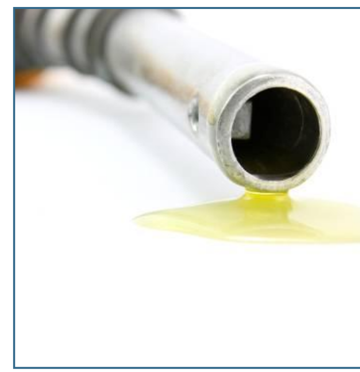
Urban buses: alternative powertrains for Europe

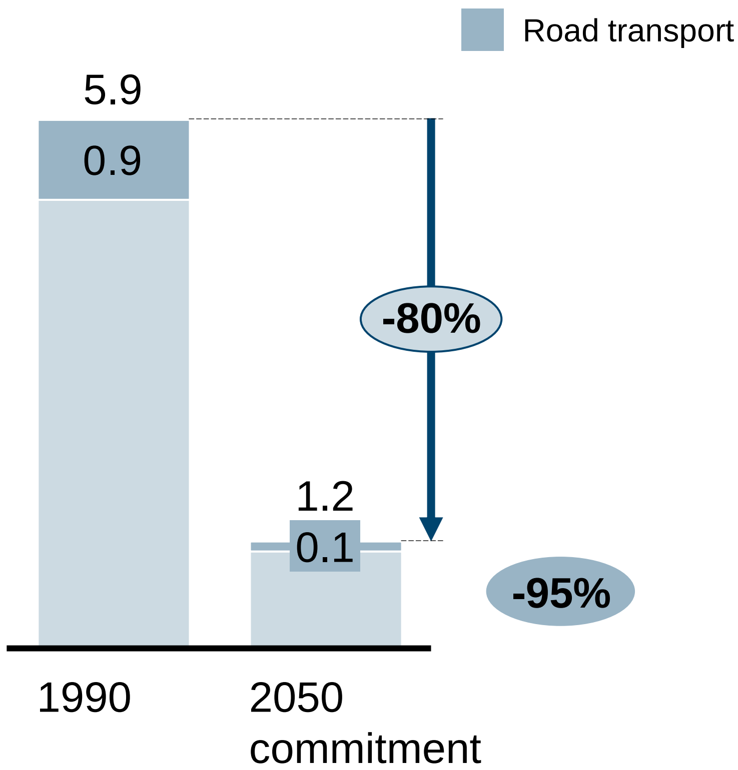


A fact-based analysis of the role of diesel hybrid, hydrogen fuel cell, trolley and electric powertrains

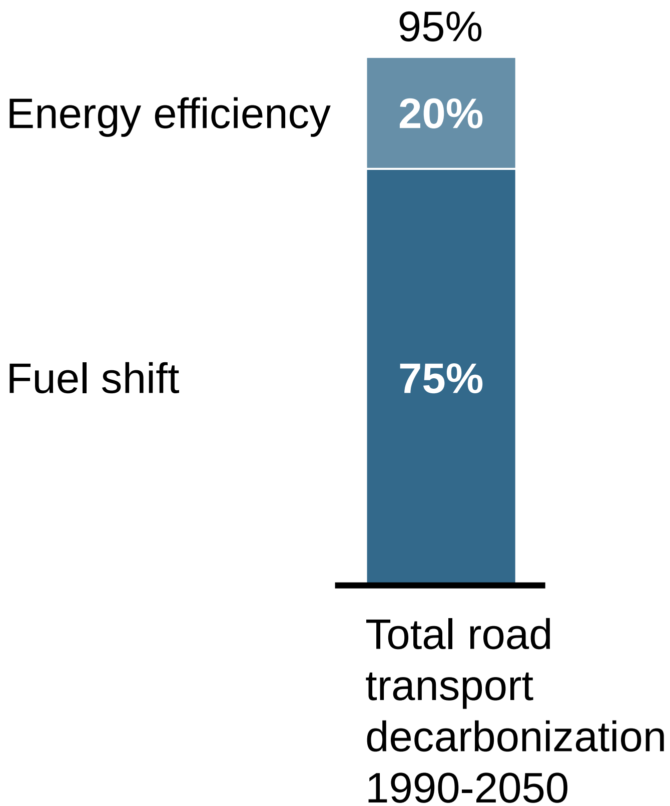
November 2012

Rationale: Only through a fuel shift can transport in the EU achieve its target of 95% GHG abatement

Road transport needs to decarbonize 95% by 2050 to achieve EU overall commitment of 80% abatement

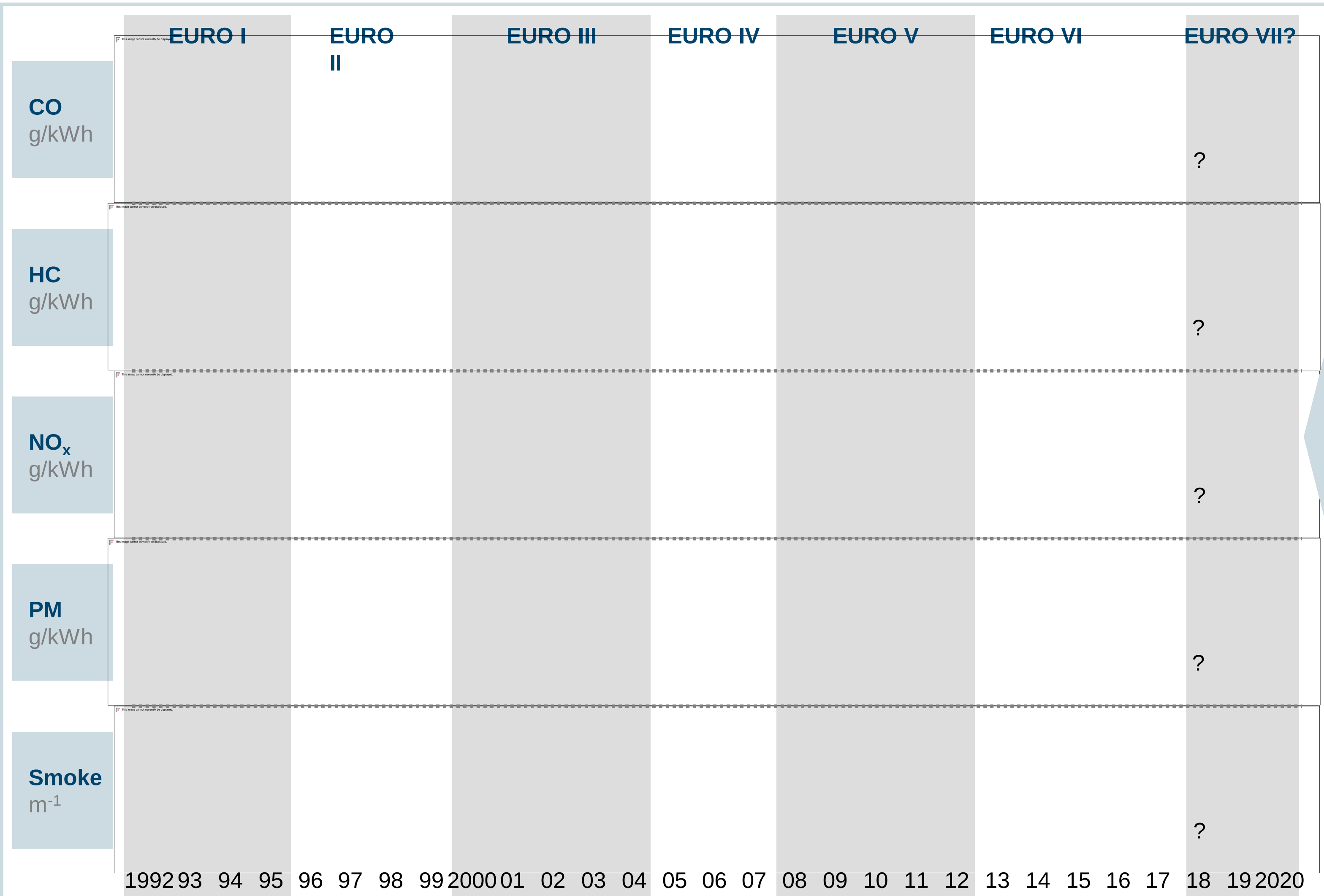


Majority decarbonization needs to come from fuel shift



Source: Roadmap 2050

It is uncertain if conventional combustion engines will be able to fulfill requirements by a potential EURO VII norm or beyond



Will conventional combustion powertrains be able to achieve a potential EURO VII and beyond?

SOURCE: Dieselnet; team analysis

Result is that European cities focus on getting newest diesel engines until 2015 but, beyond that, seem to demand powertrains with lower emissions

Restrictions on diesel engine

Non-fossil powertrain requirements

Amsterdam
All buses at least EEV[2] norm. Locally, only EEV+ buses deployed

Brussels
No procurement of diesel-powered buses from 2015 onwards

Stockholm
Renewable[1] public transport only

Cologne
Only procurement of EEV[2] (and better) buses

London
All buses meet EUROIV. 300 hybrids in service by 2012YE

Oslo
All buses use renewable fuels[1]. EURO III phased out before 2013

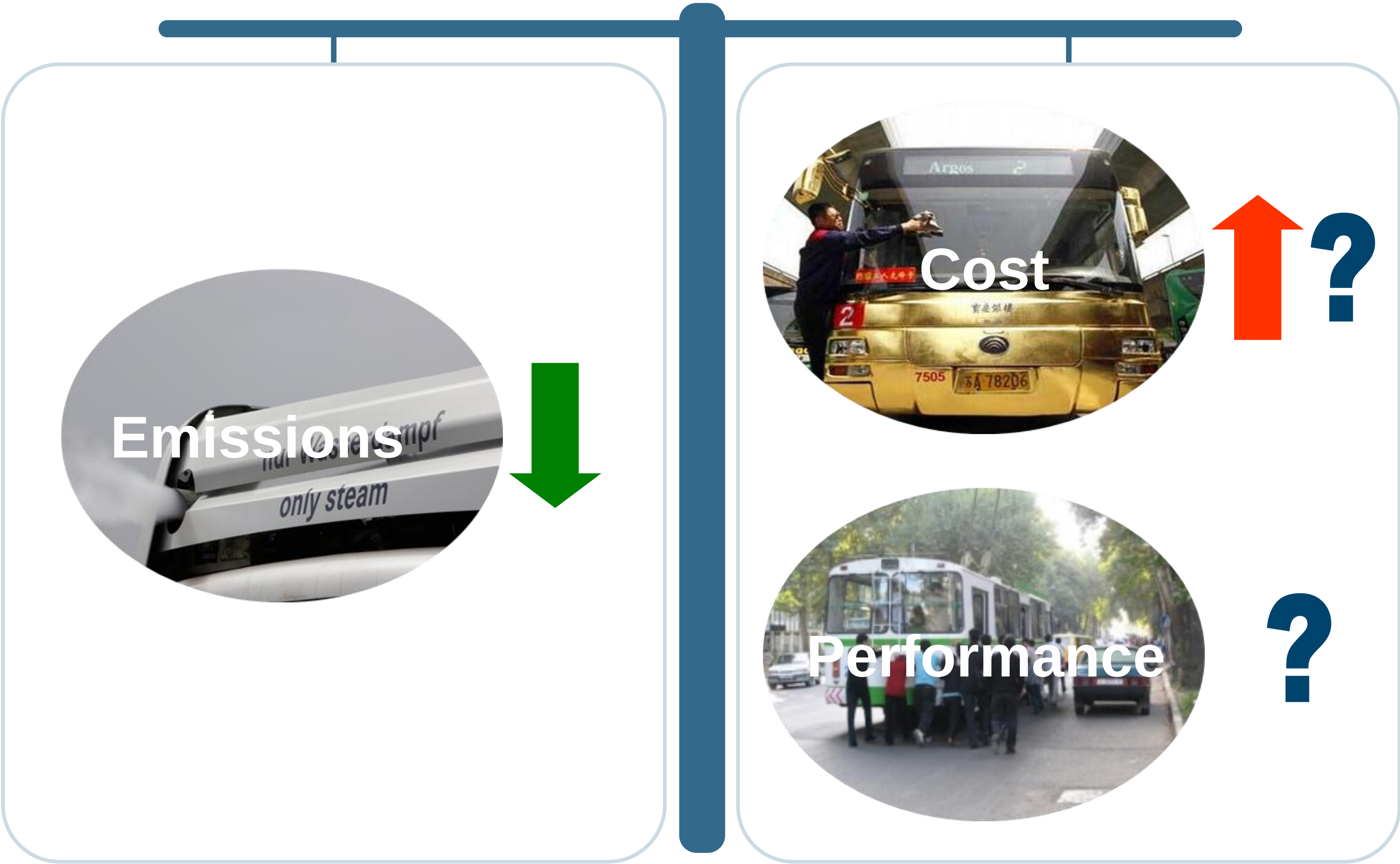
Hamburg
Only procurement of emission-free buses

2005 10 15 20 2025

1 Includes biofuels
2 EEV: Enhanced Environmentally friendly Vehicle is a EURO norm in-between EUROV and EUROVI

Source: Roadmap 2050; Dieselnet; Local city websites; 2001/81/EC; team analysis

Operators and policy makers wonder how to balance lower emissions with potentially increased costs and decreased performance



Objectives, approach and scope of the study

Objective	Approach
Fact-based evaluation of conventional and most promising alternative **powertrain technologies for urban buses**	▪ **Large coalition including all relevant stakeholders** ▪ Assessment on **cost, emissions**, and **performance** ▪ **Proprietary industry** data **objectivity** and **confidentiality** collected by a external '**clean team**'

Scope

- 8 powertrains
- Standard 12 meter city buses
- Articulated 18 meter buses

Representing ~65% of European bus market

SOURCE: FCH JU; McKinsey

The ‘Urban Buses: Alternative Powertrains for Europe’ coalition consists of more than 40 companies and organizations

Bus OEMs

EvoBus
HESS Motion & Emotion
MAN
VanHool
Solaris
Iveco
APTS / VDL Bus & Coach

7 | 70%

Technology Providers

Siemens
BAE Systems
Nucellsys
Hydrogenics Advanced Hydrogen Solutions
Voith
Škoda
EnerDel
ZF
Ballard
Bombardier
Vossloh
PM Proton Motor
UTC Power A United Technologies Company
ABB

14

Infrastructure

Air Products
Linde
Shell
Hydrogenics Advanced Hydrogen Solutions
H2 Logic
Ballast Nedam
Air Liquide
Bombardier
ABB

6[1]

Transportation Companies

GVB
RVK / HyCologne
RET
Transport for London
Hochbahn
SWS
BVG
TMB
VRR
Ruter#
MIVB STIB
Bogestra

12

Other organizations

element energy
EnergieRegion.NRW Cluster Nordrhein-Westfalen
NOW Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie
HyER

4

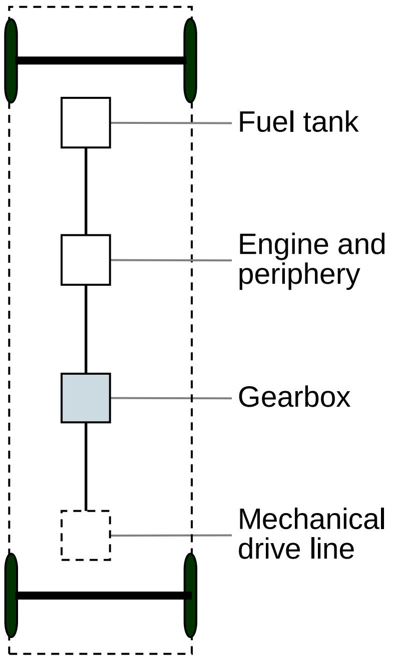
1 Bombardier, Hydrogenics and ABB participate in both the Technology Providers and the Infrastructure working groups

SOURCE: FCH JU; McKinsey

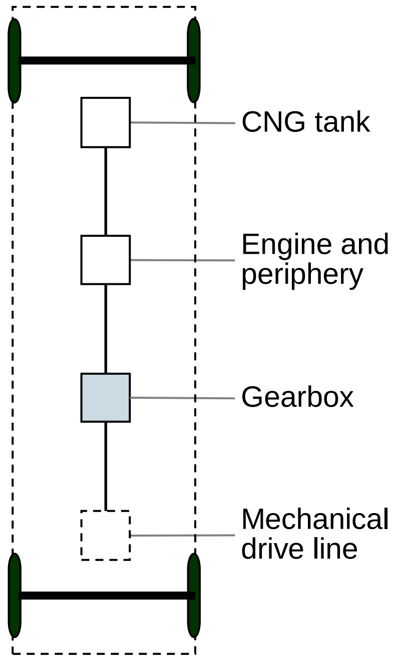
Diesel, CNG and diesel hybrids are powertrains in scope which rely (partly) on a conventional engine

ICE powertrain | Transmission | Electric powertrain | Battery or supercaps

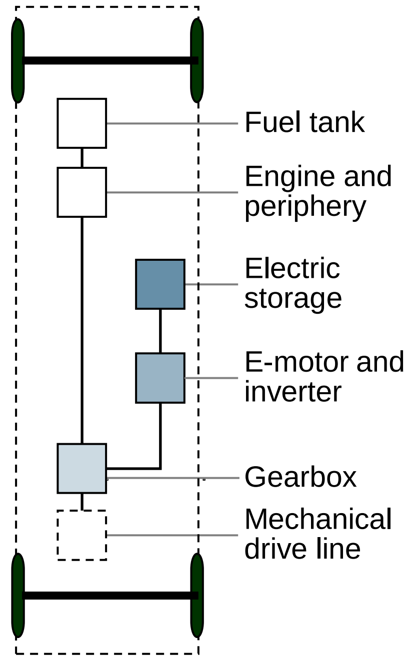
Diesel powertrain



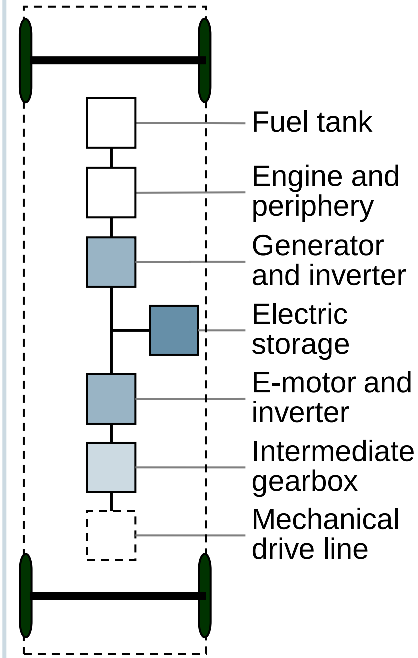
CNG powertrain



Parallel hybrid powertrain



Serial hybrid powertrain

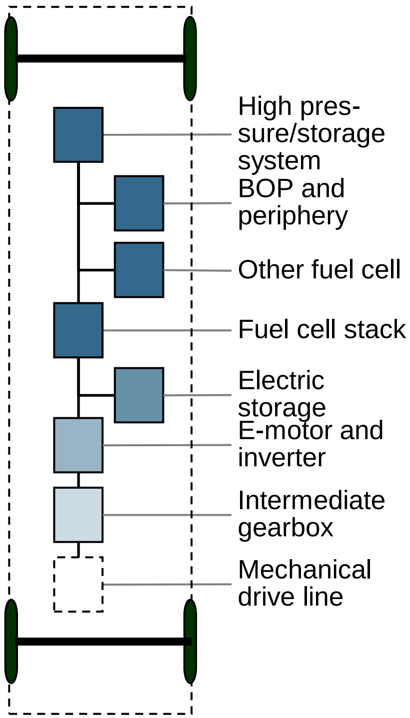


SOURCE: Study analysis; EvoBus; MAN; Iveco Irisbus

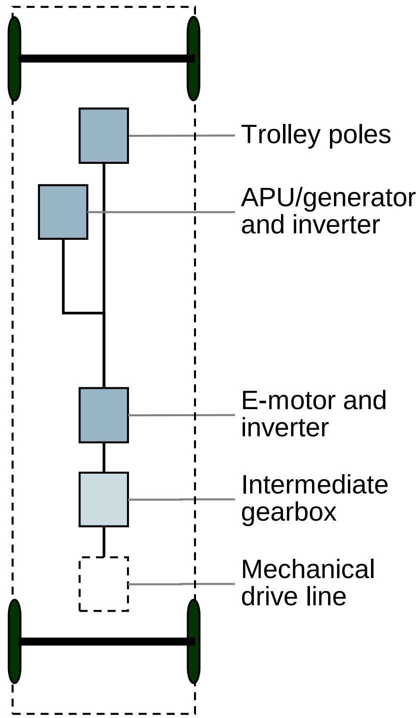
Hydrogen fuel cell, trolley and two e-buses are powertrains in scope with zero local emissions

ICE powertrain | Transmission | Electric powertrain | Battery or supercaps | FC powertrain

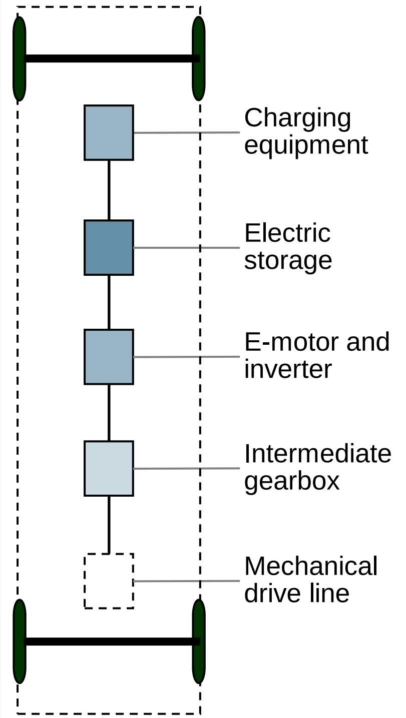
Hydrogen fuel cell powertrain



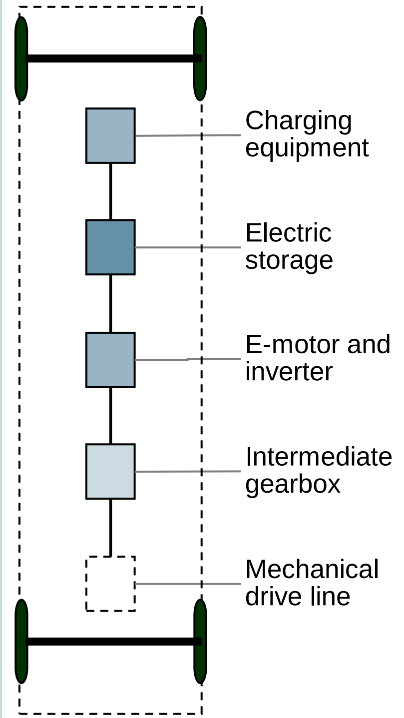
Trolley powertrain



Opportunity e-bus



Overnight e-bus



SOURCE: Study analysis; EvoBus; HESS; Solaris

Powertrains were evaluated on three dimensions

Dimension	Main evaluation criteria
Environment	▪ Overall well-to-wheel emissions ▪ Local emissions ▪ Noise
Performance	▪ Range ▪ Route flexibility/free range ▪ Refueling time ▪ Acceleration
Total Cost of Ownership (TCO)	▪ Purchase and financing costs ▪ Running costs ▪ Infrastructure costs

Powertrains were evaluated on three dimensions

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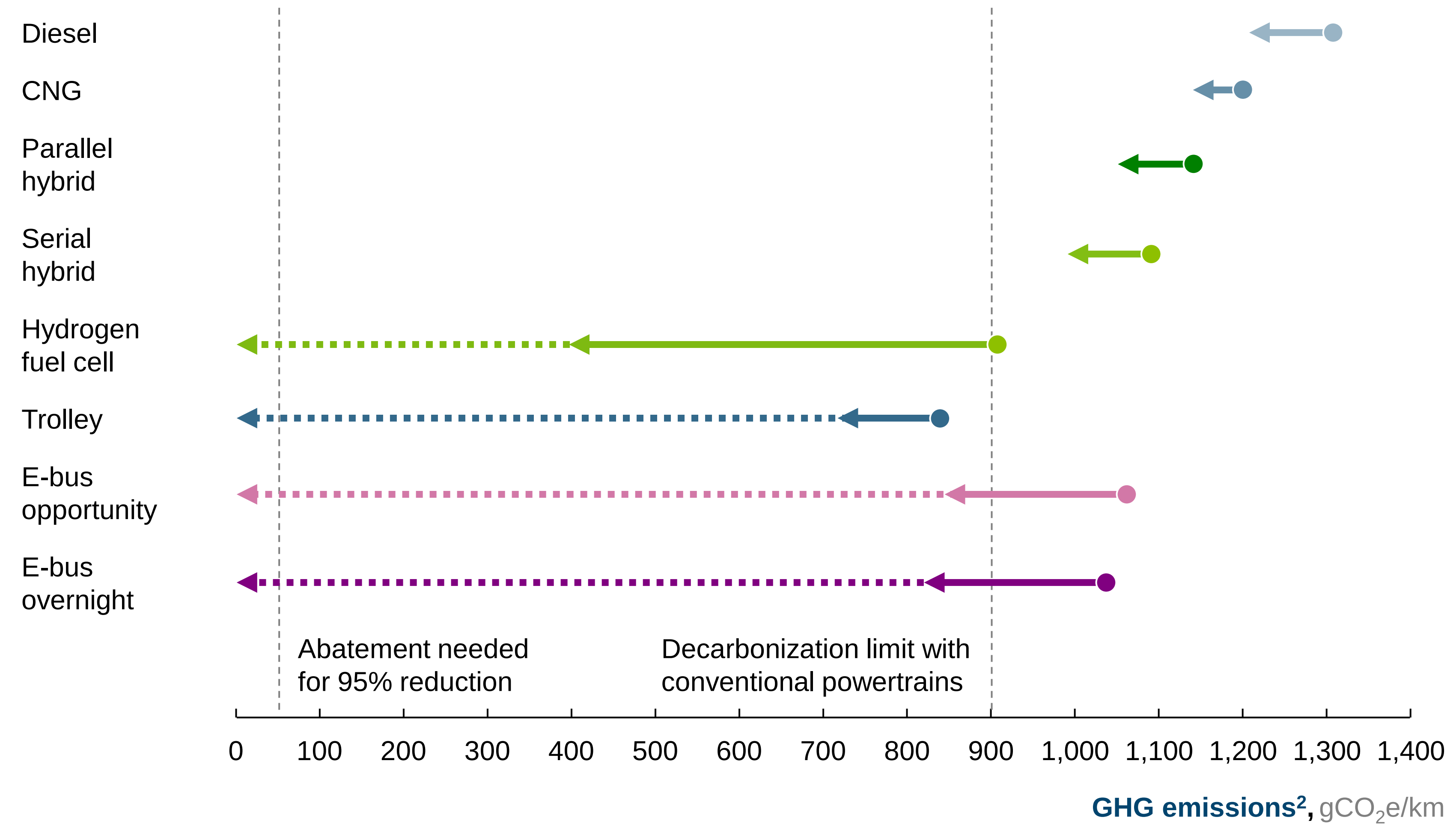
Only the hydrogen, e-bus and trolley buses have the potential to drastically reduce well-to-wheel emissions…

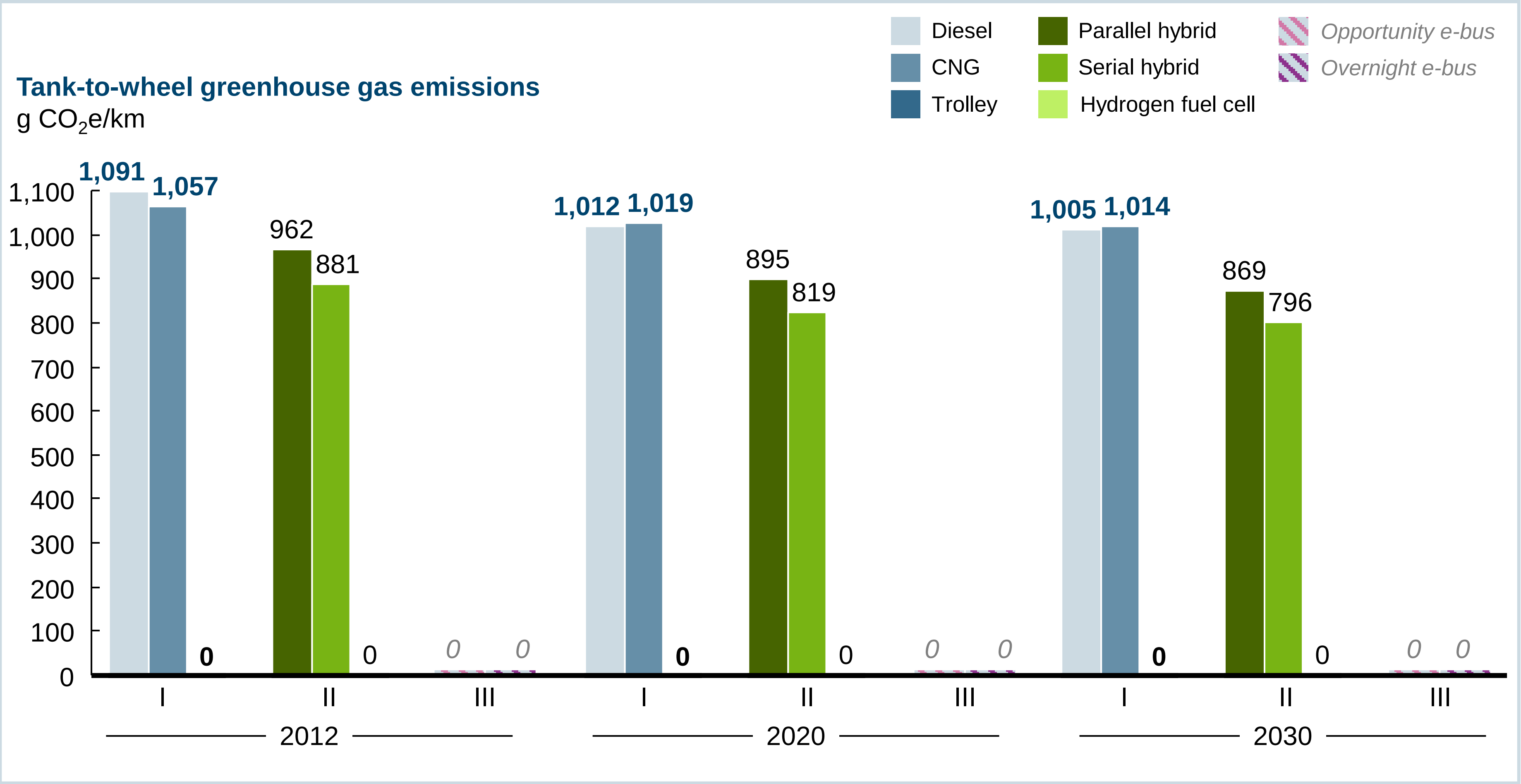
WELL-TO-WHEEL | 12 METER BUS



SOURCE: Study analysis

…and only the hydrogen, e-bus and trolley buses can achieve zero local emissions

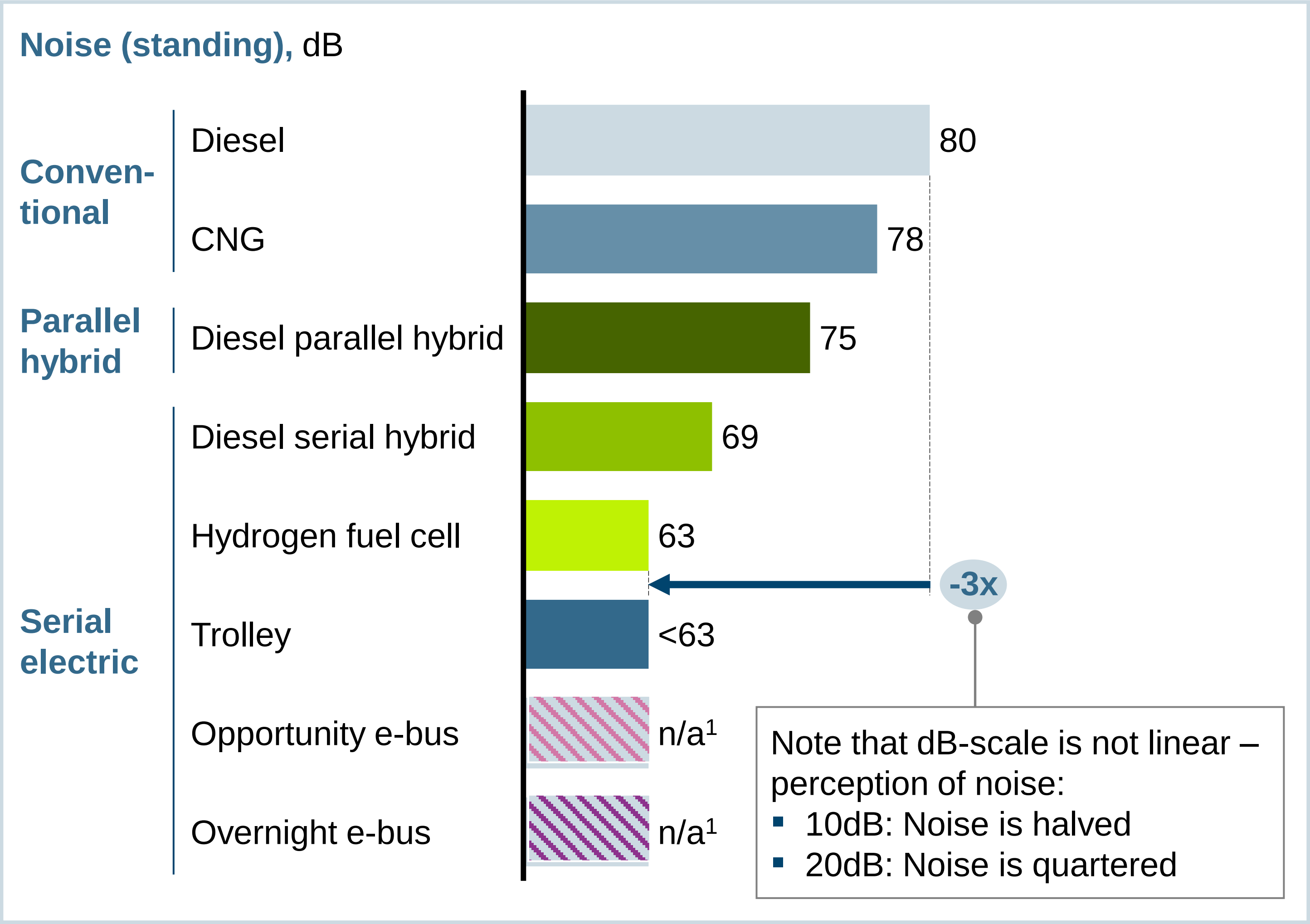
TANK-TO-WHEEL | 12 METER BUS



SOURCE: Study analysis

Perceived noise of a fuel cell hybrid is more than 3x lower than that of a conventional diesel

12 M BUS



1 No measure figures available yet – expectations are similar to hydrogen fuel cell bus

SOURCE: Study analysis

Powertrains were evaluated on three dimensions

Dimension	Main evaluation criteria
Environment	▪ Overall well-to-wheel emissions ▪ Local emissions ▪ Noise
Performance	▪ Range ▪ Route flexibility/free range ▪ Refueling time ▪ Acceleration
Total Cost of Ownership (TCO)	▪ Purchase and financing costs ▪ Running costs ▪ Infrastructure costs

Performance of the hydrogen bus is similar to conventional powertrains

12 M BUS | 2030

Similar performance

Passenger capacity

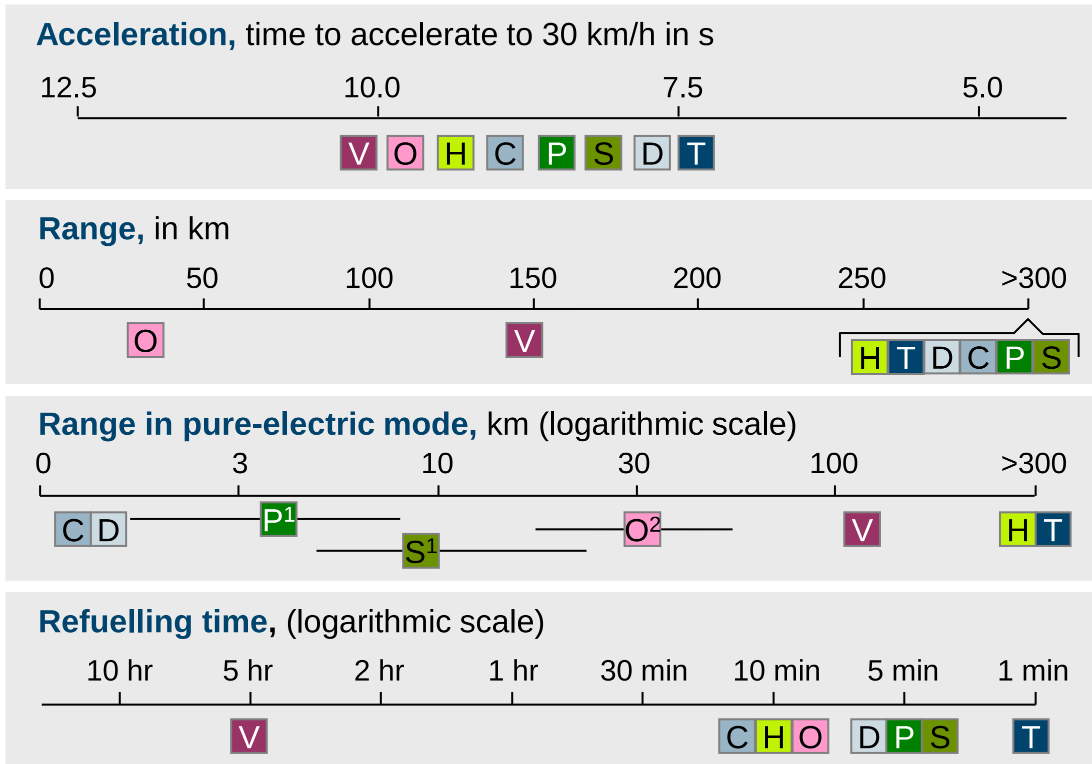
Curb weight (12 m bus)

Lowest:
Diesel (11.6 tonnes)

Highest:
Overnight e-bus
(13.5 tonnes)

Differentiated performance

D Diesel
C CNG
P Diesel parallel hybrid
S Diesel serial hybrid
H Hydrogen fuel cell
T Trolley
O Opportunity e-bus
V Overnight e-bus



- **Only hydrogen fuel cell** and **trolley** can drive with **zero-emissions** at almost **no range limitation**
- **E-buses limited** in operational range – long charging times for overnight
- **Diesel hybrids, serial in particular, capable of zero-emission** driving on certain stretches of the route with same operational conditions as conventional powertrain; serial

1 Typical values shown here – pure electric range of hybrid powertrains varies depending on concept of auxiliary units and battery capacity
2 Based on a 60 kWh battery and a consumption (including losses from charging) of 2 kWh/km

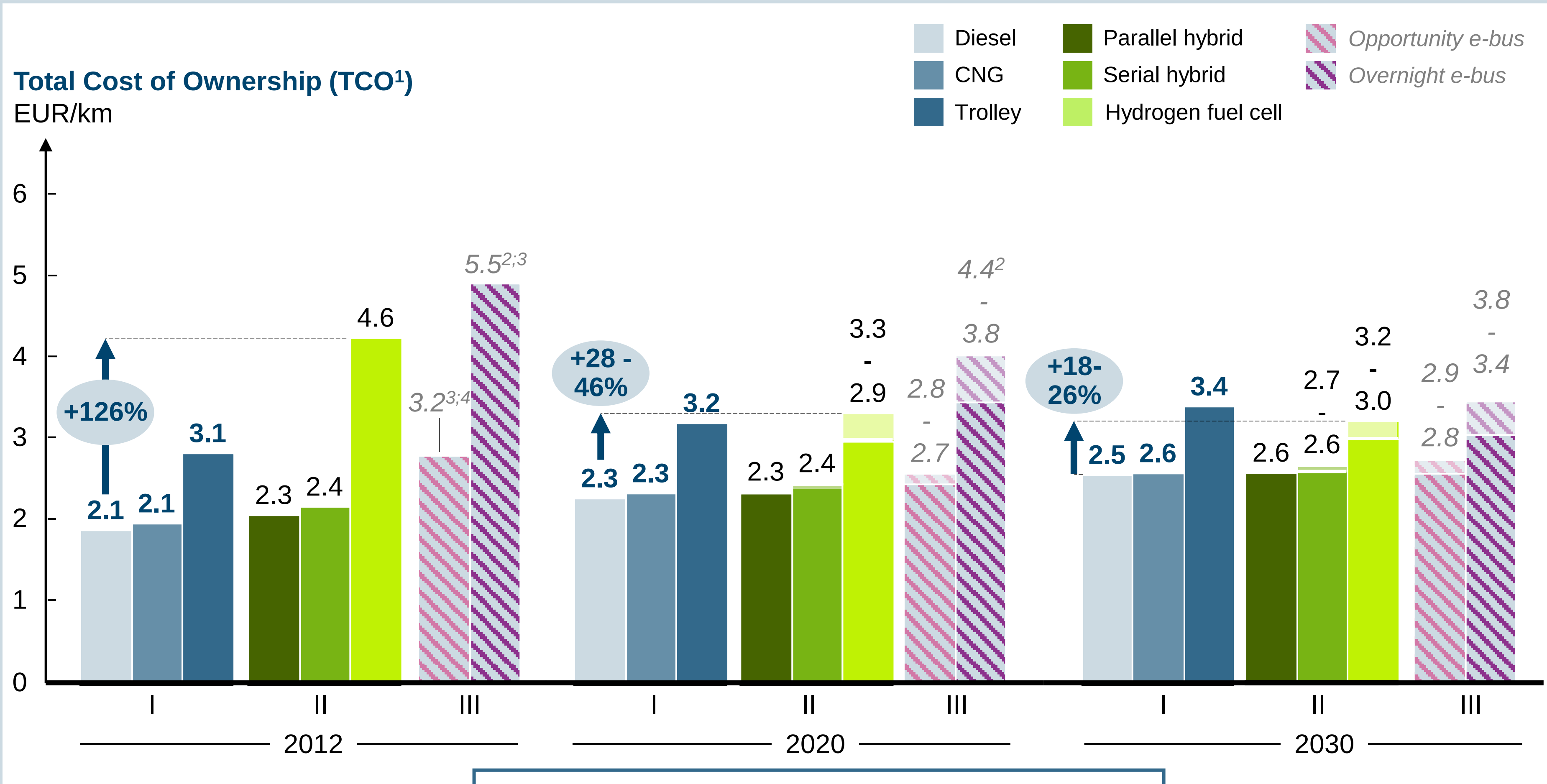
SOURCE: Study analysis

Powertrains were evaluated on three dimensions

Dimension	Main evaluation criteria
Environment	▪ Overall well-to-wheel emissions ▪ Local emissions ▪ Noise
Performance	▪ Range ▪ Route flexibility/free range ▪ Refueling time ▪ Acceleration
Total Cost of Ownership (TCO)	▪ Purchase and financing costs ▪ Running costs ▪ Infrastructure costs

The price premium for a hydrogen fuel cell bus will decrease from 125% to only 15-25%

12 METER BUS



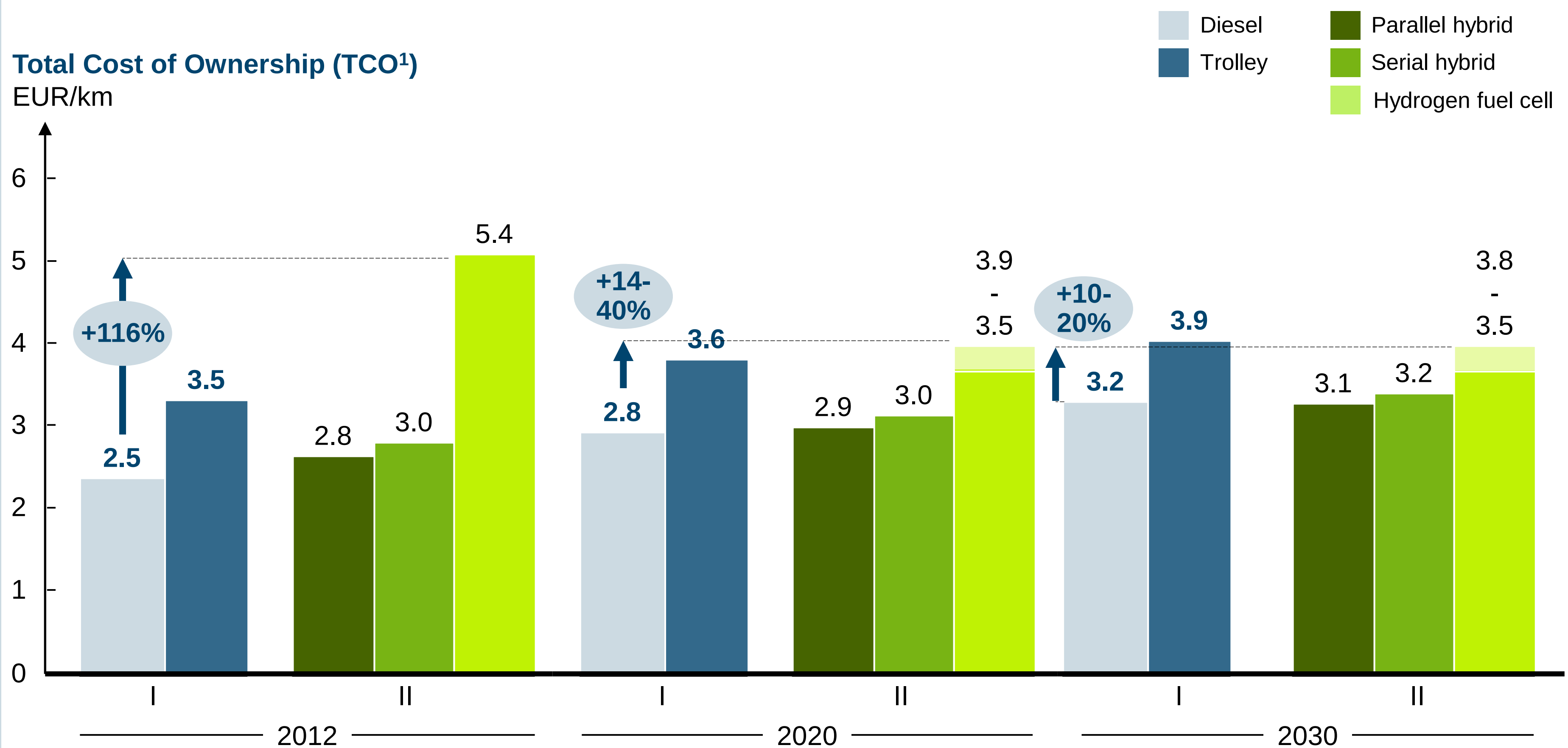
Upper bound figures = **'production-at-scale'** scenario
Lower bound figures = **'cross-industry'** scenario

1 Based on 12 years bus lifetime, 60,000 km annual mileage
2 Includes purchase price of more than 1 bus per daily shift as bus maximum mileage too short for full operational day
3 Theoretical value based on estimations as powertrain not in production yet in 2012
4 Includes cost for additional bus and driver per fleet of 9 buses to cover charging times at end of route for 2012

SOURCE: Study analysis

The hydrogen fuel cell bus is the only articulated bus expected to decrease in TCO until 2030

ARTICULATED BUS



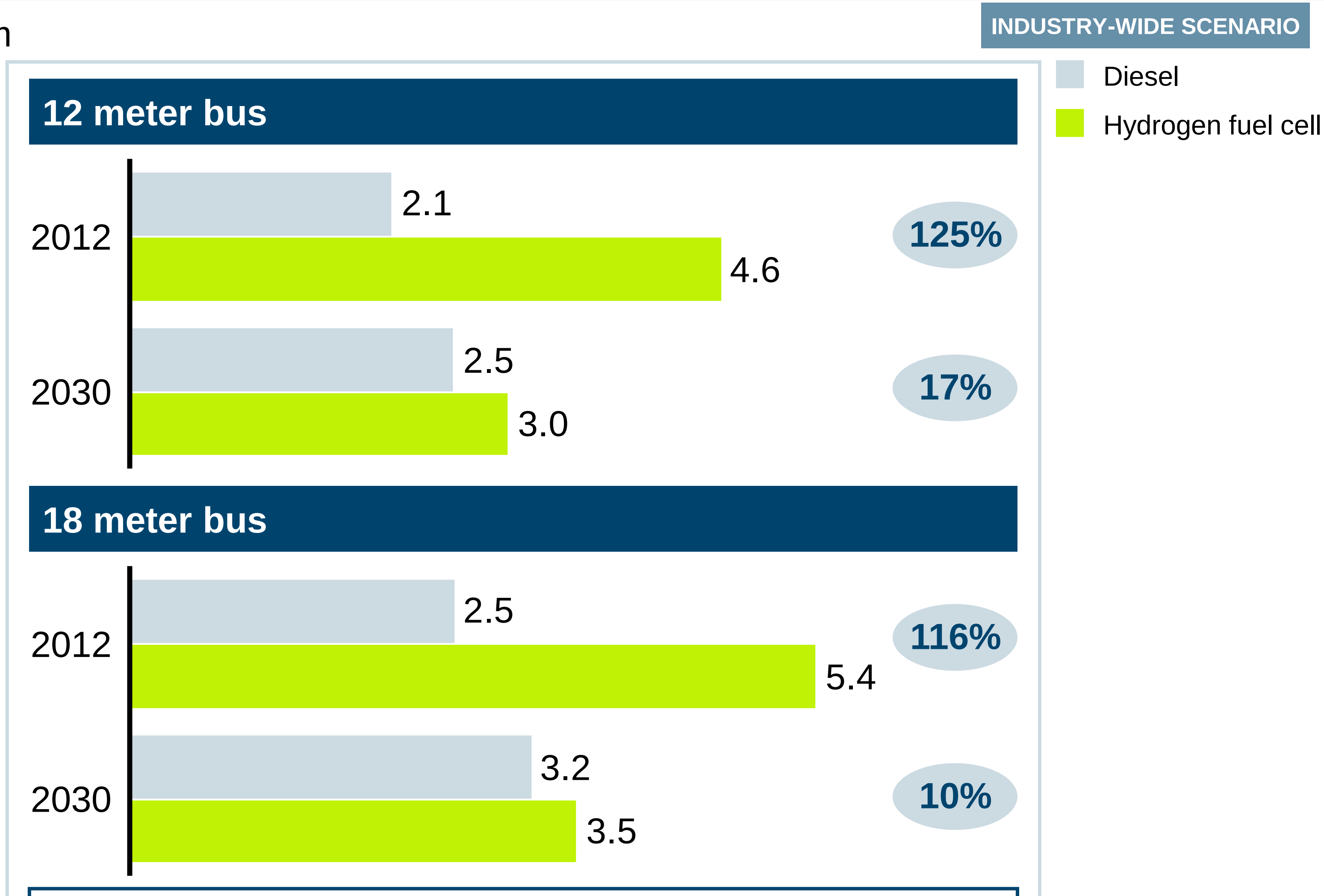
Upper bound figures = **'production-at-scale'** scenario
Lower bound figures = **'cross-industry'** scenario

1 Based on 12 years' bus lifetime, 60,000 km annual mileage

SOURCE: Study analysis

The cost premium for a hydrogen zero-local emission bus can be lower than 20% by 2030

TCO, EUR/km

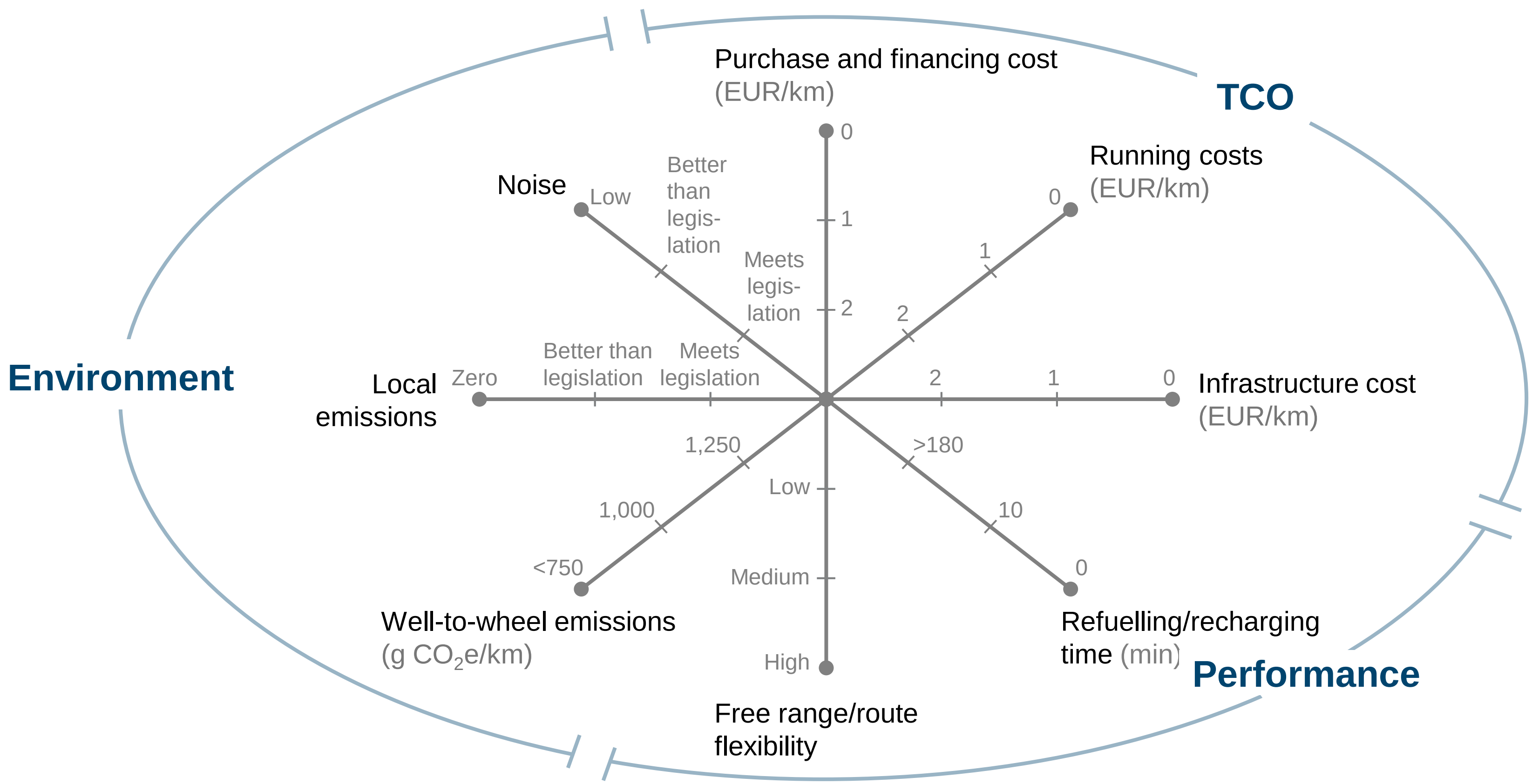


The hydrogen fuel cell bus only has a small premium over conventional diesel by 2030

Source: Study analysis

The powertrains were assessed on three dimensions: environment, performance and total cost of ownership (TCO)

PRODUCTION-AT-SCALE SCENARIO | 12 M BUS | 2030

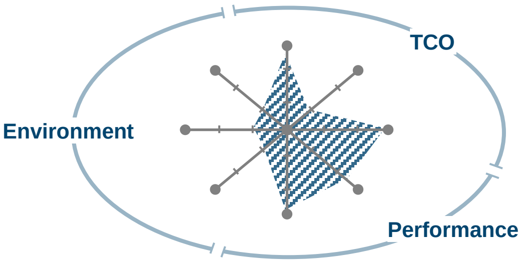


SOURCE: Study analysis

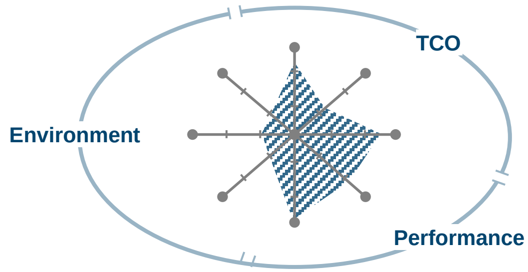
For the powertrains based on a combustion engine, the hybrids outperform the standard combustion engines

Better evaluation | PRODUCTION-AT-SCALE SCENARIO | 12 M BUS | 2030

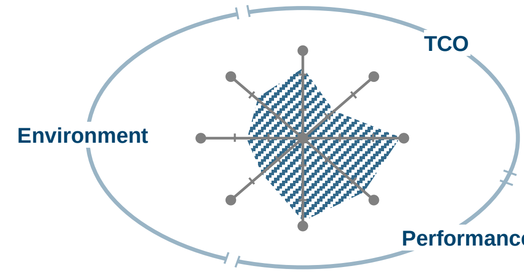
A Conventional diesel



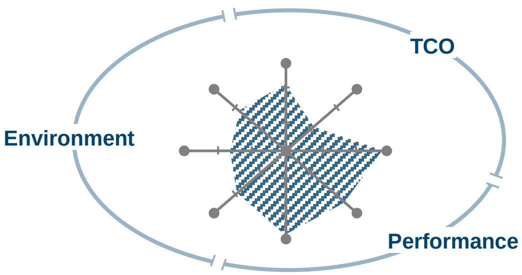
B CNG



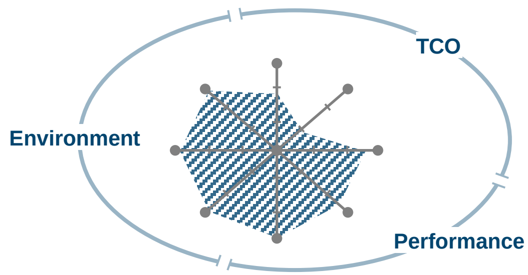
C Diesel parallel hybrid



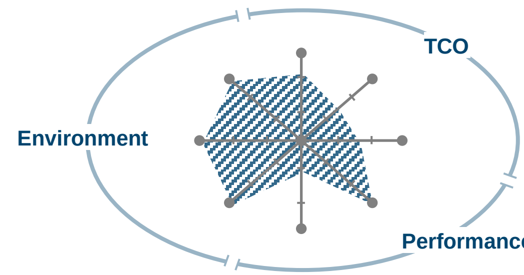
D Diesel serial hybrid



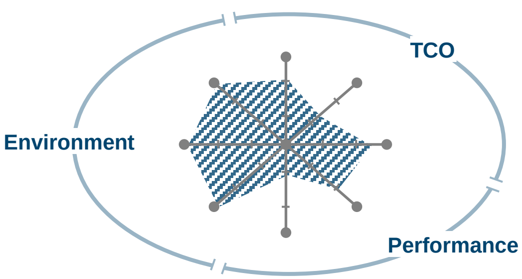
E Hydrogen fuel cell



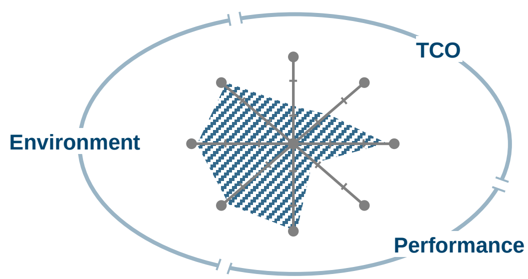
F Trolley



G Opportunity e-bus



H Overnight e-bus

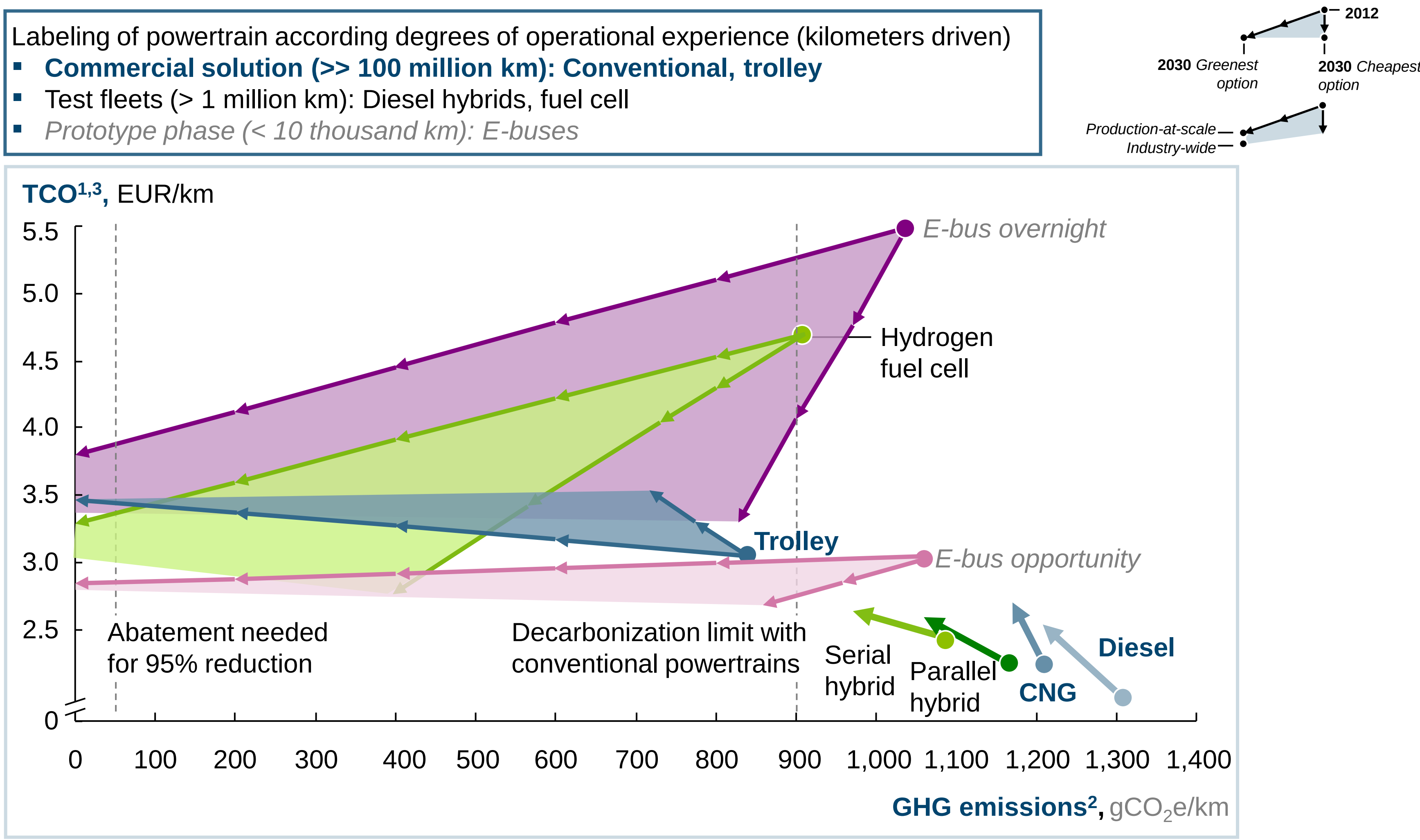


SOURCE: Study analysis

Only four powertrains can deliver a real decarbonisation; among those four, two are the cheapest

NOTE: RANGE ALSO SHOWS EFFECT OF ALTERNATIVE PRODUCTION SCENARIOS | **WELL-TO-WHEEL** | **12 M BUS** | **2012-30**

Labeling of powertrain according degrees of operational experience (kilometers driven)
- **Commercial solution (>> 100 million km): Conventional, trolley**
- Test fleets (> 1 million km): Diesel hybrids, fuel cell
- *Prototype phase (< 10 thousand km): E-buses*



1 Total cost of ownership for a 12m bus including purchase, running and financing costs based on 60,000km annual mileage and 12 years bus lifetime
2 Total CO_2e emissions per bus per km for different fuel types from well-to-wheel
3 Electricity cost for e-bus and water electrolysis part of hydrogen production based on renewable electricity price with a premium of EUR50/MWh over normal electricity

SOURCE: Study analysis

Thank you for your attention!

Questions?

Contents

- **Upside potential and risks**
- Backup to main presentation

Further upside potential for zero local-emission powertrains is possible

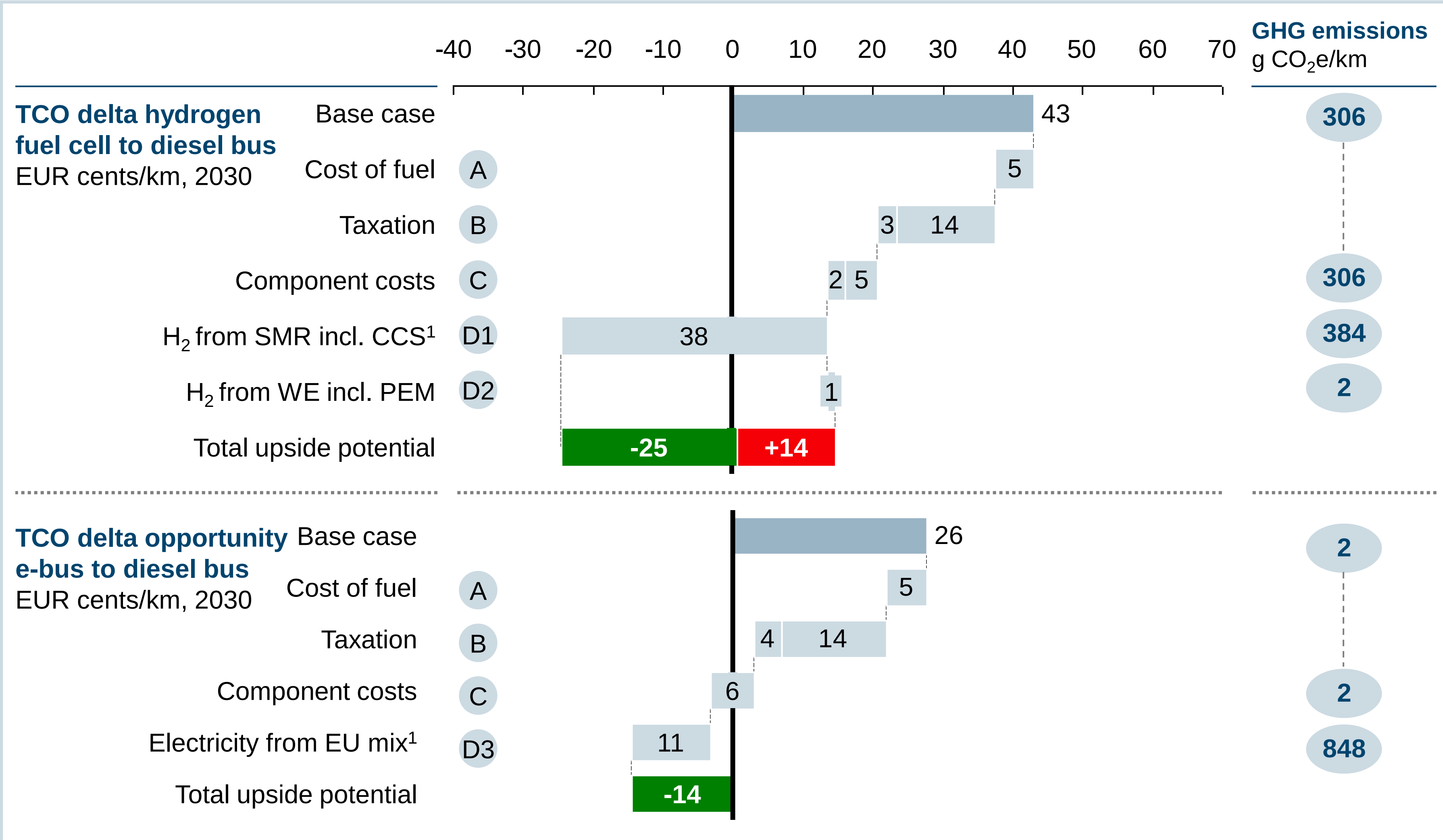
		Positive external factor	Base case assumption
Cost of fossil fuels	A	Crude oil price USD 150/bbl in 2030	Crude oil price USD 125/bbl
Taxation on fuel and emissions	B1	Variable taxes	Taxes fixed to 2012 values
	B2	Taxes on CO_2 (EUR 30/tonne)	No taxes on CO_2
Component costs	C1	Lower fuel cell stack cost: EUR 34/kW	EUR 114/kW
	C2	Lower battery cost: EUR 258/kWh	EUR 459/kW
Hydrogen and electricity production	D1	H_2 from SMR with CCS	H_2 from a balanced mix of major technologies
	D2	H_2 from WE incl. PEM	
	D3	Electricity from EU mix	Electricity from renewable sources

SOURCE: Study analysis

Total upside potential of the hydrogen fuel cell bus is 25 EURc/km cheaper than the conventional diesel; for the opportunity e-bus, this is 14 EURc/km

Upside potential

INDUSTRY-WIDE SCENARIO | 12 M BUS



1 Effect already included in ranges shown in slide 16

SOURCE: Study analysis

However, we should also be aware of the possible limit and risks for zero-emission powertrains

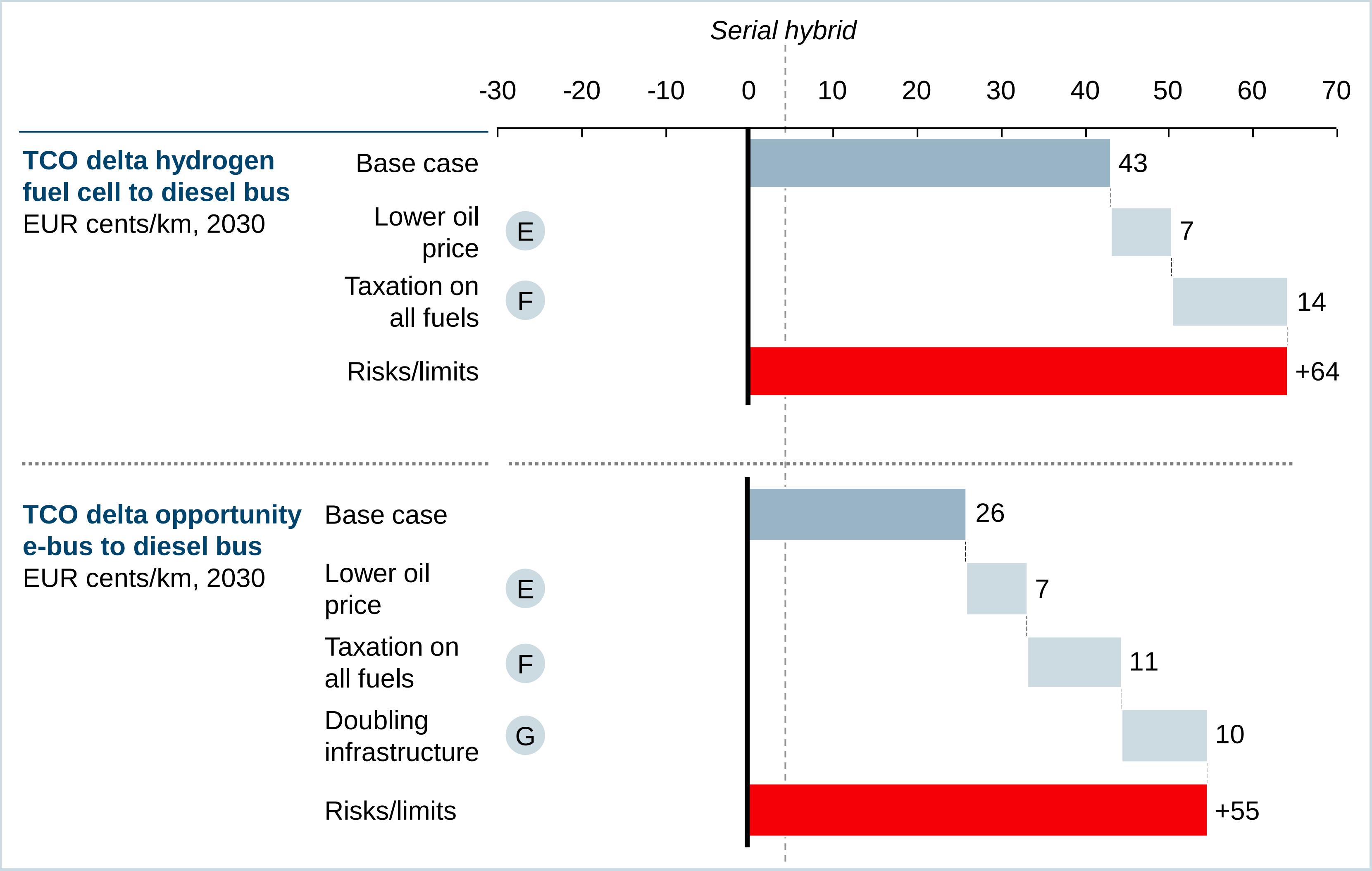
	Negative external factor	Base case assumption
Cost of fossil fuels	E Crude oil price USD 90/bbl in 2030	Crude oil price USD 125/bbl
Taxation on fuel and emissions	F Taxation as in Directive 2003/96/EC ▪ Diesel: EUR 0.4/litre ▪ CNG: EUR 0.5/kg ▪ Hydrogen: EUR 1.2/kg ▪ Electricity: EUR 35/MWh	Diesel: EUR 0.49/litre CNG: EUR 0.21/kg Hydrogen: -- Electricity: --
Component costs	G Doubling of infrastructure investment for e-bus	

SOURCE: Study analysis

The limitations could further increase the TCO gap with conventional diesel busses in 2030

Limitations

INDUSTRY-WIDE SCENARIO | 12 M BUS

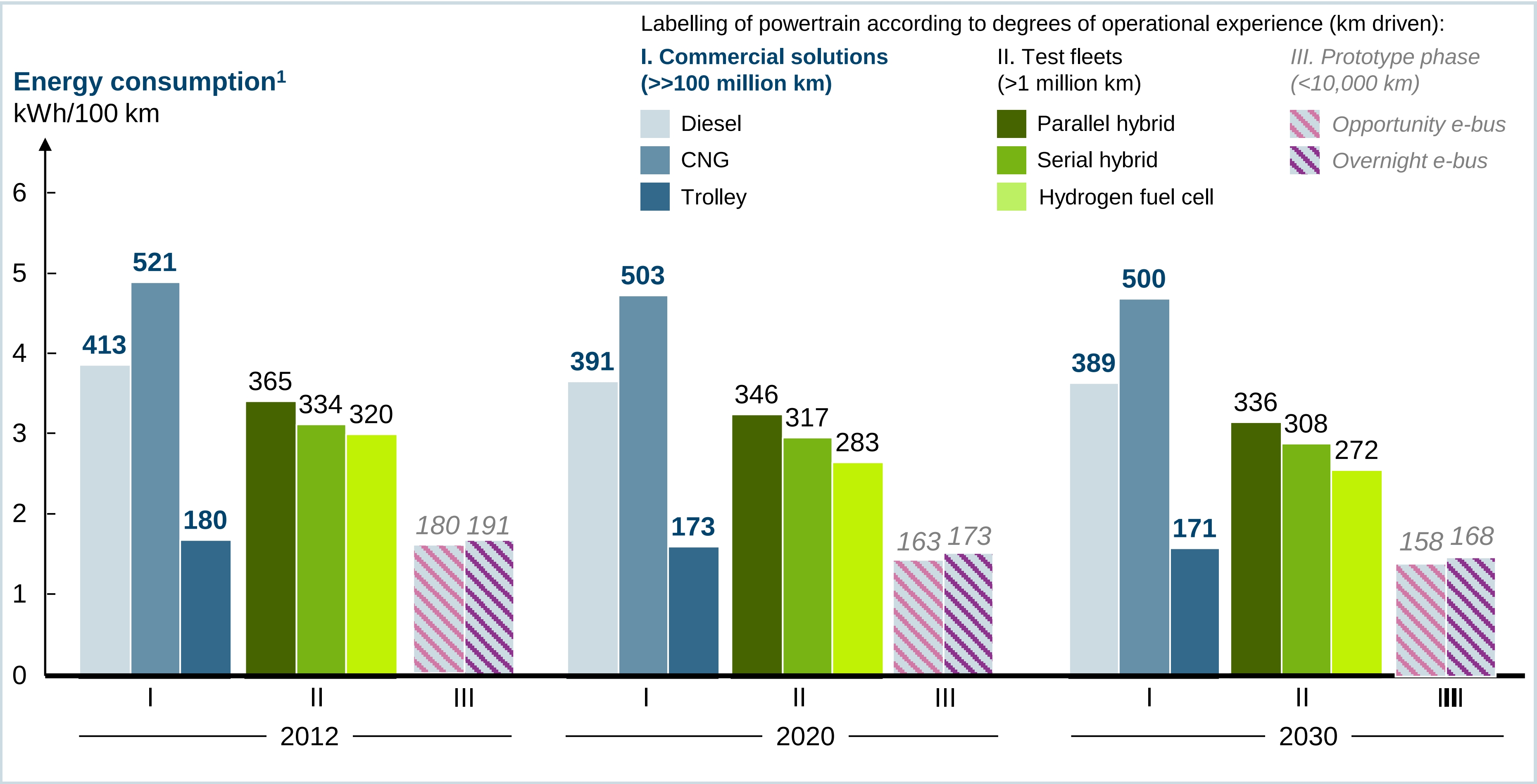


SOURCE: Study analysis

Contents

- Upside potential and risks
- **Backup to main presentation**

Energy consumption of zero-local emission powertrains is better than that of conventional powertrains



1 Powertrain energy consumption only; does not include losses in charging or losses in the production and distribution of the fuel and electricity

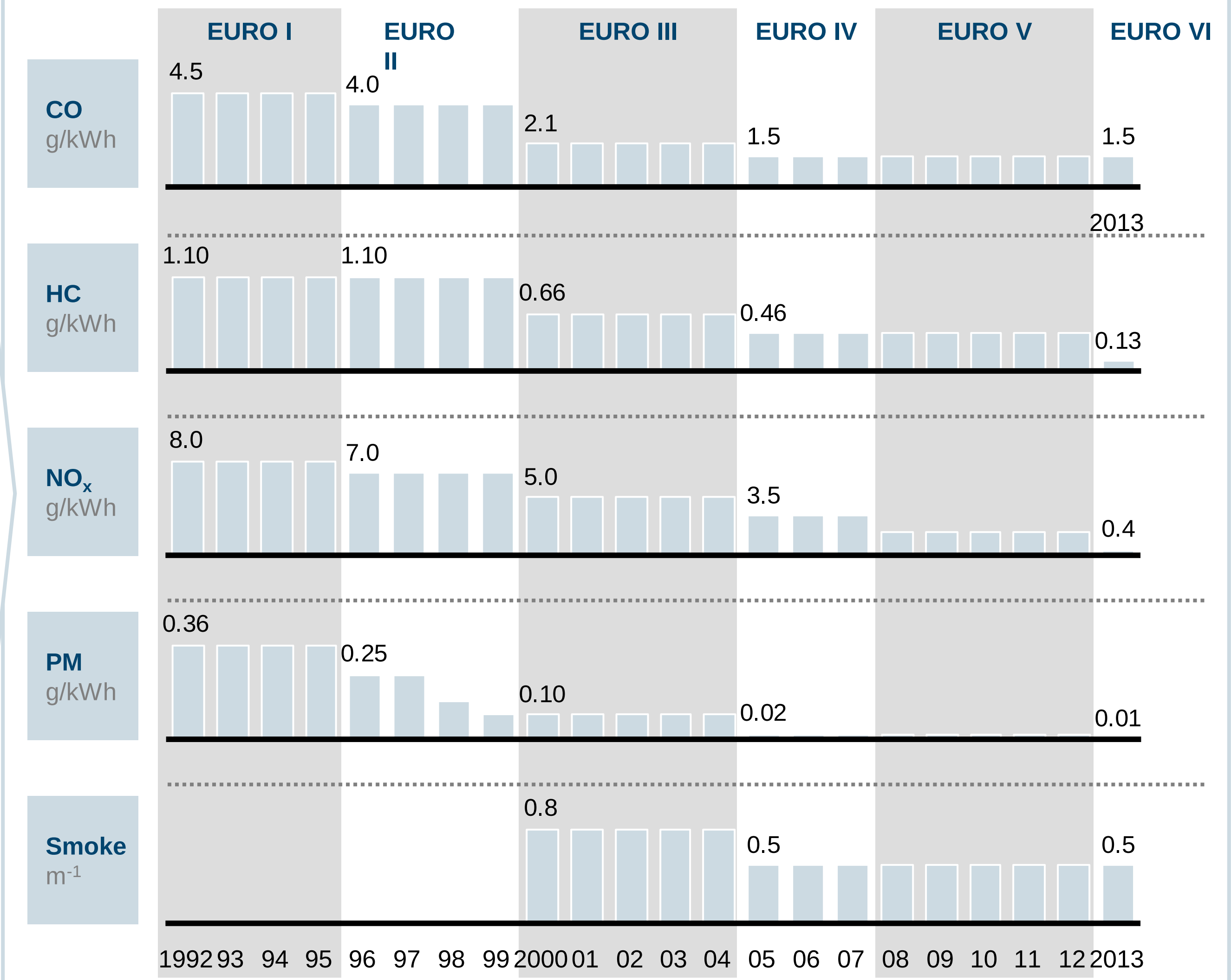
SOURCE: Study analysis

At the same time, concerns about public well-being drive further tightening of regulations for other emissions

EURO emission norms

Public health

Quality of life



SOURCE: Dieselnet; team analysis

Result is that European cities focus on getting newest diesel engines until 2015, but beyond that, seem to demand alternative powertrains

NOT EXHAUSTIVE

Restrictions on diesel engine | Non-fossil powertrain requirements

Cologne
Since 2007, only EEV[2] (and better) buses have been procured

Amsterdam
From 2015 onwards, all buses should at least conform to EEV[2] norm. Locally, EEV+ buses are deployed to meet EU air quality regulations

London
By 2015 all buses to meet EUROIV. By the end of 2012, 300 hybrid buses will be in service

Brussels
From 2015 onwards, bus operators will no longer procure diesel-powered buses in order to lower PM and NOx levels

Oslo
By 2020, all buses to use renewable fuels[1]. Phase out all EURO III before 2013

Hamburg
From 2020 onwards only emission-free buses will be procured

Stockholm
By 2025, renewable[1] public transport. Currently already 58% drives on renewable fuels

2005 | 10 | 15 | 20 | 2025

In addition, many cities focus on other measures to adhere to EU regulation on air quality:

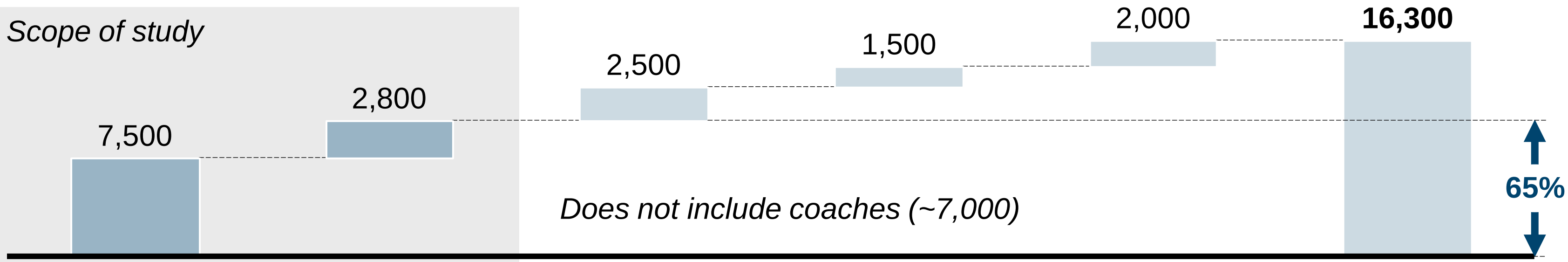
- Expanding and optimising public transport in general
- Banning cars from city centres
- Promoting electric cars

1 Includes biofuels
2 EEV: Enhanced Environmentally friendly Vehicle is a EURO norm in-between EUROV and EUROVI

SOURCE: Local city websites; 2001/81/EC

The study covers ~65% of the European city bus market by focusing on standard city and articulated buses

2010 European urban bus market segments[1]
Number of annual registrations, Western Europe



	Standard bus, city	Articulated bus	Standard bus, overland	Double-decker bus	Midibus	Total
Market EUR millions	~1,800[2]	~1,000[2]	~600[2]	~600[2]	~360[2]	~4,360[2]
	▪ ~12 metres ▪ ~18 tonnes ▪ 200 to 150 kW ▪ ~40 passengers seated, up to 70 passengers unseated ▪ Low entry	▪ 18 to 20 metres[4] ▪ Up to 30 tonnes ▪ 230 to 280 kW ▪ Up to 70 passengers seated ▪ Up to 100 passengers unseated	▪ ~12 metres ▪ ~18 tonnes ▪ 200 to 250 kW ▪ ~50 passengers seated ▪ Up to 30 passengers unseated ▪ Technically close to city bus	▪ 12 to 14 metres ▪ Up to 30 tonnes ▪ >230 kW ▪ ~80 passengers seated ▪ ~40 passengers unseated ▪ Used mainly in very big cities	▪ 8 to 10.5 metres ▪ Up to 18 tonnes ▪ 200 to 250 kW ▪ 20 to 30 passengers seated ▪ ~35 passengers unseated	

1 Split based on 2010 registrations for UK, FRA, IT, ESP; total number of registrations in Europe via extrapolation based on population size (Europe vs. UK, FRA, IT, ESP together); coaches not taken into account
2 Based on the estimated numbers above and estimated average prices
3 Figures for midibus, standard bus and articulated bus based on estimations by study participants
4 Sometimes more e.g. double articulated buses

SOURCE: Truck & Bus Builder Reports Ltd., SMMT, AAA, UNRAE, IEA, VDV, OEM publications, Study analysis

Different degrees of experience with novel technologies imply different levels of data certainty

Facts as of 2012 for Western Europe (12 m and 18 m buses)

	Diesel/ CNG/Trolley	Diesel hybrids[1]	Hydrogen fuel cell bus	Opportunity e-bus	Overnight e-bus[3]
Number of buses deployed	*Diesel, CNG and trolley buses are considered fully mature as they have been in use for >50 years and cover >95% of the current market (for 12 m and 18 m buses)*	> 1,000	> 30	0[3]	0[4]
Number of kilometres driven		>> 10,000,000	> 1,000,000 (> 5,000,000)[2]	0[3]	0[4]
Recharging/ refuelling procedures completed		*Same as diesel*	> 500	0[3]	0[4]
Number of years in operation		~2-3 years	~ 2 years	▪ No operation yet for 12 m/18 m buses ▪ ~2 years for 8 m overnight e-buses	
Supply industry/ adjacent industries		▪ Battery ▪ Electric drives	▪ Fuel cell in automotive ▪ H_2 supply ▪ Battery, electric drives	▪ Infrastructure ▪ Battery ▪ Electric drives	▪ Infrastructure ▪ Battery ▪ Electric drives

Data on all **powertrains** to be **treated with appropriate caution** as

- Data on **hydrogen fuel cell** bus are **based on real-life operations** (12 m or 18 m buses) in **small-scale fleets** with a **timeframe** of a **few years**
- Data on **electric buses** (opportunity and overnight e-buses) are based on **clean team data** for the **core components**, **diesel serial hybrid clean team data** for **other components** and **expert estimates** for the **remaining parts** as no information from actual operation of 12 m or 18 m buses was available
- Data on **hybrids** are based on a **few years of experience** only despite **large number of buses**

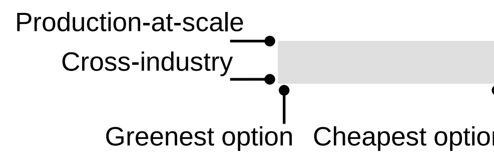
1 Latest generation serial hybrid and parallel hybrid
2 For all hydrogen fuel cell buses (without hybridisation of powertrain)
3 An estimated 20-30 8-9 meter opportunity e-buses, some or all from Chinese manufacturers, operate in Turin, Genoa, Coventry and are ordered in Vienna
4 A number of European cities operate or have ordered models by Chinese manufacturers; number of European-made busses is unknown

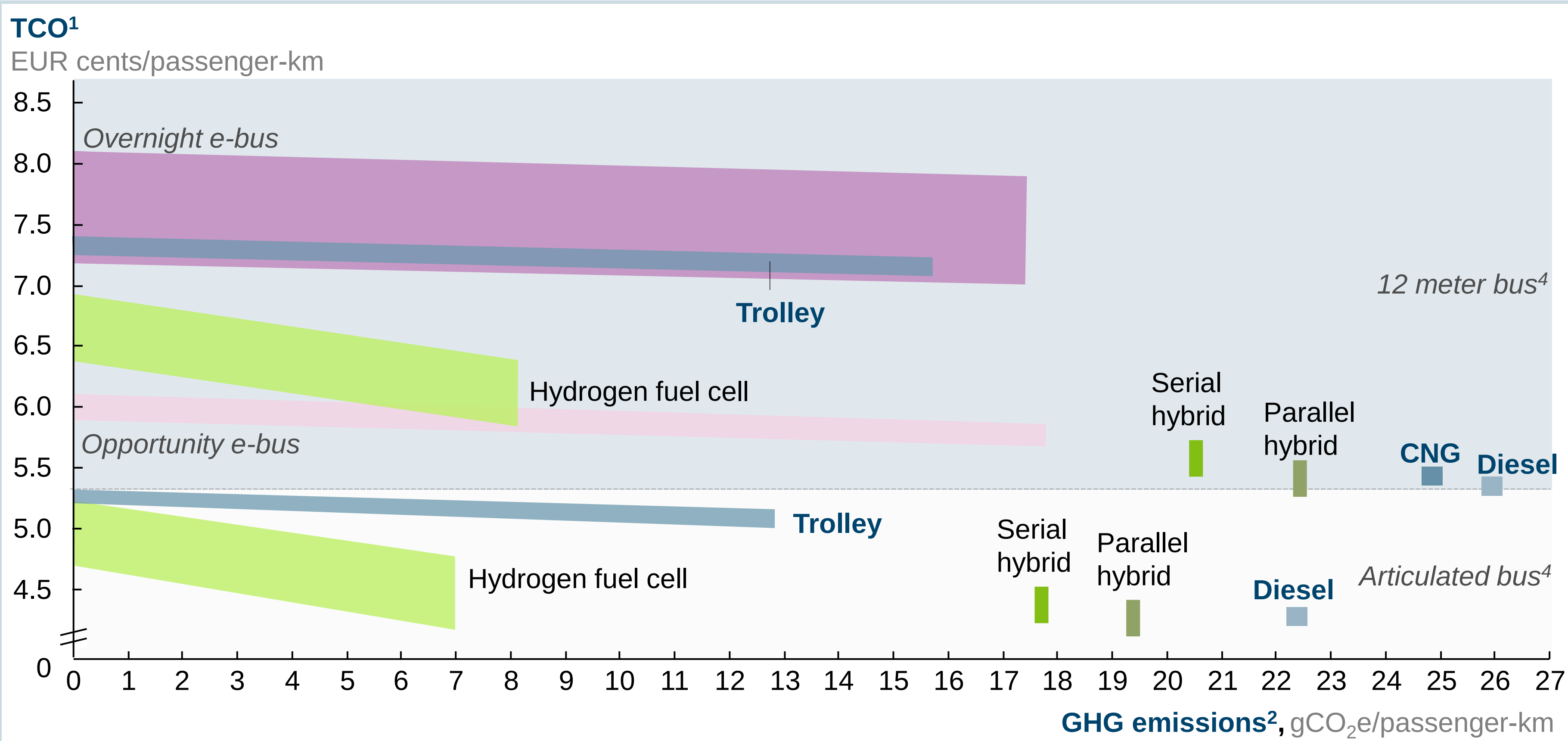
SOURCE: Study analysis

On a per passenger-km basis, hydrogen fuel cell articulated is the cheapest zero local-emission options by 2030

NOTE: RANGE ALSO SHOWS EFFECT OF ALTERNATIVE H_2 AND ELECTRICITY PRODUCTION SCENARIOS (CH. 4) | **WELL-TO-WHEEL** | **2030**

Labelling of powertrain according to degrees of operational experience (kilometres driven):
- **Commercial solution (>> 100 million km): conventional, trolley**
- Test fleets (> 1 million km): diesel hybrid, hydrogen fuel cell
- *Prototype phase (< 10 thousand km): e-buses*



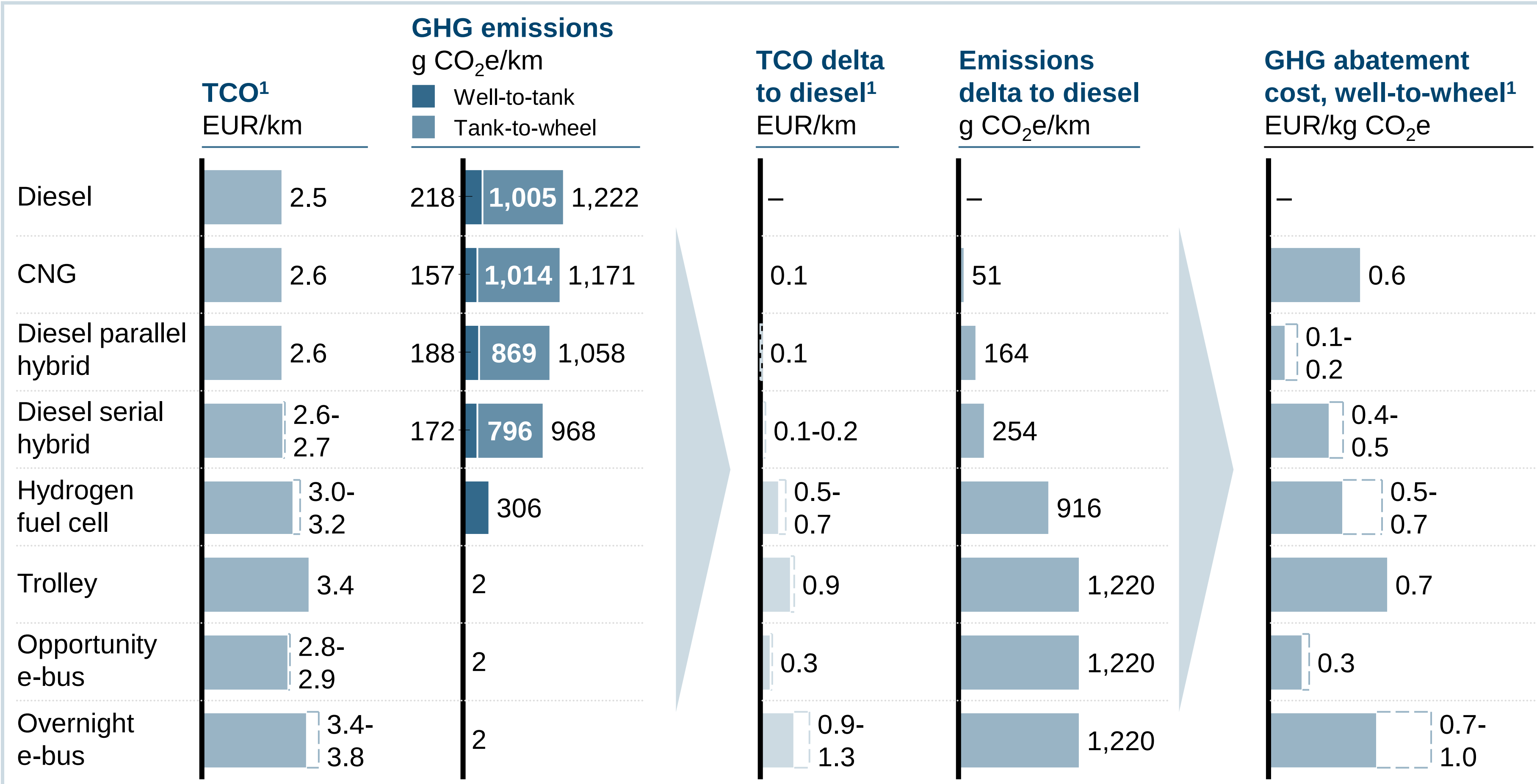


1 Total cost of ownership for a bus, including purchase, running and financing costs based on 60,000 km annual mileage and 12 years' bus lifetime 2 Total CO2e emissions per bus per km for different fuel types from well-to-wheel 3 For greenest option, electricity cost for e-bus and water electrolysis hydrogen production based on renewable electricity price with a premium of EUR50/MWh over normal electricity
4 Passenger loading 47 per standard bus, 73 per articulated bus as per UITP definition

SOURCE: Study analysis

Opportunity charging e-bus offers the cheapest GHG abatement of zero-local emission powertrains; diesel parallel hybrid the cheapest overall

12 M BUS 2030



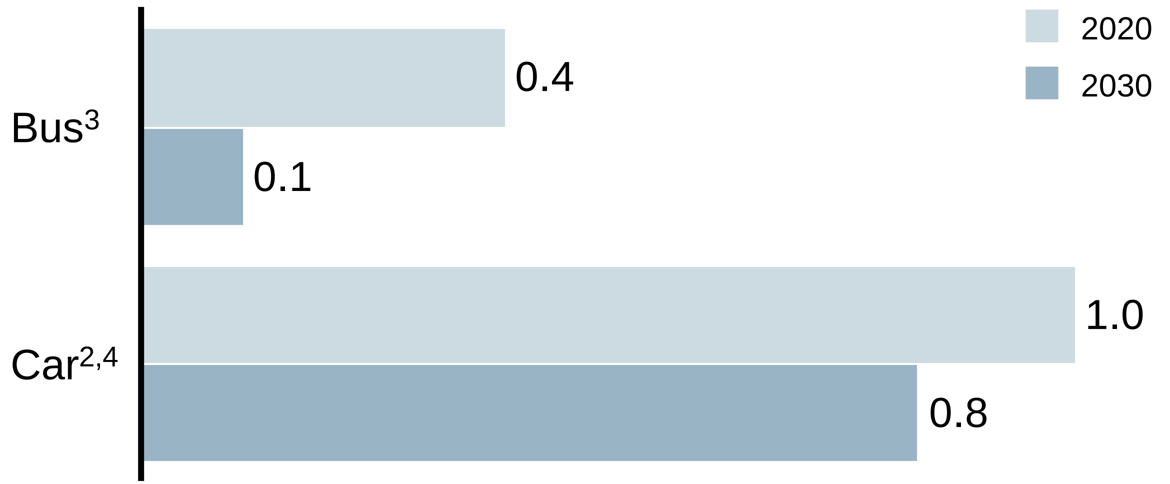
With an even more renewable hydrogen production mix, further upside can be achieved

1 Lower numbers correspond to 'cross-industry' scenario with cheapest H_2 and electricity production mix, higher numbers to 'production-at-scale' scenario with green H_2 and electricity
2 Taking the upside potential and potential limitations into account (see Chapters 4 & 5), GHG abatement costs for hydrogen fuel cell bus and opportunity e-bus could become lower than EUR 0.1/kg CO2e or increase to more than EUR 1.0/kg CO2e

SOURCE: Study analysis

The city bus shows less abatement cost per passenger km than passenger car with 0.1 EUR/gCO_2e vs. 0.8 EUR/gCO_2e

Abatement cost of "cheapest" alternative powertrain vs. conventional powertrain[1]
EUR/kg CO_2e

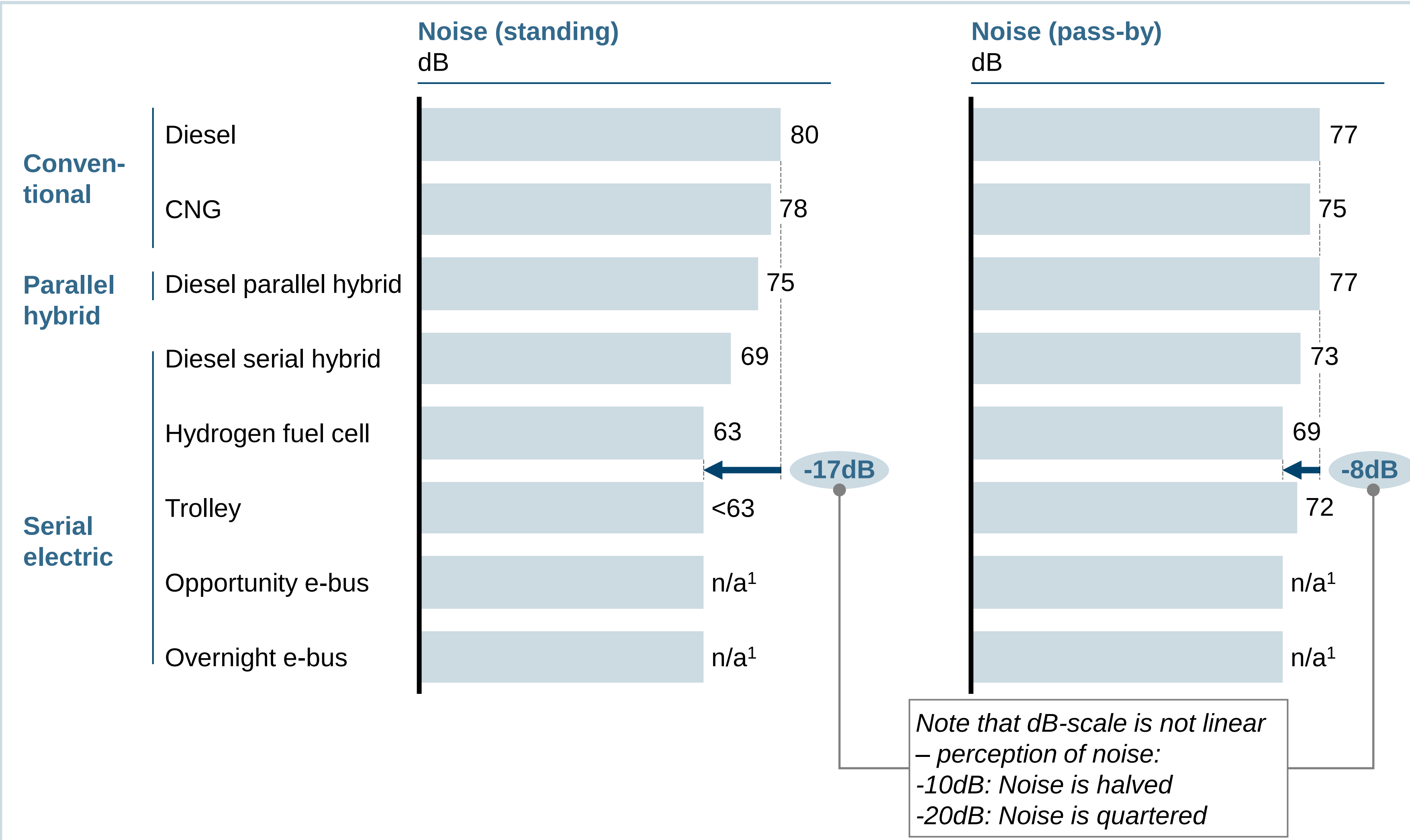


1 No CO2 price included in TCO
2 HEV as conventional powertrain, PHEV as cheapest alternative; assuming average passenger car loading factor of 1.2 passengers per car
3 Diesel as conventional powertrain, parallel hybrid as alternative powertrain; assuming 12 m bus with 47 passengers according to UITP definition
4 Compact-class car (C-segment)

SOURCE: Study analysis

Powertrains with zero local-emissions also have lowest noise emissions

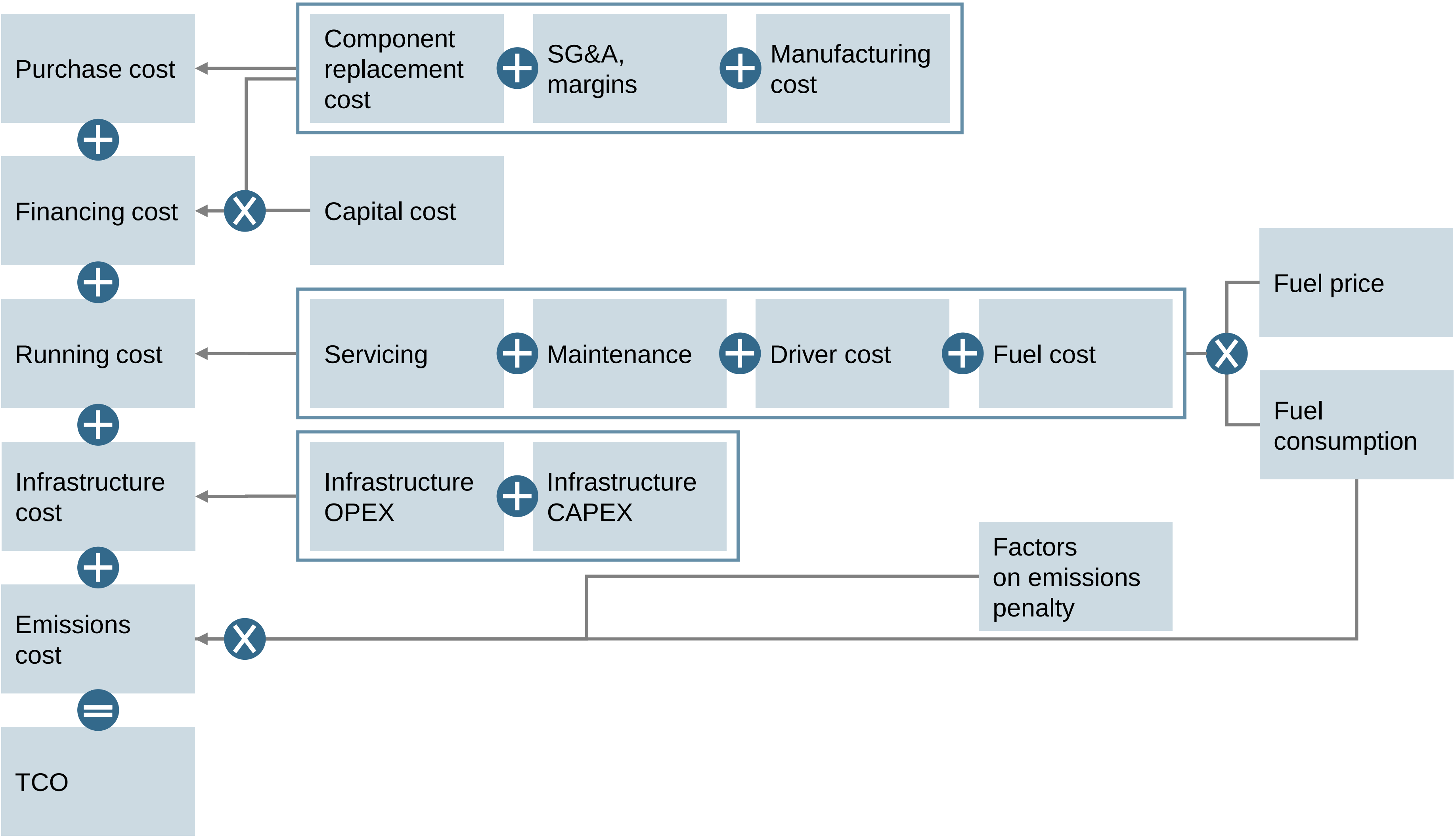
12 M BUS



1 No measure figures available yet – expectations are similar to hydrogen fuel cell bus

SOURCE: Study analysis

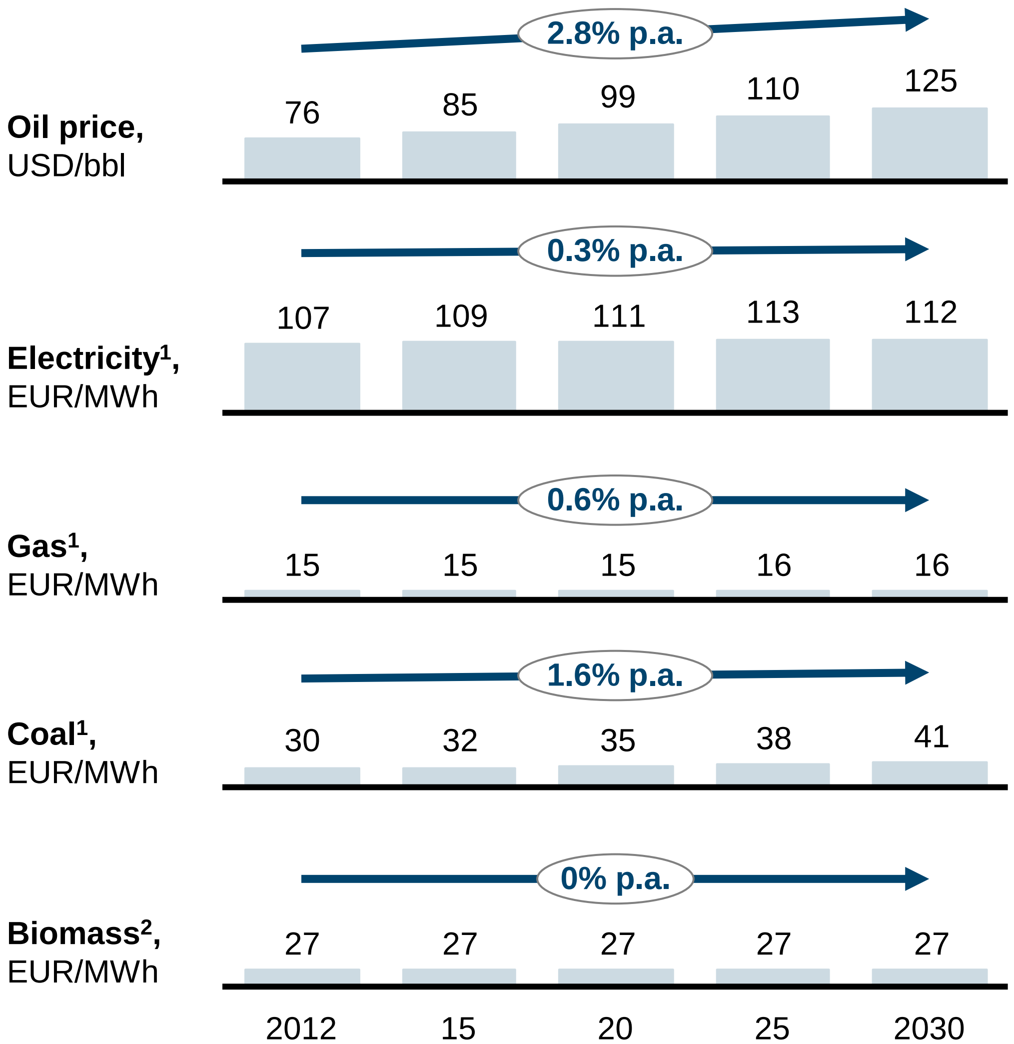
Overview of total cost of ownership (TCO) components



SOURCE: Study analysis

Based on Enerdata's Recovery scenario, the following prices are used in the study

European average energy prices, 2011 real terms

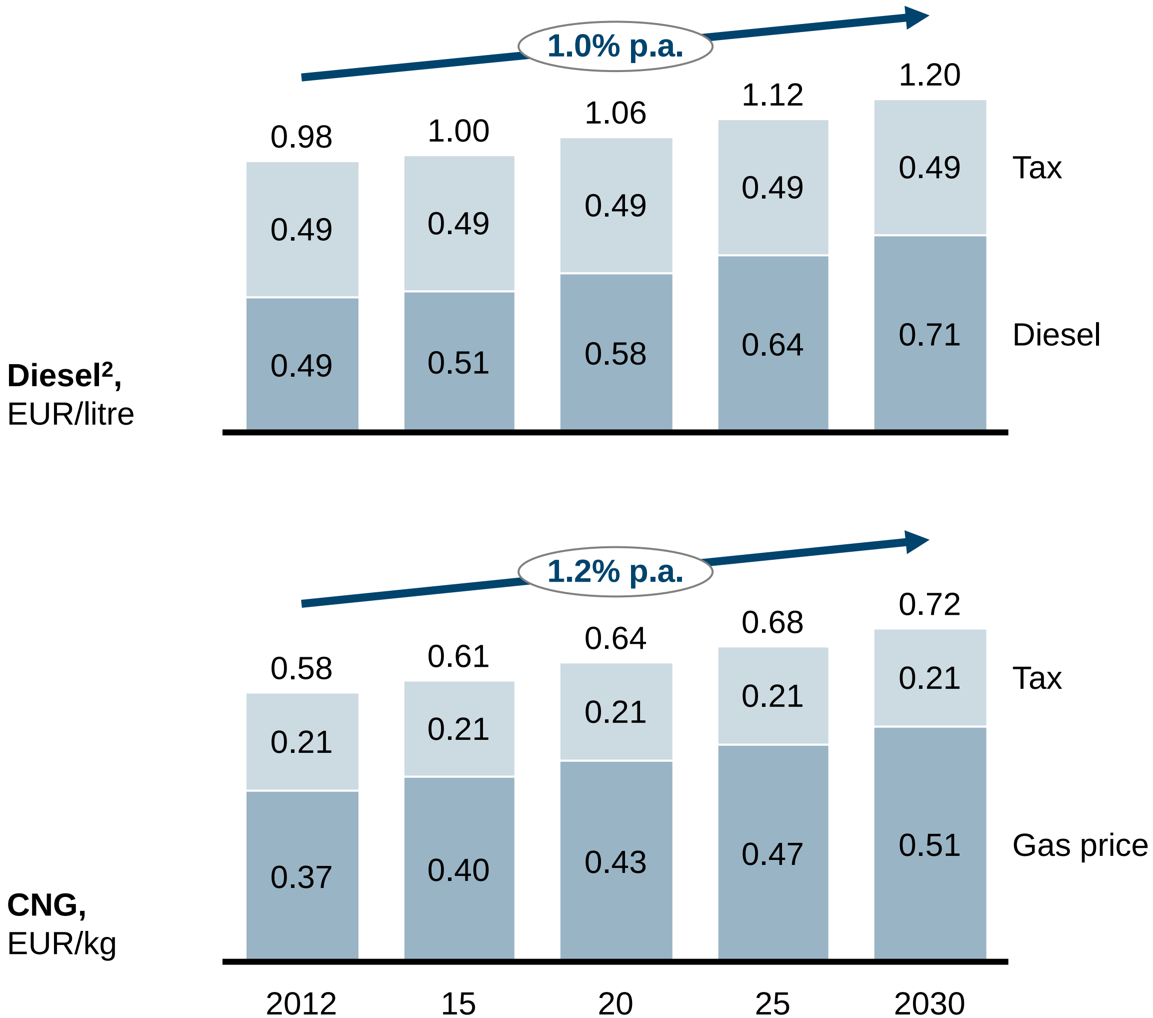


1 Based on weighted industrial average prices (excl. VAT) in Belgium, France, Germany, Italy, Netherlands, Spain and UK
2 Based on historical industrial pellet prices in the Netherlands, Germany and Sweden

SOURCE: Enerdata Recovery Scenario 2011, industry analysis

Based on Enerdata's Recovery scenario, the following fuel prices used in the study

European average industrial prices[1] w/o VAT, 2011 real terms



1 Based on weighted (by population) industrial average prices (excl. retail mark-up) in Belgium, France, Germany, Italy, Netherlands, Spain and UK
2 Diesel price based on fix mark-up on oil price, incl. distribution costs to filling station, no retail mark-up

SOURCE: Enerdata Recovery Scenario 2011, European Commission Oil Bulletin 2012, Platts, Bloomberg, study analysis

The Coalition defined reference buses specified by a list of parameters

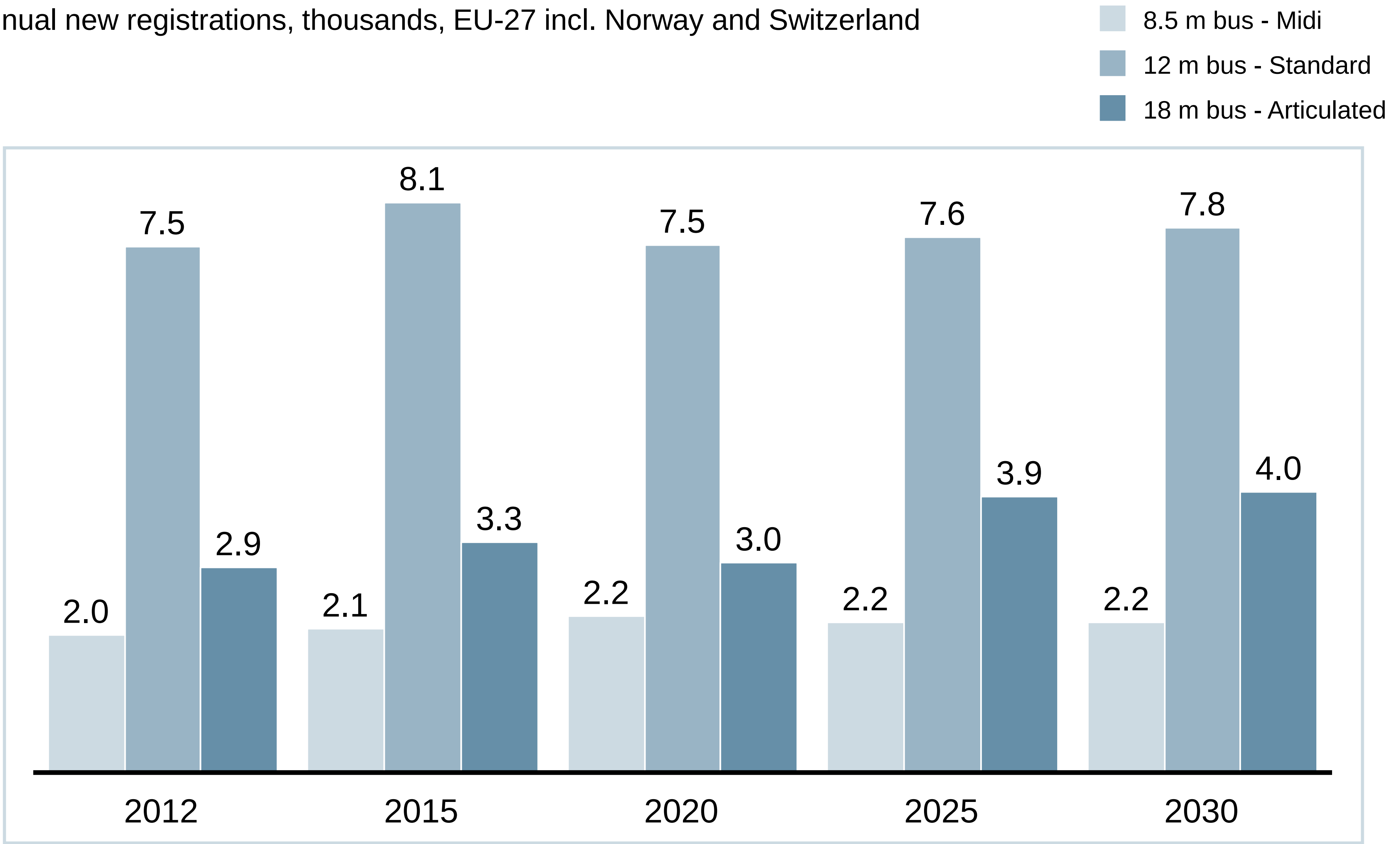
Reference vehicle specifics	Standard bus[2]	Articulated bus
Typical number of passengers (seated/standing)[1]	32/68	43/90
Length in m	11.8 - 12.2	17.7 - 18.3
Height in m	2.9 - 3.1	2.9 - 3.1
Width in m	2.50 - 2.55	2.50 - 2.55
Empty weight in tonnes	11 - 12	16 - 18
Curb weight in tonnes	18 - 19	28 - 29
Traction power in kW	170 - 220	200 - 260
Number of doors	2/3	3
Floor type	Low floor	Low floor
Safety requirements	▪ EU standard/ECE standard	
Other specifications	▪ Typical equipment incl. air-conditioning and heating ▪ Single-walled windows	

1 Actual capacity dependent on customer requirements
2 Includes modified version to cover suburban routes

SOURCE: Study analysis

Expected development of the European urban bus market

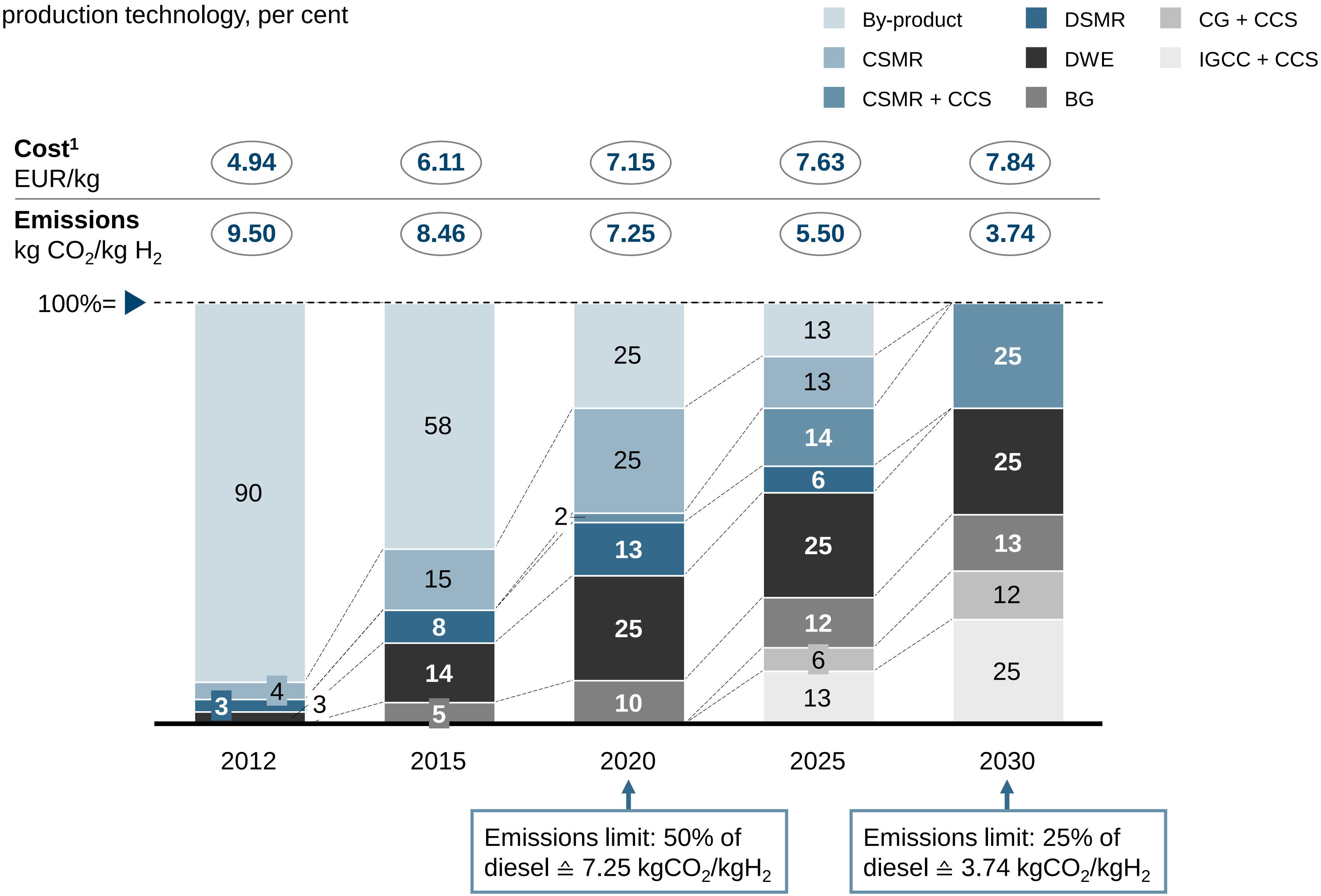
Annual new registrations, thousands, EU-27 incl. Norway and Switzerland



SOURCE: Study analysis

Ramp-up towards mix in 2030

Share per production technology, per cent



1 Including margins and cost of distribution

SOURCE: Study analysis

For ten different production methods data was collected in the Clean Team

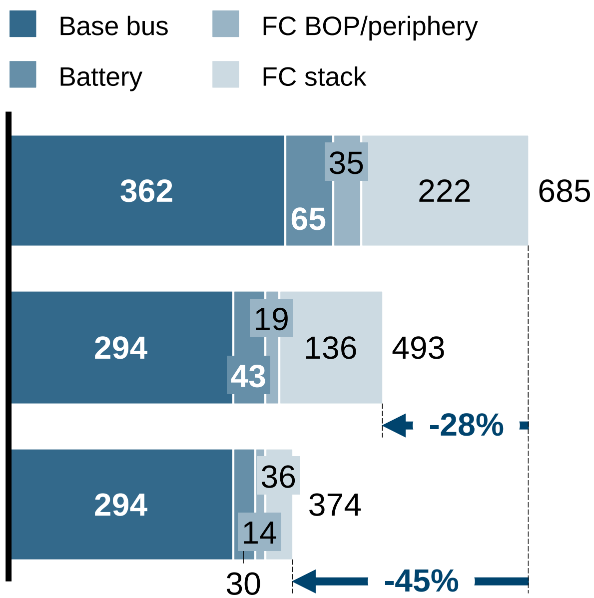
Technology	Process	Governing reaction[1]	Variations
SMR Steam Methane Reforming	Methane, Steam → H_2, CO_2	$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$	▪ On-site SMR ▪ Central SMR ▪ Central SMR + CCS
WE Water Electrolysis	Water, Electricity → H_2, O_2	$2H_2O \rightarrow 2H_2 + O_2$	▪ On-site WE ▪ Central WE
CG/(IGCC) Coal Gasification/ Internal Gasification Combined Cycle	Coal, Steam → H_2, CO_2	$C + 2H_2O \rightarrow CO_2 + 2H_2$	▪ CG ▪ CG + CCS ▪ IGCC ▪ IGCC + CCS
BG Biomass Gasification	Biomass, Steam → H_2, CO_2	$C_xH_yO_z + H_2O \rightarrow CO_2 + H_2$	▪ BG

1 Simplified reaction

SOURCE: Study analysis

Effects of the 'production-at-scale' and 'cross-industry' scenario add up to a reduction of 45% compared to the niche scenario, 2030

Purchase cost hydrogen fuel cell bus, 12 m bus
EUR thousands



	Initial component cost			Component replacement cost		
	Battery	FC BOP/ periphery	FC stack	Battery	FC BOP/ periphery	FC stack
Niche scenario	35	33	104	31	2	118
Production-at-scale scenario	23	19	74	20	–	62
Cross-industry scenario	14	14	19	14	–	16

- Volume effect of **production-at-scale** scenario vs. **niche scenario** leads to **reduction** in purchase price **of 28%**
- Additional **cross-industry effects** from car industry on fuel cell system components **and battery yields total cost reduction of ~45%**

SOURCE: Study analysis

Trolley has highest infrastructure cost; diesel and hybrids have cheapest infrastructure to install

Capex | Opex | 2030 | Medium depot

		Description -	Investment required[3] EUR thousands	Total yearly cost[1] EUR thousands/year (Capex / Opex / Total)	x.xx EUR/bus km[2]
Conventional	Diesel	Filling station with 4 dispensers	324	26 / 133 / 159	0.03
	CNG	Fast-filling station	3,194	256 / 493 / 749	0.15
Parallel hybrid	Diesel parallel hybrid	Filling station with 4 dispensers	324	26 / 133 / 159	0.03
Serial electric	Diesel serial hybrid	Filling station with 4 dispensers	324	26 / 133 / 159	0.03
	Hydrogen fuel cell	Medium-size gaseous 500-bar station	3,753	301 / 345 / 646	0.13
	Trolley	Overhead wiring, transformers, ~85 km network	38,250	3,069 / 1,199 / 4,268	0.84
	Opportunity e-bus	~8-9 routes equipped with 2 charging poles each	7,333	588 / 465 / 1,053	0.21
	Overnight e-bus	85 charging spots within depot	3,490	280 / 349 / 629	0.12

1 Based on WACC of 5% and 20 years' lifetime

2 Based on 85 buses and 60,000 km/year

3 Not including infrastructure required to produce or transport fuel to the depot (e.g. pipeline)

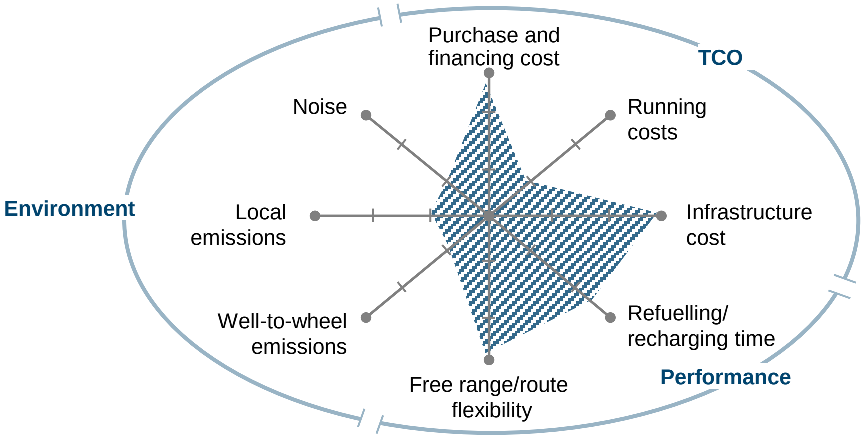
SOURCE: Study analysis, EUCAR/CONCAWE/EC JRC 2011

BACKUP

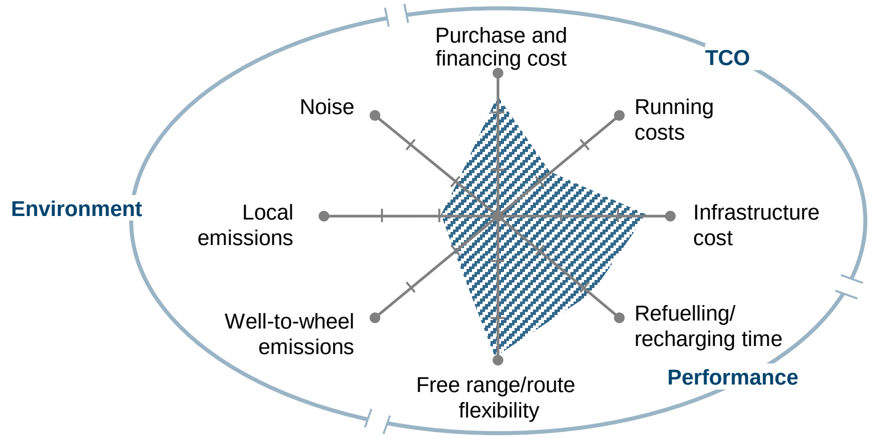
For the powertrains based on a combustions engine, the hybrids outperform the standard combustion engines

Better evaluation | PRODUCTION-AT-SCALE SCENARIO | 12 M BUS | 2030

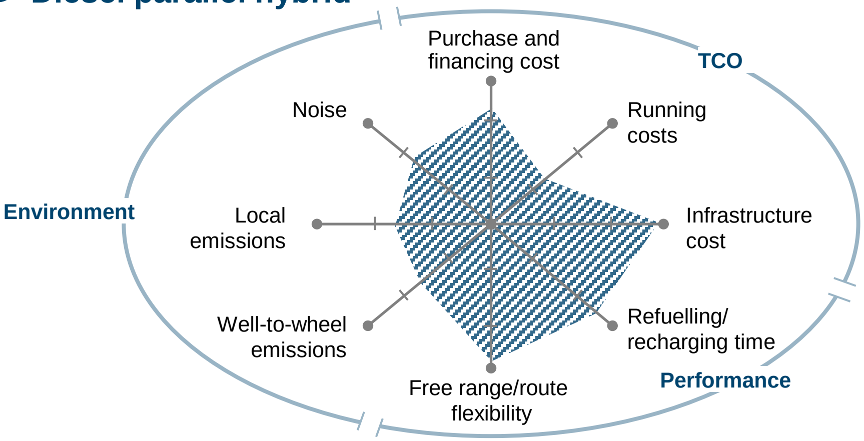
A Conventional diesel



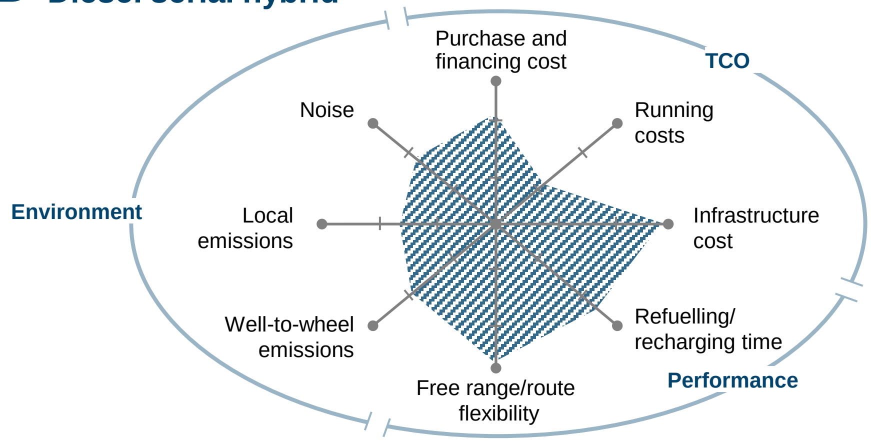
B CNG



C Diesel parallel hybrid



D Diesel serial hybrid

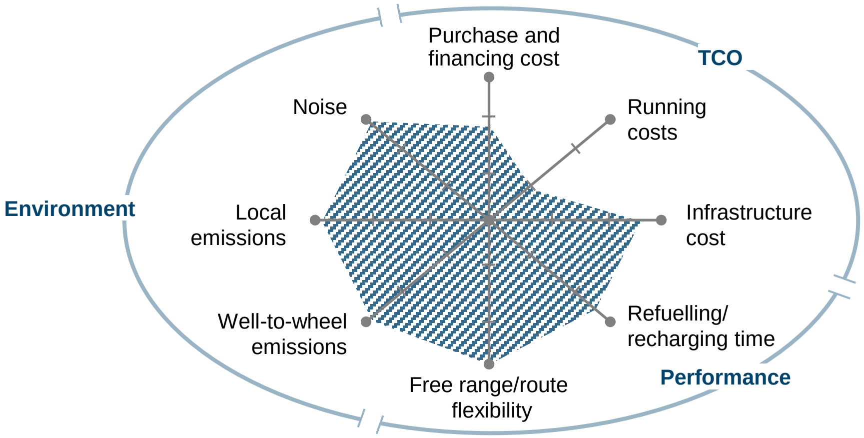


SOURCE: Study analysis

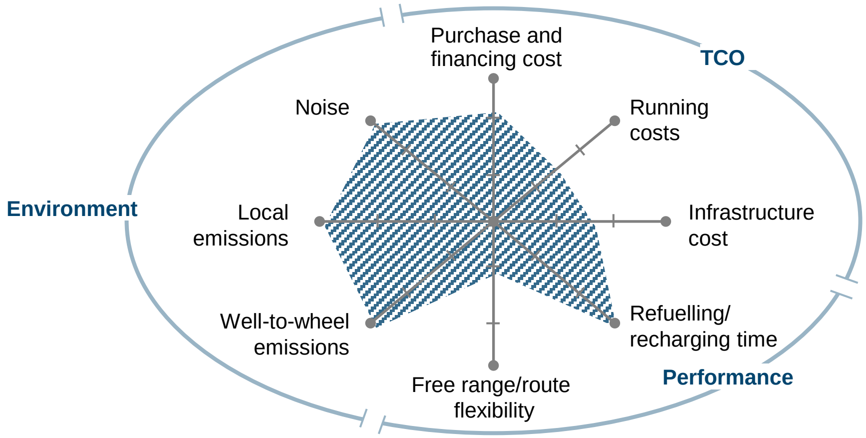
The alternative powertrains all score high on environment and have mixed results on performance and TCO

Better evaluation | **PRODUCTION-AT-SCALE SCENARIO** | **12 M BUS** | **2030**

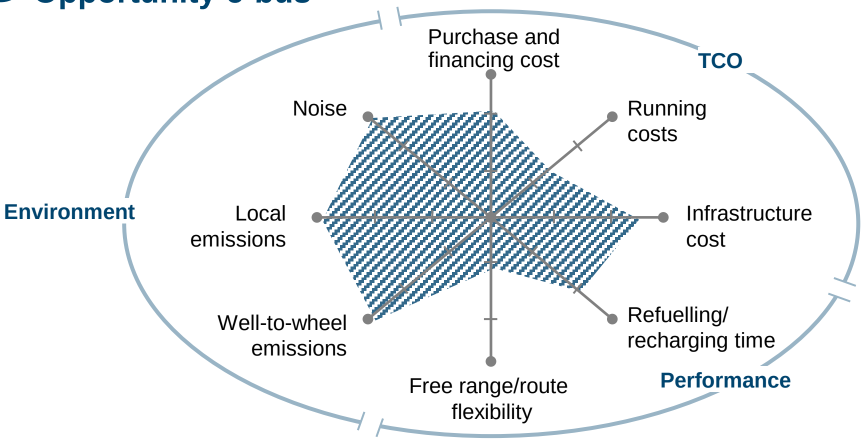
E Hydrogen fuel cell



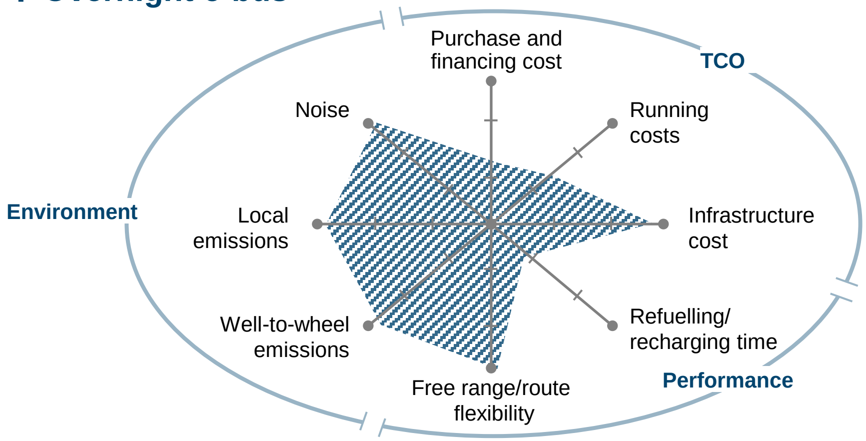
F Trolley



G Opportunity e-bus



H Overnight e-bus



SOURCE: Study analysis