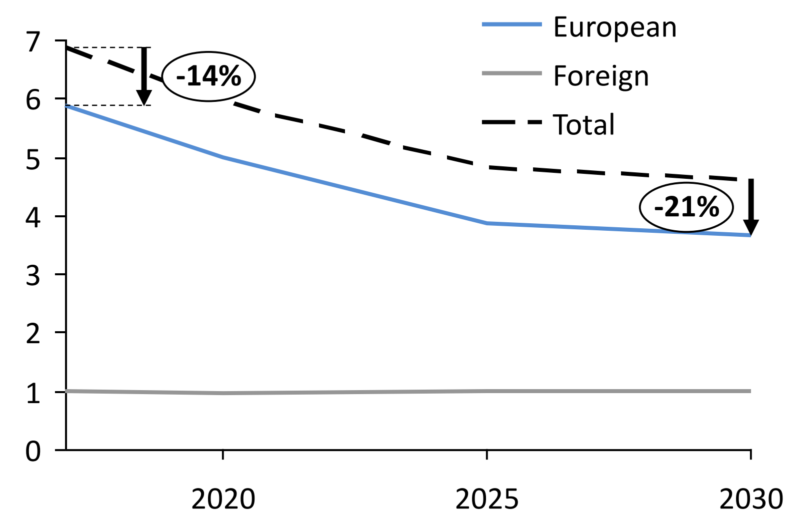
€/kg H_2

Assumed 25% of hydrogen production



Overall hydrogen value chain

€/kg H_2



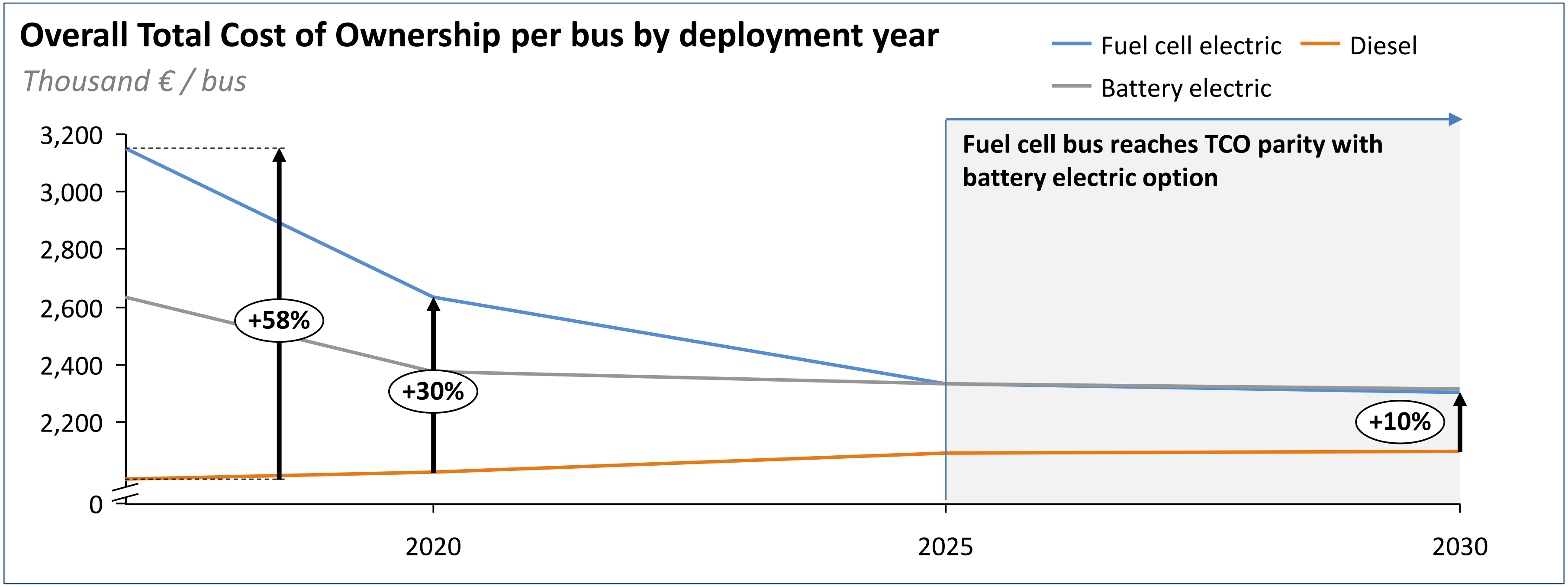
- This analysis above assumes a 50% share of SMR hydrogen production
- The modelled fuel cost drops from ~ €7,00 / kg to under €5,00 / kg
- Including aggressive production cost reductions and utilisation improvements for all technologies, the resultant proportion of European value remains at roughly 80%

Total Cost of Ownership analysis suggests that the gap between zero emission buses and diesel buses will narrow over the coming decade

Hydrogen production pathways

Using the overall costs and value fractions detailed in the previously, the Total Cost of Ownership (TCO) of each type of bus has been assessed. This indicates several important points:

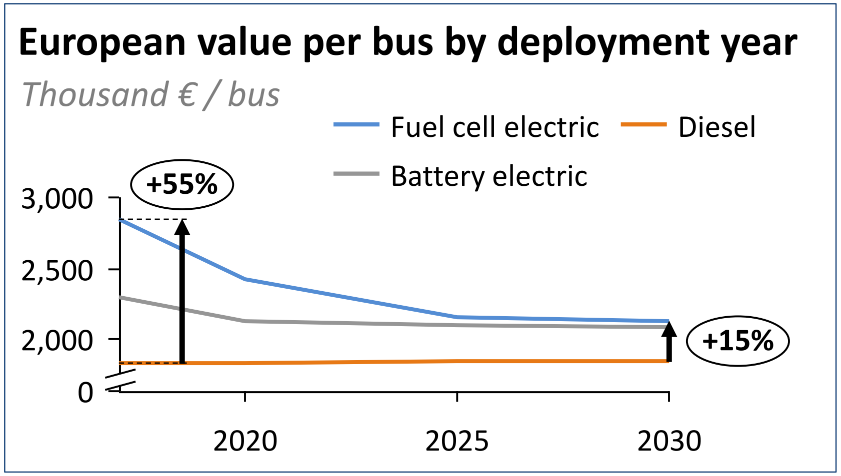
- The TCO of today's zero emission buses is significantly higher than diesel buses
- As deployment of zero emission buses is ramped up, significant TCO reductions are expected
- Fuel cell buses could approach TCO parity with battery electric buses in 2025 By 2030, the fuel cell bus has a 10% premium relative to a diesel bus, and the electric option has an 11% premium.

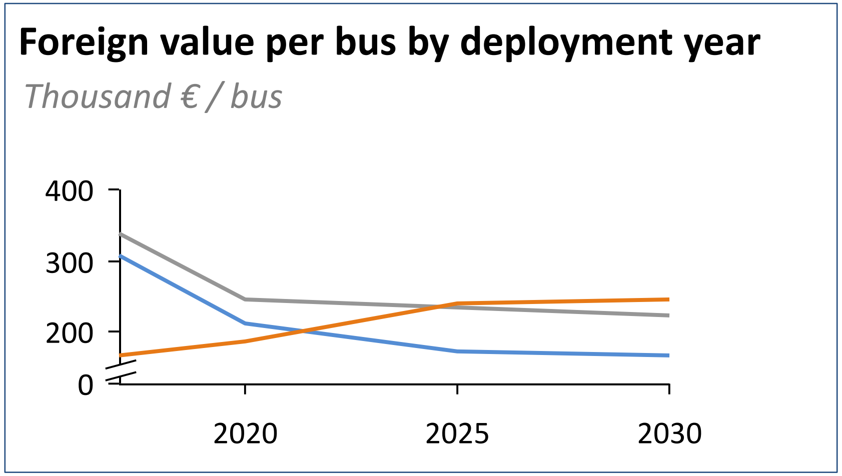


Analysis of the relative value creation suggests that fuel cell buses create the most European value

Value creation analysis conclusions

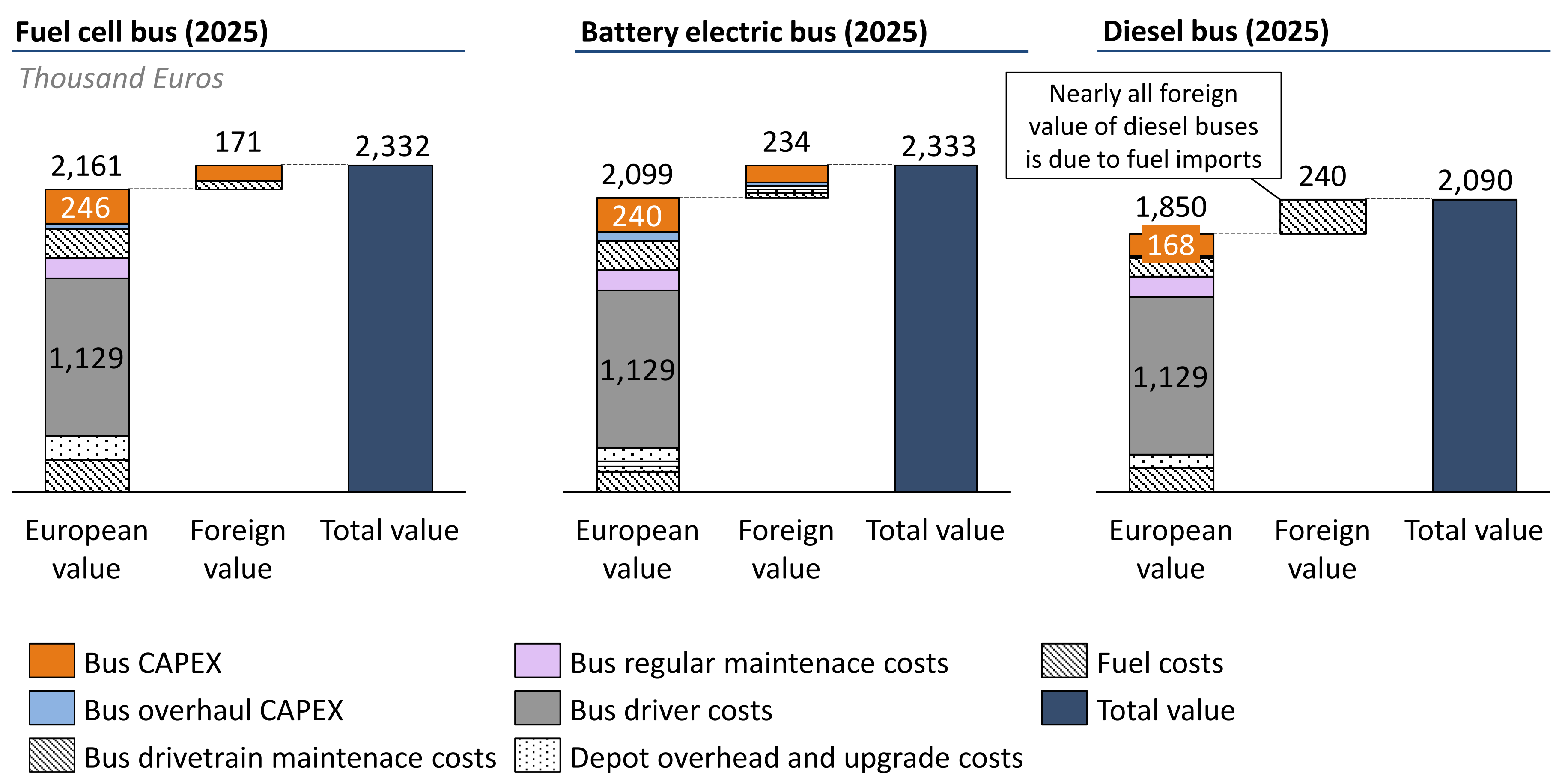
- **Fuel cell buses create the most European value.** In 2017, a sale of a fuel cell bus creates ~55% more value for Europe than a diesel bus, and around 25% more than a battery electric bus.
- By 2030, the cost reductions in the fuel cell bus ownership reduce this relative value creation to 15% vs a diesel bus, and 2% versus a battery electric option
- **In the 2020s, fuel cell buses export the least value.** The foreign value creation from the fuel cell bus, though initially 86% higher than diesel buses, becomes lower in the early 2020s.
- By 2030, the foreign value creation due to the fuel cell bus is 67% of that of a diesel bus
- **Battery electric technologies result in significantly higher value creation in Europe than diesel buses.** For example, in 2017 and 2030, the battery electric option results in 25% and 13% more European value than the diesel bus.
- From ~2025 battery electric buses result in less exported value than diesel buses





The analysis suggests diesel buses export most value due to the necessary fuel imports

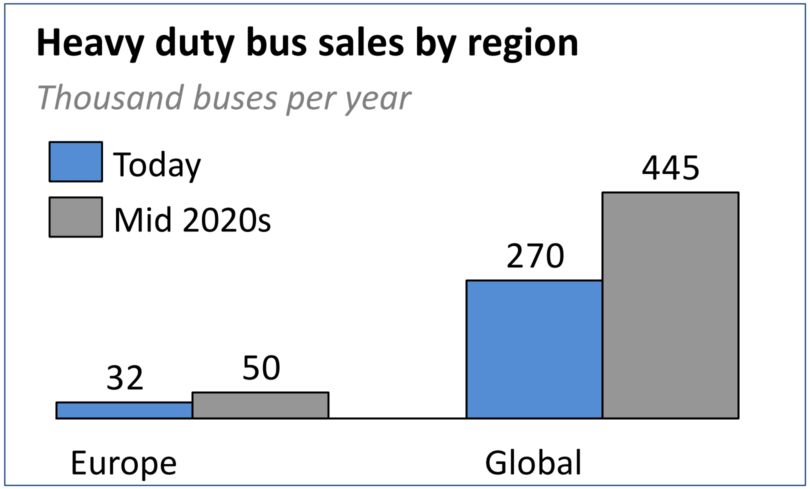
- The plots below present the total value creation arising from fuel cell, electric, and diesel buses, both in Europe and abroad
- This suggests that fuel cell buses create the most value in Europe, and come at ~ a 10% cost premium relative to a diesel bus

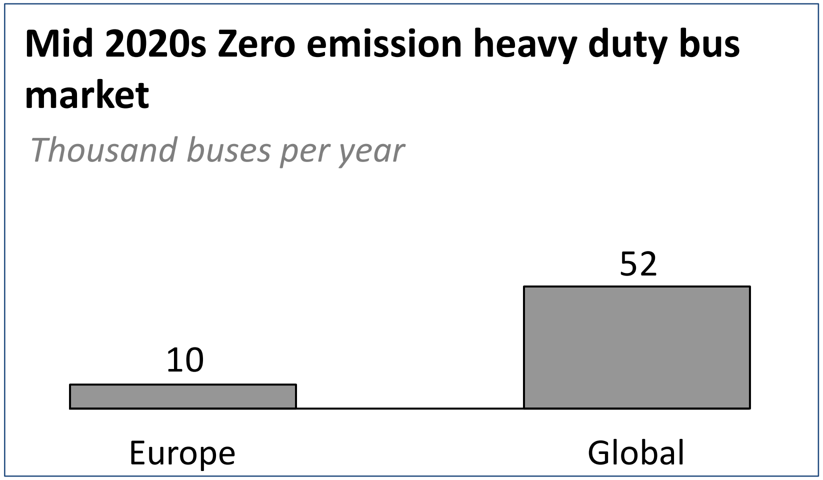


The market for zero emission buses could grow to 10,000 per year by the mid 2020s

Estimates of the total European zero emission bus market

- The results shown previously are based on a single bus
- This section investigates the aggregated benefit of a large deployment of different bus types
- Several major cities have announced their intention to phase out diesel buses
- For instance, Hamburg plans to purchase only zero emission buses from 2020, and Paris, Madrid and Amsterdam plan to gradually phase out all diesel buses by 2025
- Roughly 50 low or zero emission zones are expected to be in place across Europe by 2020, these would likely prohibit the operation of diesel buses
- If the 50 largest European cities – which are likely the most polluted – procure only zero emission buses, in the mid-2020s, the market for zero emission buses could grow to 10,000 sales per year by the mid-2020s



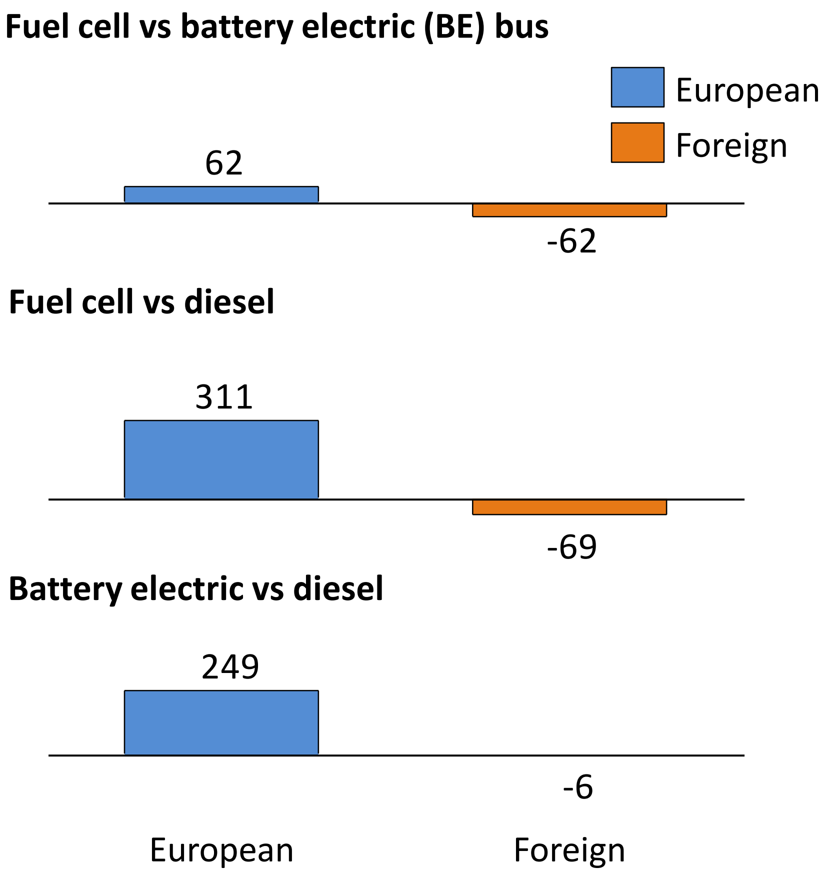


Note the above plots do not use the same scale

Deployment of 2,000 fuel cell buses could result in 100s of millions of Euros of value relative to diesel uptake

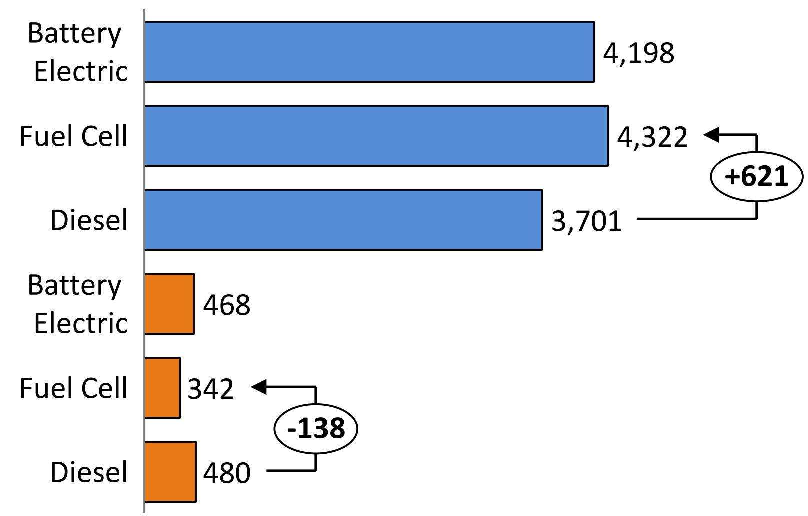
Relative whole life value creation (including drivers) by bus type under 2025 assumptions

Thousand Euros per bus



Whole life value creation for 2000 buses deployed in 2025

Million Euros



- This analysis implies that deployment of 2,000 fuel cell buses in Europe in 2025 could result in a net value creation of ~620 million Euros
- Moreover, it suggests that compared to battery electric options, fuel cell uptake could create over 100 million Euros worth of value in Europe

The aggregated analysis points to a number of high level conclusions

Conclusions of the aggregated analysis

It is possible to draw several high level conclusions from the aggregated results:

- **Deployment of all bus types leads to significant whole life value creation in Europe.** Because the major component of the bus's lifetime cost is driver salaries, which are assumed to result entirely in European value, the value creation for all bus types is largely European. This is less likely to be the case for vehicles without employees dedicated to driving (such as privately owned passenger cars).
- **Displacement of 2,000 diesel buses with fuel cell buses in the year 2025 could create over 600 million Euros of additional value over the life of the buses for Europe.** This is significantly higher than the 500 million Euro increase projected for displacement of diesel buses by long range battery electric buses.
- **Such a displacement results in a reduction of over 200 million Euros of exported whole life value compared to diesel buses over the life of the buses.** As discussed previously, this is largely due to offset oil imports and is relatively insensitive to the sourcing of the fuel cell. In comparison, the modelling suggests that an equivalent deployment of battery electric buses leads to an increase of roughly 100 million Euros of exported value relative to a diesel bus.
- **In comparison with battery electric buses, deployment of fuel cell buses can lead to over 120 million Euros more European whole life value creation.** These outputs imply that the deployment of 2,000 electric buses would export around 126 million Euros more value abroad than the fuel cell bus.

Together, these results indicate that although the modelled cost of the fuel cell bus is significantly higher than the diesel bus, and similar to the electric bus in 2025, fuel cell buses can result in significantly more indigenous value creation than these options.

Sensitivity analyses on fuel cell sourcing suggests the results are relatively insensitive to the sourcing of the fuel cell

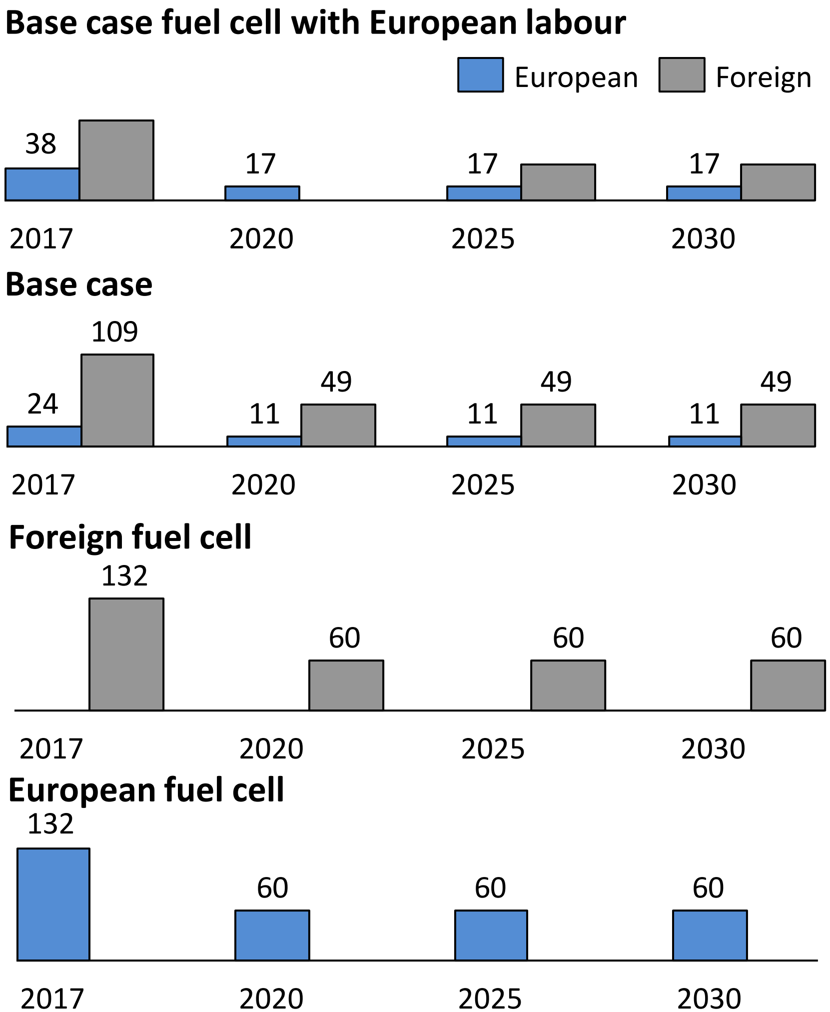
Sensitivity to fuel cell sourcing

- The fuel cell is one of the major components of the fuel cell bus CAPEX. The previous analysis shown assumed that 18% of the fuel cell stack's value is retained in Europe, based on today's practices.
- This is because many of the major producers of the bus fuel cell systems themselves are located outside of the European Union and this is the reason why a fraction of the value in non-European. Several manufacturers are considering investing in European manufacture
- As a result, a sensitivity to moving assembly to Europe is investigated by analysing an additional 11% of European fuel cell value creation (based on a Ballard estimate for the value of European fuel cell system assembly), 0% European fuel cell value creation and 100% European fuel cell value creation as sensitivities.
- The result of this sensitivity analysis is shown on the next slide.
- Under these assumptions, there is a 1 – 2% reduction in the fuel cell bus value creation in Europe when comparing a bus with a European assembled fuel cell, and a solely foreign fuel cell.
- However, these changes are not enough to alter the conclusion that the fuel cell provides the most value to Europe, albeit by a smaller margin for an entirely foreign fuel cell
- At today's costs, a European fuel cell resulting in 100% value results in only 6% additional value compared to a bus with a wholly foreign fuel cell
- Furthermore, in 2025, the same analysis suggests a wholly European fuel cell would only increase the share of European value by only 3%

Changing the sourcing of the fuel cell can lead to a 3 – 6% change in the whole-life value creation of a fuel cell bus

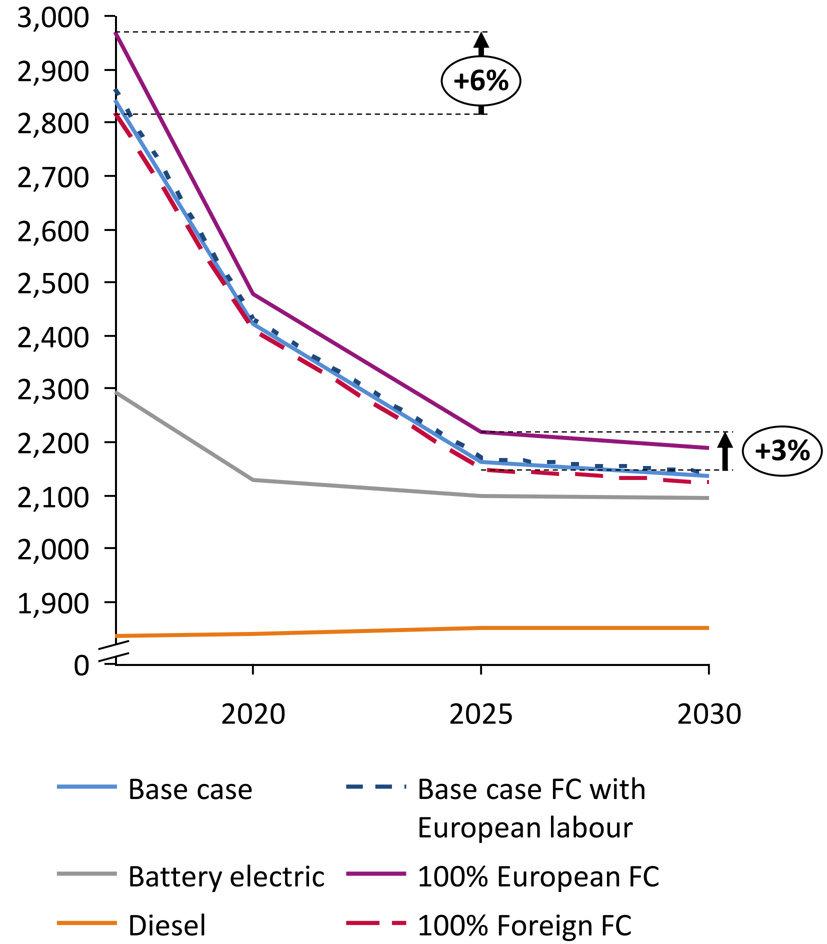
Fuel cell sourcing value chain sensitivity

Thousand Euros per bus



European value per bus by deployment year

Thousand € / bus



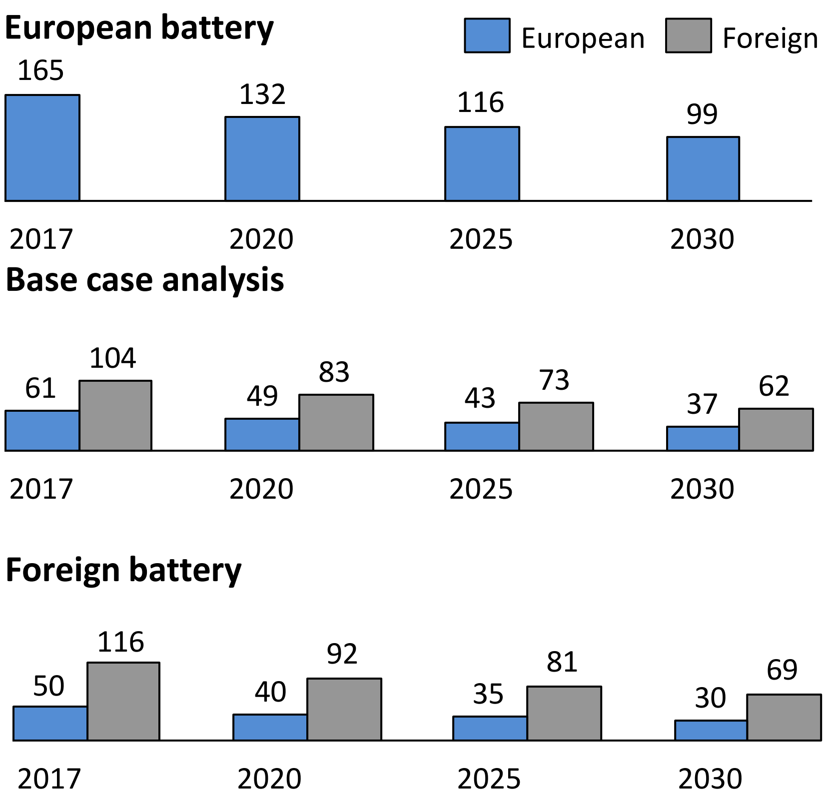
Sensitivity analyses on battery sourcing suggests the results are more sensitive to the sourcing of the battery

Sensitivity to battery sourcing

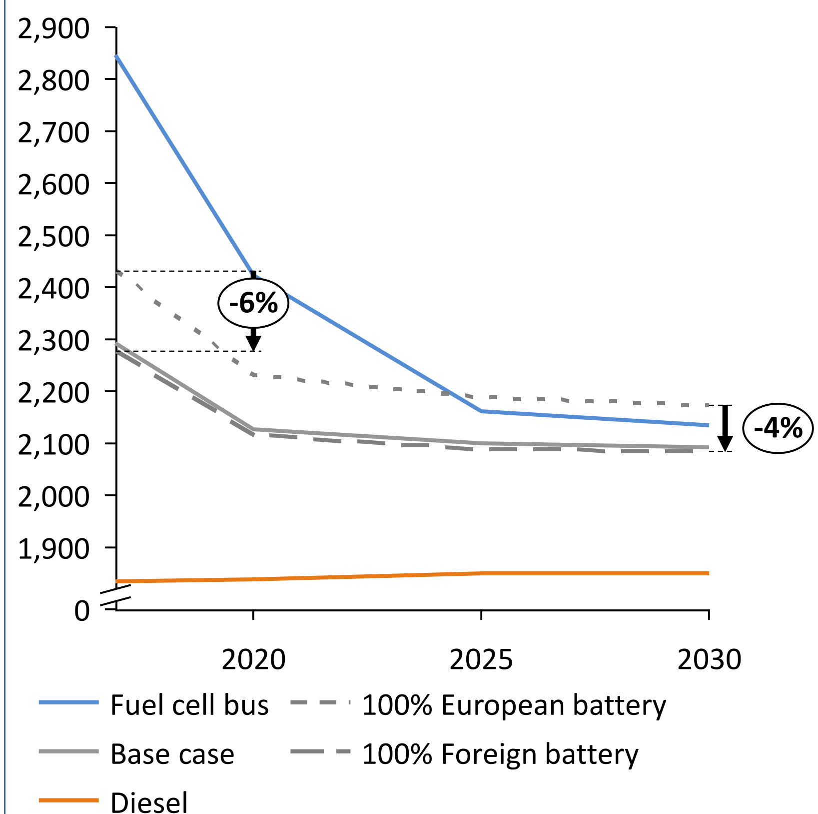
- The analysis shown previously also assumed that 37% of the value creation resulting from a battery electric bus's battery pack is retained in Europe
- This reflects the relatively low output of Europe's automotive battery manufacturing industry
- A key priority of the European industry is to increase the European share of battery manufacture, The sensitivity analysis shown on the next slide shows the effect of a wholly European battery value chain, vs a foreign battery
- Like the sourcing of the fuel cell, changing the battery sourcing has little effect on the overall value creation, resulting in a 4 – 6% spread of the battery electric European value creation from 0 to 100% European content.
- Before 2025, this does not alter the conclusion that a fuel cell creates more value for Europe.
- After 2025 however, this analysis suggests that an electric bus with fully European battery manufacture could create more European value than a fuel cell option using today's sourcing
- 100% value retention due to battery manufacture is unlikely, since many components would likely be procured from outside of Europe, and given the current domination of the supply chain by Asian companies

A sensitivity analysis suggests that a fully European battery could lead to 4 – 6% European value creation for battery electric buses

Battery sourcing value chain sensitivity
Thousand Euros per bus



European value per bus by deployment year
Thousand € / bus



All bus types considered here either directly on indirectly result in CO_2 emissions

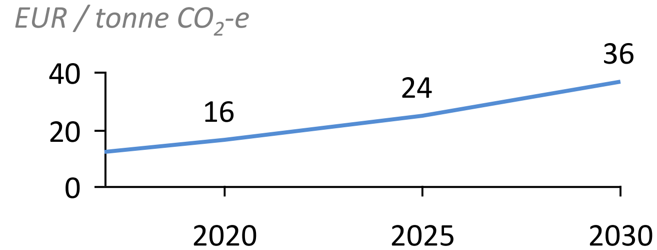
Emissions prices and fuel CO_2 intensity

The EU has introduced an Emissions Trading System (ETS) as a means of financially incentivising CO_2 emissions reductions.

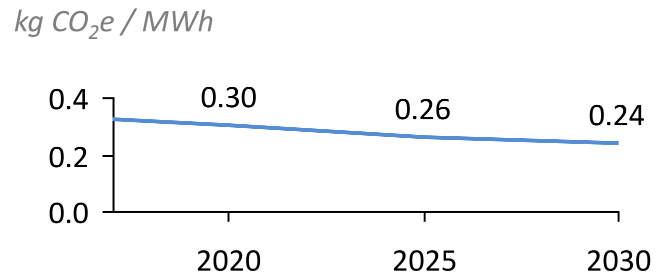
Each of the bus types considered leads to CO_2 emissions either directly or indirectly:

- **Diesel buses** cause CO_2 emissions at the point of use. Approximately 2.7 kg CO_2 e per litre of diesel are emitted by a diesel bus.
- **Battery electric buses** usually run using grid electricity. Figure 16 shows the emissions intensity of the European electric grid (also under the European Commission's reference scenario for decarbonisation).
- **Fuel cell buses** run using hydrogen. Each production pathway can result in CO_2 emissions. The UK H2Mobility roadmap indicates that by 2020 fuel cell vehicles could result in 60% lower emissions than an equivalent diesel vehicle, and by 2030 75% lower emissions[2]. This implies that the hydrogen would need to have lower CO_2 emissions intensity than the electric grid, and would likely be achieved by:
    - Operation of electrolysers at night when grid CO_2 is low;
    - SMR use in conjunction with biomass or CCS
    - or Direct coupling of electrolysers to renewable generators

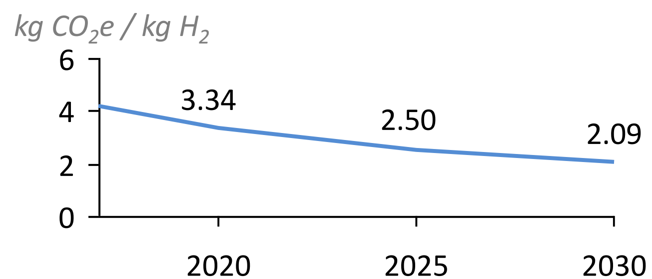
EU ETS carbon price – reference scenario[1]



European Grid Carbon Intensity[1]



Hydrogen Production Carbon Intensity

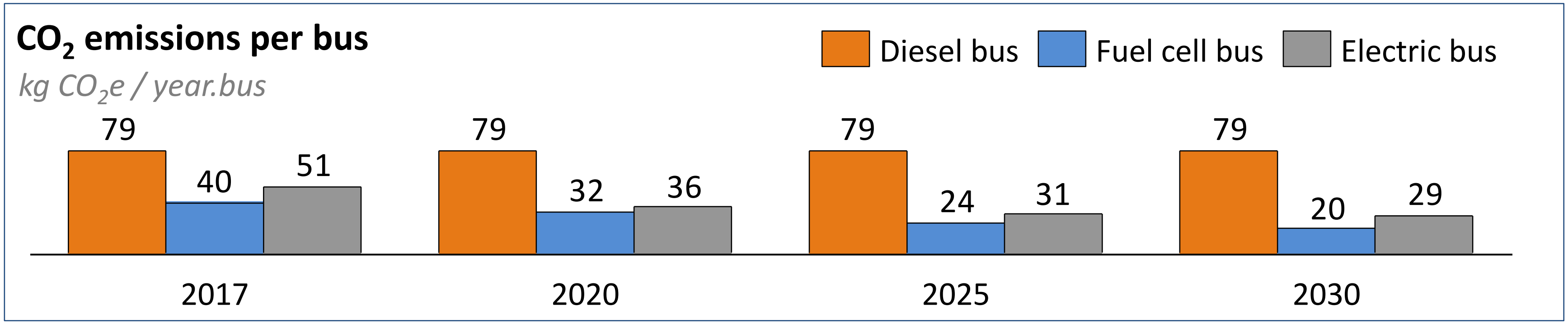


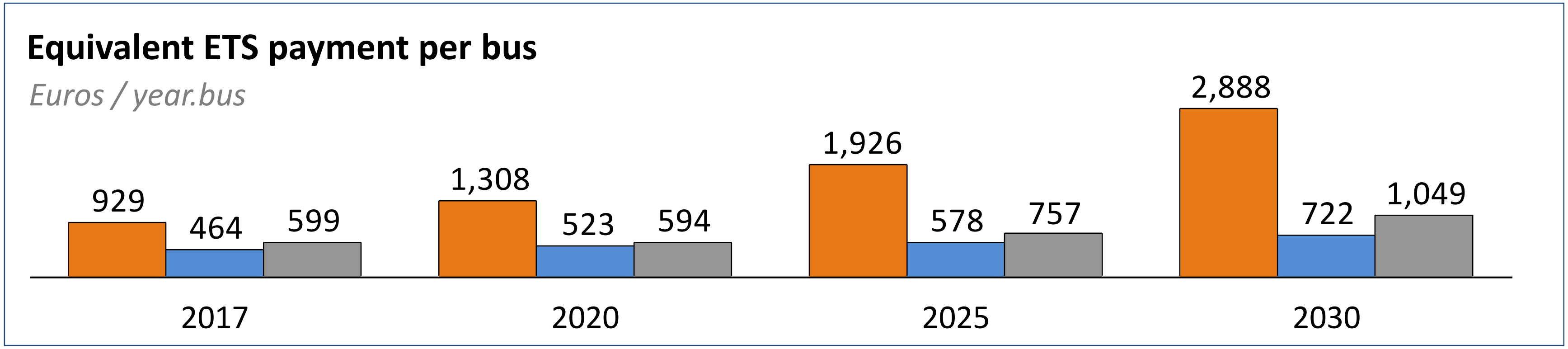
1: European Commission: *European Reference Scenario 2016* – Note that this grid intensity is a relatively pessimistic representation because electric buses are expected to refuel mostly at night, when the CO_2 intensity of the grid is lower than average. Also note that although electricity consumption is non-traded under the ETS, this results in payment on the generator side, so is included in this overview analysis. 2: UK H_2Mobility: *Phase 1 Results* (2013)

The equivalent ETS price corresponding to projected CO_2 savings from using ZE buses (vs diesel) is on order of €1000s per bus in the 2020s

Equivalent carbon price recovered by bus type

- The plots below show the results of an analysis of the lifetime CO_2 emissions and relative costs (the full analysis is shown in the annex).
- The result of this analysis implies that operation of both electric and fuel cell buses can result in significantly lower CO_2 emissions than an equivalent diesel bus.
- This translates into ETS savings of thousands of Euros per year per bus.





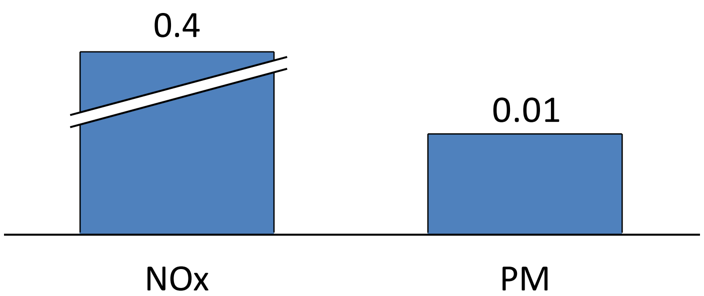
Deployment of zero emission buses can result in significant pollution reductions

Zero emission buses and air pollution

- Urban pollution is a growing problem in European cities
- For example, the World Health Organisation estimates that Air pollution costs Europe 1.6 trillion dollars per year[1]
- Urban areas suffer particularly from this due to the density of their traffic
- The analysis shown below shows the cost of pollution due to Euro VI standards based on marginal pollutant costs developed for large urban areas in Ireland[2]
- This analysis suggests that Euro VI standard deployments could result in over €4,000 / bus of additional European cost for Europe relative to zero emission options such as battery electric and fuel cell buses
- For 2,000 buses this would amount to €8 million

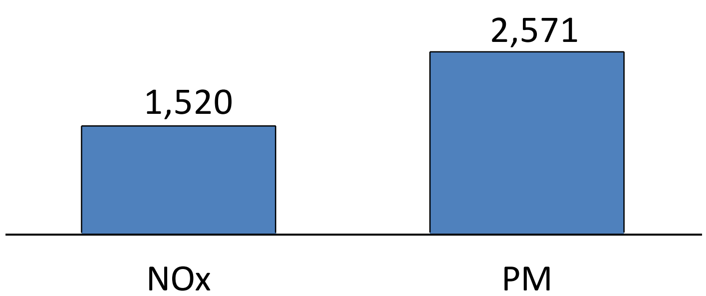
EURO VI standards for pollutant emissions

g / kWh



Cost of pollution over 12-year lifetime

Thousand € / bus



1: WHO press release: *Air pollution costs European economies US $1.6 trillion a year in diseases and deaths, new WHO study says (2015)*
2: Envecon: *Air Pollutant Marginal Damage Values Guide for Ireland (2015)*

The standard deviation in a given year in crude oil spot prices can be as high as ~33%

Crude oil price volatility

An issue of growing concern for the energy industry is that of energy security

In addition to having a largely foreign value chain, the wholesale prices of diesel are highly volatile

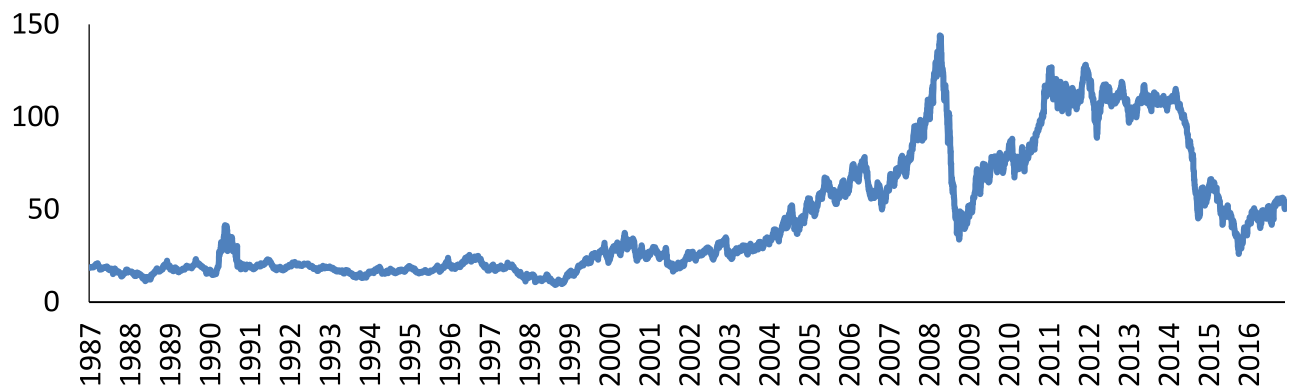
This point is illustrated in the plots on the right

These show that the annual standard deviation in spot price has reached over 30% within the last decade

This volatility is in part due to the impact of disasters at production sites, but the causes of recent disruptions have been attributed to political dispute and conflict[1]

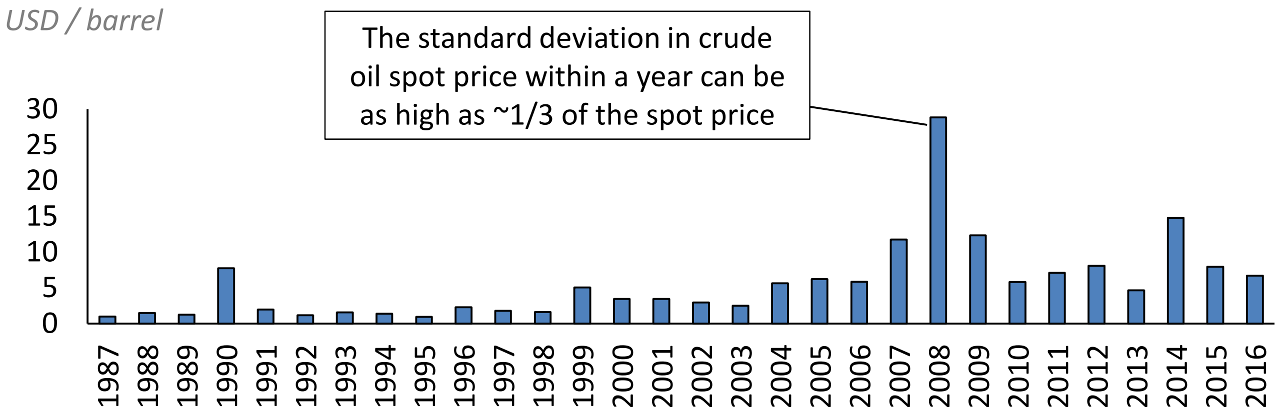
Europe Brent Spot Price

USD / barrel



Standard Deviation in crude oil price by year

USD / barrel



1: US EIA: *Unplanned global oil supply disruptions reach highest level since 2011 (2016)* https://www.eia.gov/todayinenergy/detail.php?id=26592

At least 76% of Europe's crude oil imports come from states with below average political stability

Political risk to supply chain

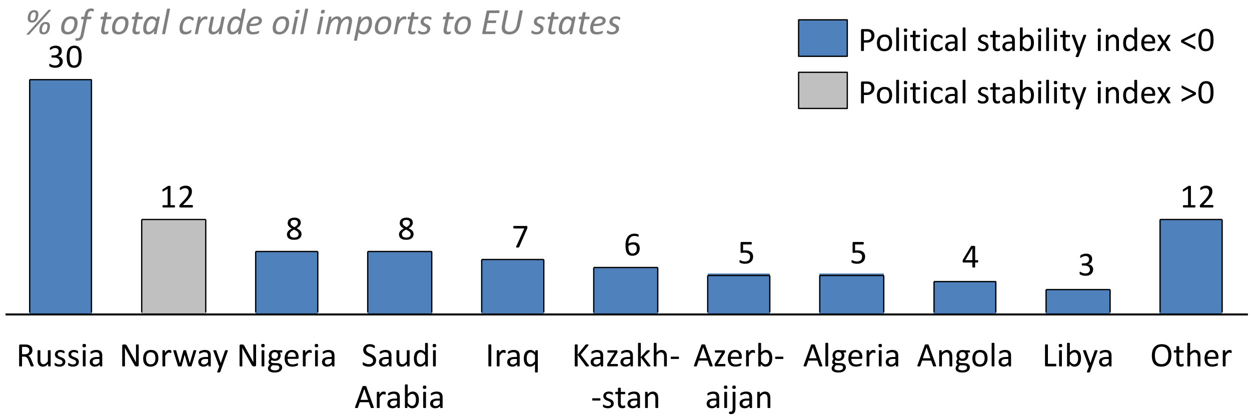
The political risk to the diesel supply chain is difficult to quantify systematically

However, indices developed by international organisations and multilateral development banks can provide an overview

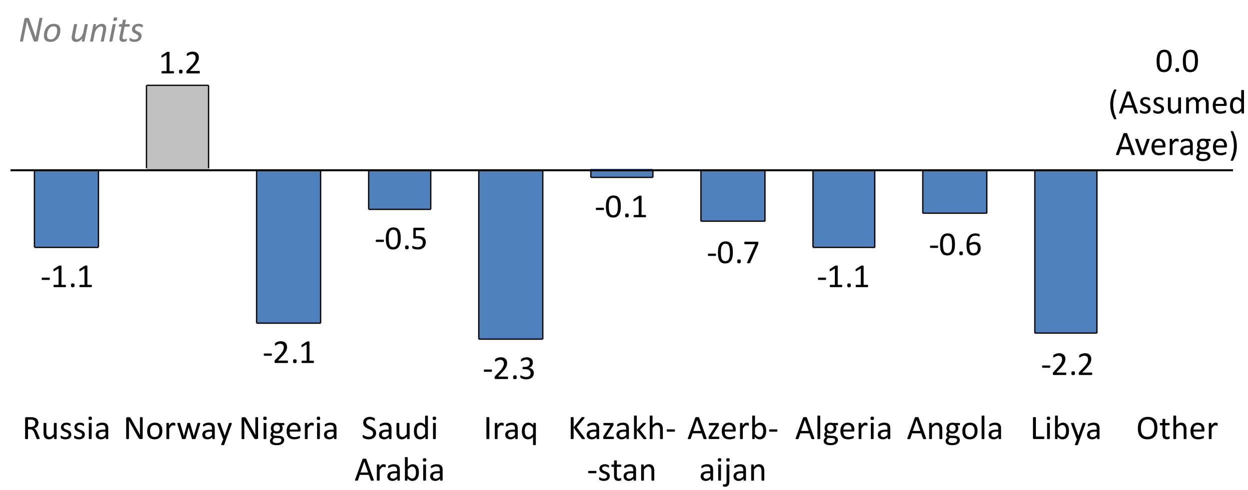
For example, the World Bank's Political Stability Index assigns different states values between -2.5 and 2.5, with a global average of zero based on their stability (-2.5 being the least stable)

This suggests that at least 76% of Europe's crude oil imports originate from states with a value below average political stability

Proportion of European crude oil imports by country of origin[1]



Political stability index of major oil importers to the EU[2]



1: Based on Cambridge Econometrics: *A study on Oil Dependency in the EU* (July 2016); H2FCSUPERGEN: *The Economic Impact of Hydrogen and Fuel Cells in the UK* analysis of Eurostat figures

2: http://databank.worldbank.org/data/databases.aspx?orderby=alphabetical&direction=desc

Both battery electric and hydrogen buses may be able to contribute the security of Europe's transport and energy systems

Zero emission buses and energy security

- Electricity can be produced via combustion of fossil fuels such as coal and natural gas, but also from nuclear power and renewables.
- These all have more indigenous supply chains within Europe than crude oil and renewable electricity does not rely on fuel imports at all
- Renewable generators are subject to significant short term fluctuations in output. There are several reasons why both battery electric, and fuel cell buses can help to manage this issue.
- **Battery electric buses** are expected to recharge at night. Overall demand on the electricity system is lower at night, so this can allow the consumption of surplus wind power.
- **Fuel cell buses** can run using electrolytic hydrogen which can support renewables in several ways:
    - It can be produced at any time, and thus can act to absorb large amounts of surplus renewable electricity.
    - Electrolysers are highly responsive loads and could be used to provide grid balancing services, which can act to stabilise the electricity system
    - Electrolysers in direct connection with renewable generators, or in areas with highly constrained renewable generation.
- Therefore, overall it is anticipated that fuel cell and battery electric buses could both improve the overall resilience of Europe's energy system

1: https://ec.europa.eu/energy/en/topics/imports-and-secure-supplies

Bus CAPEX and OPEX value creation assumptions

Commodity	European value proportion	PRCCODE / source
Unit	%	-
Generic components		
Glider	99%	29201050
Depot overheads	100%	Assumption based on today's practises
Depot upgrades	100%	Assumption based on today's practises
Charging infrastructure	10%	Assumed the same as cell manufacture
Drivetrain integration	100%	Assumption based on today's practises
Driver salary	100%	Assumption based on today's practises
Infrastructure maintenance	10%	Assumed the same as cell manufacture
Electric / fuel cell bus components		
DC-DC converter	32%	27111090
Electric drivetrain	32%	27111090
Battery pack manufacture	10%	Assumption based on today's practises
Infrastructure costs	55%	27123170
Electric drivetrain maintenance	100%	33141120
Fuel cell bus		
Materials and manufacturing	20%	Assumption based on today's practises
Labour	0%	Assumption based on today's practises
Diesel bus components		
Internal combustion engine	85%	Based on 29312250, 29312270, 29313030
Diesel tank	95%	25911100
Gearbox and clutch	93%	28152450
ICE maintenance	100%	33121100

Costs and value assignment for fuel cell electric bus

Parameter				
Year	2017	2020	2025	2030
Capex	666,000	500,000	347,766	339,766
European value	453,749	365,054	245,593	240,308
Foreign value	212,251	134,946	102,173	99,458
Bus overhaul Capex	117,647	70,588	47,059	35,294
European value	80,153	51,537	33,233	24,963
Foreign value	25,545	13,909	9,764	7,307
Components				
Glider	240,000	240,000	150,000	150,000
European value	238,648	238,648	149,155	149,155
Foreign value	1,352	1,352	845	845
Electric drivetrain	117,647	80,000	50,000	50,000
European value	38,055	25,877	16,173	16,173
Foreign value	79,592	54,123	33,827	33,827
Drivetrain integration	94,118	38,236	25,000	25,000
European value	94,118	38,236	25,000	25,000
Foreign value	-	-	-	-
Drivetrain Power System	214,235	141,764	122,766	114,766
European value	82,928	62,293	55,264	49,980
Foreign value	131,307	79,471	67,502	64,786

Drivetrain value breakdown for the fuel cell bus

The drive train power system is broken down based on and each individual component is assigned a value share based on the estimates shown previously. Subcomponents of the fuel cell system are assumed to result in 20% European value (labour costs are assumed to account for 11% of the total fuel cell cost, and are assumed wholly foreign) and battery pack (broken down into cell manufacture, cost estimates, based on 10% manufacturing value remaining in Europe as above, and 30% assembly costs, which are assumed European) are highlighted in green.

Drivetrain Power System Breakdown				
Year	**2017**	**2020**	**2025**	**2030**
Fuel cell system	132,353	60,000	60,000	60,000
European value	23,559	10,680	10,680	10,680
Labour	14,559	6,600	6,600	6,600
European value	-	-	-	-
Materials and components	117,794	53,400	53,400	53,400
European value	23,559	10,680	10,680	10,680
Storage tanks	46,588	30,000	30,001	25,000
European value	38,899	25,049	25,049	20,874
Battery pack	23,529	40,000	21,000	18,000
European value	8,706	14,800	7,770	6,660
Manufacturing cost	16,471	28,000	14,700	12,600
European value	1,647	2,800	1,470	1,260
Cell assembly cost	7,059	12,000	6,300	5,400
European value	7,059	12,000	6,300	5,400
Build labour	11,765	11,764	11,765	11,766
European value	11,765	11,764	11,765	11,766

Fuel cell bus OPEX and value shares

The following OPEX shares are also assigned, note that these are all assumed to result in entirely European value.

Fuel cell electric bus OPEX breakdown				
Year	**2017**	**2020**	**2025**	**2030**
Electric drivetrain maintenance	**35294**	**17647**	**17647**	**17647**
European value	35294	17647	17647	17647
Foreign value	0	0	0	0
Regular maintenance	**11765**	**11765**	**11765**	**11765**
European value	11765	11765	11765	11765
Foreign value	0	0	0	0
Depot overheads	**8235**	**8235**	**8235**	**8235**
European value	8235	8235	8235	8235
Foreign value	0	0	0	0
Depot upgrades	**5882**	**5882**	**5882**	**5882**
European value	5882	5882	5882	5882
Foreign value	0	0	0	0
Driver salary	**47059**	**47059**	**47059**	**47059**
European value	47059	47059	47059	47059
Foreign value	0	0	0	0

Costs and value assignment for long range battery electric buses

Parameter				
Year	**2017**	**2020**	**2025**	**2030**
Capex	**562,647**	**432,000**	**359,032**	**342,535**
European value	360,582	290,526	242,030	235,927
Foreign value	202,065	141,474	117,002	106,608
Bus overhaul Capex	**176,471**	**94,118**	**94,118**	**94,118**
European value	113,094	63,295	63,446	64,825
Foreign value	40,616	20,728	20,676	20,176
Components				
Glider	**176,471**	**176,471**	**150,000**	**150,000**
European value	175,476	175,476	149,155	149,155
Foreign value	994	994	845	845
Electric drivetrain	**117,647**	**70,588**	**50,000**	**50,000**
European value	38,055	22,833	16,173	16,173
Foreign value	79,592	47,755	33,827	33,827
Drivetrain integration	**58,824**	**29,412**	**20,000**	**20,000**
European value	58,824	29,412	20,000	20,000
Foreign value	-	-	-	-
Drivetrain Power System	**209,706**	**155,529**	**139,032**	**122,535**
European value	88,227	62,805	56,702	50,599
Foreign value	121,479	92,725	82,331	71,936

Costs and value assignment for long range battery electric buses

Parameter				
Year	2017	2020	2025	2030
Capex	**562,647**	**432,000**	**359,032**	**342,535**
European value	360,582	290,526	242,030	235,927
Foreign value	202,065	141,474	117,002	106,608
Bus overhaul Capex	**176,471**	**94,118**	**94,118**	**94,118**
European value	113,094	63,295	63,446	64,825
Foreign value	40,616	20,728	20,676	20,176
Components				
Glider	**176,471**	**176,471**	**150,000**	**150,000**
European value	175,476	175,476	149,155	149,155
Foreign value	994	994	845	845
Electric drivetrain	**117,647**	**70,588**	**50,000**	**50,000**
European value	38,055	22,833	16,173	16,173
Foreign value	79,592	47,755	33,827	33,827
Drivetrain integration	**58,824**	**29,412**	**20,000**	**20,000**
European value	58,824	29,412	20,000	20,000
Foreign value	-	-	-	-
Drivetrain Power System	**209,706**	**155,529**	**139,032**	**122,535**
European value	88,227	62,805	56,702	50,599
Foreign value	121,479	92,725	82,331	71,936

Drivetrain value breakdown for battery electric bus CAPEX

Drivetrain Power System Breakdown				
Year	2017	2020	2025	2030
DC-DC Converter	**21,176**	**11,765**	**11,766**	**11,767**
European value	6,776	3,765	3,765	3,765
Battery pack	**165,000**	**132,000**	**115,500**	**99,000**
European value	61,050	48,840	42,735	36,630
Manufacturing cost	**115,500**	**92,400**	**80,850**	**69,300**
European value	11,550	9,240	8,085	6,930
Cell assembly cost	**49,500**	**39,600**	**34,650**	**29,700**
European value	49,500	39,600	34,650	29,700
Build labour	**11,765**	**5,882**	**5,883**	**5,884**
European value	11,765	5,882	5,883	5,884
Other components	**11,765**	**5,882**	**5,883**	**5,884**
European value	8,636	4,318	4,319	4,319

OPEX value breakdown for battery electric buses

The following OPEX costs and value creation shares are assigned to the battery electric bus, note that these are all assumed to result in entirely European value, apart from the infrastructure CAPEX which is assumed to have the same value share as the batteries.

Long range battery electric bus OPEX				
Year	2017	2020	2025	2030
Electric drivetrain maintenance	**17647**	**17647**	**17647**	**17647**
European value	17647	17647	17647	17647
Foreign value	0	0	0	0
Regular maintenance	**11765**	**11765**	**11765**	**11765**
European value	11765	11765	11765	11765
Foreign value	0	0	0	0
Depot overheads	**8235**	**8235**	**8235**	**8235**
European value	8235	8235	8235	8235
Foreign value	0	0	0	0
Infrastructure CAPEX per bus	**51765**	**51765**	**51765**	**51765**
European value	28252	28252	28252	28252
Foreign value	23512	23512	23512	23512
Infrastructure maintenance	**5882**	**5882**	**5882**	**5882**
European value	588	588	588	588
Foreign value	5294	5294	5294	5294
Driver salary	**47059**	**47059**	**47059**	**47059**
European value	47059	47059	47059	47059
Foreign value	0	0	0	0

Costs and value assignment for diesel buses

Parameter	Diesel			
Year	2017	2020	2025	2030
Capex	**170,894**	**170,894**	**170,894**	**170,894**
European value	168,089	168,089	168,089	168,089
Foreign value	2,805	2,805	2,805	2,805
Bus overhaul Capex	**4,118**	**4,118**	**4,118**	**4,118**
European value	4,050	4,050	4,050	4,050
Foreign value	66	66	66	66
Components				
Glider	150,000	150,000	150,000	150,000
European value	149,155	149,155	149,155	149,155
Foreign value	845	845	845	845
Drivetrain Power System	18,541	18,541	18,541	18,541
European value	16,737	16,737	16,737	16,737
Foreign value	1,804	1,804	1,804	1,804
Gearbox and clutch	2,353	2,353	2,353	2,353
European value	2,197	2,197	2,197	2,197
Foreign value	156	156	156	156

Costs and value assignment for diesel bus drivetrain and OPEX

ICE Drivetrain System Breakdown				
Year	**2017**	**2020**	**2025**	**2030**
Build labour	5,882	5,882	5,882	5,882
European value	5,882	5,882	5,882	5,882
Internal combustion engine	12,188	12,188	12,188	12,188
European value	10,407	10,407	10,407	10,407
Diesel tank	471	471	471	471
European value	448	448	448	448

Diesel bus OPEX breakdown				
Year	**2017**	**2020**	**2025**	**2030**
ICE maintenance	**11765**	**11765**	**11765**	**11765**
European value	11765	11765	11765	11765
Foreign value	0	0	0	0
Regular maintenance	**11765**	**11765**	**11765**	**11765**
European value	11765	11765	11765	11765
Foreign value	0	0	0	0
Depot overheads	**8235**	**8235**	**8235**	**8235**
European value	8235	8235	8235	8235
Foreign value	**11765**	**11765**	**11765**	**11765**
Driver salary	**47059**	**47059**	**47059**	**47059**
European value	47059	47059	47059	47059
Foreign value	0	0	0	0

Diesel fuel value chain assumptions

The following assumptions based on the BP energy outlook underlie the analysis of European cure oil and refining imports

European refining throughput and demand		
Component	**Unit**	**2015**
Net throughput	*Million barrels per day*	13.1
Product demand	*Million barrels per day*	14.1
Oil imports and exports		
Component	**Unit**	**2015**
Crude imports	*Million barrels per day*	9.8
Crude exports	*Million barrels per day*	0.20
Crude production	*Million barrels per day*	4.48
Product imports	*Million barrels per day*	3.85
Product exports	*Million barrels per day*	2.7
Product indigenous production	*Million barrels per day*	13.1

Diesel fuel value cost assumptions

The following assumptions based on the DECC: *Energy and emissions forecasts*, Delloite for DECC: *Study of the UK petroleum retail market (2012)*, Rusinga: *Value Chain analysis along the Petroleum Supply Chain*, and *McKinsey and Company: UKH2Mobility Phase 1 Report* underlie the diesel cost breakdown used here

Wholesale cost breakdown					
Component	**Unit**	**2017**	**2020**	**2025**	**2030**
Oil wholesale	*%*	79%	79%	79%	79%
Refining	*%*	4%	4%	4%	4%
Retailer margin	*%*	18%	18%	18%	18%
Cost components					
Component	**Unit**	**2017**	**2020**	**2025**	**2030**
Wholesale	*EUR / l*	0.41	0.44	0.49	0.64
Duty	*EUR / l*	0.33	0.33	0.33	0.33
Refining	*EUR / l*	0.02	0.02	0.02	0.02
Retailer margin	*EUR / l*	0.09	0.10	0.11	0.14
European value shares					
Wholesale	*EUR / l*	-	-	-	-
Duty	*EUR / l*	0.33	0.33	0.33	0.33
Refining	*EUR / l*	0.02	0.02	0.03	0.03
Retailer margin	*EUR / l*	0.10	0.11	0.14	0.15
Foreign value shares					
Wholesale	*EUR / l*	0.44	0.49	0.64	0.65
Duty	*EUR / l*	-	-	-	-
Refining	*EUR / l*	-	-	-	-
Retailer margin	*EUR / l*	-	-	-	-

Grid electricity fractional costs

Breakdown of the fractional costs of electricity (based on DECC: *Electricity Generation Costs* for 2017 and 2020, and US Energy Information Administration: *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016* for 2025 and 2030)

Proportion of value of electricity					
Component	**Unit**	**2017**	**2020**	**2025**	**2030**
VAT	*%*	5%	5%	5%	5%
Levies	*%*	15%	15%	13%	13%
Supplier charges	*%*	1%	1%	1%	1%
Transmission charges	*%*	5%	5%	4%	4%
Distribution charges	*%*	20%	20%	17%	17%
Energy cost	*%*	55%	55%	60%	60%
Proportion of grid mix					
Natural gas	*% of supply mix*	17%	17%	20%	22%
Renewables	*% of supply mix*	27%	37%	40%	43%
Nuclear	*% of supply mix*	27%	22%	21%	22%
Coal and Lignite + other	*% of supply mix*	29%	24%	19%	13%
European value proportion					
VAT	*%*	100%	100%	100%	100%
Levies	*%*	100%	100%	100%	100%
Supplier charges	*%*	100%	100%	100%	100%
Transmission charges	*%*	100%	100%	100%	100%
Distribution charges	*%*	100%	100%	100%	100%
Energy cost	*%*	70%	70%	66%	66%
Breakdown					
Electricity cost	*EUR / MWh*	111	107	130	128
European value	*EUR / MWh*	93	90	103	102
Foreign value	*EUR / MWh*	19	17	27	26

European grid mix by year

Breakdown of the European grid's generation mix by year (based on European Commission EU reference scenario)

Year	CAPEX	Fixed O&M	Fuel	Decommissioning costs
-	*% of total LCOE*	*% of total LCOE*	*% of total LCOE*	*% of total LCOE*
Gas CCGT				
2017	13%	17%	70%	0%
2020	13%	17%	70%	0%
2025	25%	3%	73%	0%
2030	25%	3%	73%	0%
Nuclear				
2017	76%	18%	3%	3%
2020	76%	18%	3%	3%
2025	75%	12%	11%	2%
2030	75%	12%	11%	2%
Coal IGCC				
2017	42%	12%	46%	0%
2020	42%	12%	46%	0%
2025	70%	7%	23%	0%
2030	70%	7%	23%	0%
Renewables				
2017	78%	22%	0%	0%
2020	79%	21%	0%	0%
2025	79%	21%	0%	0%
2030	79%	21%	0%	0%

Breakdown of the proportion of value for each LCOE component

Commodity	Value proportion for Europe	PRCCODE / source
Unit	%	-
Power generator CAPEX		
Gas turbines	18%	Based on 28112300, 28113300
Coal turbines	18%	Assumed same as gas turbines
Nuclear reactors	95%	Based on 25302100, 25302200
Renewables	90%	Assumption
Fuel		
Natural gas fuel	34%	Fuel assumption based on https://ec.europa.eu/energy/en/topics/imports-and-secure-supplies; assumed constant to 2030
Nuclear fuels	60%	Fuel assumption based on https://ec.europa.eu/energy/en/topics/imports-and-secure-supplies; assumed constant to 2030
Coal and other solid fuels	58%	Fuel assumption based on https://ec.europa.eu/energy/en/topics/imports-and-secure-supplies; assumed constant to 2030
Fixed OPEX and decommissioning		
All fixed plant OPEX	90%	Assumption
Decommissioning of plants	100%	Assumption

Electrolysis cost and performance assumptions

The assumptions listed here underlie the hydrogen production analyses for PEM and alkane electrolysers. The Electrolyser cost and operation parameters are based on the FCH JU report Water Electrolysis in the European Union.

PEM electrolysers	Units	2017	2020	2025	2030
Electrolyser CAPEX	*EUR / kW*	1,113	932	605	588
Lifetime	*years*	10	10	10	10
OPEX as % of CAPEX	*%*	3%	3%	3%	3%
Proportion time on	*%*	40%	70%	90%	90%
Stack cost as % of CAPEX	*%*	60%	60%	60%	60%
Stack lifetime	*hours*	54,000	60,000	70,000	80,000
Efficiency of electrolyser	*kWh/kg*	50	48	48	47
Efficiency of compressors and clean up	*kWh/kg*	2	2	2	2
Electricity cost	*EUR / kWh*	0.071	0.071	0.071	0.071

Alkaline electrolysers	Units	2017	2020	2025	2030
Electrolyser CAPEX	*EUR / kW*	659	550	505	505
Lifetime	*years*	10.00	10.00	10.00	10.00
OPEX as % of CAPEX	*%*	3%	3%	3%	3%
Proportion time on	*%*	40%	70%	90%	90%
Stack cost as % of CAPEX	*%*	50%	50%	50%	50%
Stack lifetime	*hours*	80,000	80,000	80,000	80,000
Efficiency of electrolyser	*kWh / kg*	52.60	52.00	51.00	50.00
Efficiency of compressors and clean up	*kWh / kg*	1.50	1.50	1.50	1.50
Electricity cost	*EUR / kWh*	0.071	0.071	0.071	0.071

Assumptions underlying the cost of hydrogen production via centralised SMR and its distribution

The SMR costs shown here are based on analysis undertaken for the Carbon Trust's Hydrogen for Transport TINA. Distribution costs are based on Element Energy and E4Tech for Innovate UK: *Hydrogen and Fuel cells: Opportunities for growth*

Trucked SMR	Units	2017	2020	2025	2030
Depreciation period	*years*	10	10	10	10
Electricity price	*EUR / kWh*	0.07	0.07	0.07	0.07
Compressors					
Trailers filled per day	*number*	12	12	12	12
Time required to fill up the trailers	*hours*	2	2	2	2
Needed compression capacity	*kgH2/hour*	150	500	500	500
Compressor size needed to meet daily compression needs	*kW-e*	173	894	894	894
Total compressor capex	*EUR*	604,275	604,275	604,275	604,275
Compressors OPEX	*% of Capex per year*	0.05	0.05	0.05	0.05
30 (SMR plant) to 200bar energy consumption	*kWh/kgH2*	0.36	0.36	0.36	0.36
70 to 200bar energy consumption	*kWh/kgH2*	0.56	0.56	0.56	0.56
200bar to 500bar energy consumption	*kWh/kgH2*	0.00	0.51	0.51	0.51
Total Compression Energy requirements	*kWh/kgH2*	0.92	1.43	1.43	1.43
Trailers for distribution					
Average distance driven per trip (return)	*km*	150	150	150	150
Trailer utilisation (per annum)	*%*	0.40	0.70	0.90	0.90
Trailer capex	*EUR*	235,294	588,235	411,765	235,294
Trailers capacity	*tonne H2*	0.30	1.00	1.00	1.00
H2 delivered per annum	*tonne/year*	44	256	329	329
OPEX trailers	*% of Capex*	0.03	0.03	0.03	0.03
Personnel costs - trailers swapping etc.	*EUR / kgH2*	0.46	0.14	0.14	0.14
Fuel costs	*EUR / km*	0.41	0.41	0.41	0.41
Number of trips per annum per trailer	*#*	146	256	329	329
SMR costs					
Natural gas price (2015)	*EUR / kWh*	0.04	0.04	0.04	0.04
Energy Consumption (electrical, LHV)	*kWh/kg-H2*	0.60	0.60	0.60	0.60
Energy Consumption (gas, LHV)	*kWh/kg-H2*	46.80	46.80	46.80	46.80
Approximate OPEX/capex contribution	*EUR / kg*	0.24	0.24	0.24	0.24

Hydrogen refuelling stations cost and performance assumptions, and hydrogen production / dispensing value shares

Hydrogen refuelling stations	Units	2017	2020	2025	2030
HRS CAPEX	*EUR / kWh*	3,728	3,617	2,224	2,030
Lifetime	*Years*	15.00	15.00	15.00	15.00
Efficiency (for hydrogen produced onsite)	*kWh / kg*	3.00	3.00	3.00	3.00
Efficiency (for hydrogen trucked in)	*kWh / kg*	1.25	1.25	1.25	1.25
OPEX	*as % of CAPEX per year*	0.03	0.03	0.03	0.03
Utilisation	*%*	0.40	0.40	0.40	0.40
Electricity cost	*EUR / kWh*	0.07	0.07	0.07	0.07

Commodity	Value proportion for Europe	PRCCODE / source
Unit	*%*	-
Power generation		
Trailer CAPEX / trailer OPEX	100%	30112300
Personnel costs	100%	Assumption
SMR CAPEX / OPEX	100%	Based on 24413070
Compressors CAPEX and OPEX	77%	Based on 28132300 and 33121210
Electrolyser CAPEX and OPEX	100%	Based on 24413070
HRS CAPEX and OPEX	100%	Assumed same as electrolyser

Summary of assumptions used in value chain analysis

The total value creation analysis makes a series of technical and operational assumptions regarding the buses (e.g. the efficiency and mileage are key to understanding the fuel consumption). These are summarised below, along with the aggregated CAPEX and OPEX and fuel prices derived previously.

Lifetime value creation analysis inputs			Fuel cell electric				Battery electric (long range)				Diesel			
Parameter	Foreign / Domestic Value	Units	2017	2020	2025	2030	2017	2020	2025	2030	2017	2020	2025	2030
Bus mileage	-	km / year	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000
Bus inputs														
Bus availability	-	%	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Bus capex	European	EUR / bus	453,749	365,054	245,593	240,308	356,182	288,326	239,830	233,727	168,089	168,089	168,089	168,089
Bus capex	Foreign	EUR / bus	212,251	134,946	102,173	99,458	206,465	143,674	119,202	108,809	2,805	2,805	2,805	2,805
Bus lifetime	-	Years	12	12	12	12	12	12	12	12	12	12	12	12
Powertrain overhaul capex	European	EUR / bus	80,153	51,537	33,233	24,963	111,714	62,816	62,870	64,221	4,050	4,050	4,050	4,050
Powertrain overhaul capex	Foreign	EUR / bus	25,545	13,909	9,764	7,307	40,994	20,891	20,873	20,400	66	66	66	66
Powertrain lifetime	-	Years	6	6	6	6	6	6	6	6	6	6	6	6
Bus drivetrain maintenance	European	EUR / year.bus	35,294	17,647	17,647	17,647	17,647	17,647	17,647	17,647	11,765	11,765	11,765	11,765
Bus drivetrain maintenance	Foreign	EUR / year.bus	-	-	-	-	-	-	-	-	-	-	-	-
Diesel consumption	-	l / 100km	-	-	-	-	-	-	-	-	37	37	37	37
Electricity consumption	-	kWh / 100km	-	-	-	-	200	150	150	150	-	-	-	-
Electricity consumption	-	kWh / 100km	-	-	-	-	200	150	150	150	-	-	-	-
Hydrogen consumption	-	kg / 100km	8.0	7.5	6.5	6.5	-	-	-	-	-	-	-	-
Bus regular maintenance	European	EUR / year.bus	11,765	11,765	11,765	11,765	11,765	11,765	11,765	11,765	11,765	11,765	11,765	11,765
Bus regular maintenance	Foreign	EUR / year.bus	-	-	-	-	-	-	-	-	-	-	-	-
Driver salary	European	EUR / year.bus	47,059	47,059	47,059	47,059	47,059	47,059	47,059	47,059	47,059	47,059	47,059	47,059
Driver salary	Foreign	EUR / year.bus	-	-	-	-	-	-	-	-	-	-	-	-
Additional driver salary	European	EUR / year.bus	-	-	-	-	-	-	-	-	-	-	-	-
Additional driver salary	Foreign	EUR / year.bus	-	-	-	-	-	-	-	-	-	-	-	-
Depot overheads	European	EUR / bus	8,235	8,235	8,235	8,235	8,235	8,235	8,235	8,235	8,235	8,235	8,235	8,235
Depot overheads	Foreign	EUR / bus	-	-	-	-	-	-	-	-	-	-	-	-
Depot upgrade	European	EUR / bus	5,882	5,882	5,882	5,882	-	-	-	-	-	-	-	-
Depot upgrade	Foreign	EUR / bus	-	-	-	-	-	-	-	-	-	-	-	-
Infrastructure inputs														
Infrastructure CAPEX	European	EUR / bus	-	-	-	-	28,252	28,252	28,252	28,252	-	-	-	-
Infrastructure CAPEX	Foreign	EUR / bus	-	-	-	-	23,512	23,512	23,512	23,512	-	-	-	-
Infrastructure maintenance	European	EUR / year.bus	-	-	-	-	3,211	3,211	3,211	3,211	-	-	-	-
Infrastructure maintenance	Foreign	EUR / year.bus	-	-	-	-	2,672	2,672	2,672	2,672	-	-	-	-

Fuel prices and value creation ratios used in the analysis

The foreign and European value creation from each fuel derived in the analysis are summarised below

Fuel prices						
Parameter	**Foreign / Domestic Value**	**Units**	**2017**	**2020**	**2025**	**2030**
Hydrogen cost	European	*EUR / kg*	5.79	4.90	3.70	3.50
Hydrogen cost	Foreign	*EUR / kg*	0.92	0.88	0.95	0.94
Electricity cost	European	*EUR / kWh*	0.09	0.09	0.10	0.10
Electricity cost	Foreign	*EUR / kWh*	0.02	0.02	0.03	0.03
Diesel costs	European	*EUR / l*	0.43	0.44	0.47	0.48
Diesel costs	Foreign	*EUR / l*	0.46	0.51	0.67	0.68

Analysis of the pollution emissions due to EURO VI standard buses

The following assumptions underlie the air quality analysis

Pollutant emissions analysis		CO	HC	NOx	PM
Euro VI standard	*g / kWh*	1.50	0.13	0.40	0.01
Bus efficiency	*kWh / 100km*	396	396	396	396
Bus mileage	*km / year*	80,000	80,000	80,000	80,000
Pollution over 12 year lifetime	*Tonnes*	5.70	0.49	1.52	0.04
Marginal cost of pollutant	*EUR / tonne*	-	-	1,000	67,650
Cost per bus	*EUR / bus*	-	-	1,520	2,571

Analysis of the CO_2 emissions from different bus types

The CO2 emissions and equivalent ETS price analysis is based on the following assumptions

CO_2 emissions analysis					
Parameter	Units	2017	2020	2025	2030
Diesel CO2 content	*kg CO2e / l*	2.68	2.68	2.68	2.68
Hydrogen CO2 content assuming UKH2M targets	*kg CO2e / kg H2*	4.17	3.34	2.50	2.09
Grid electricity co2 content	*kgCO2e / kWh*	0.32	0.30	0.26	0.24
Annual fuel consumption					
Diesel bus	*l / year*	29,600	29,600	29,600	29,600
Fuel cell bus	*kg / year*	6,400	6,000	5,200	5,200
Electric bus	*kWh / year*	160,000	120,000	120,000	120,000
Annual CO2 emissions					
Diesel bus	*Tonnes CO2 / year.bus*	79	79	79	79
Fuel cell bus	*Tonnes CO2 / year.bus*	39.66	31.73	23.80	19.83
Electric bus	*Tonnes CO2 / year.bus*	51	36	31	29
Cost of CO2 emissions per bus at ETS price					
Diesel bus	*EUR / year.bus*	929	1,308	1,926	2,888
Fuel cell bus	*EUR / year.bus*	464	523	578	722
Electric bus	*EUR / year.bus*	599	594	757	1,049