Fuel cells and hydrogen
Joint undertaking

Urban buses: alternative powertrains for Europe

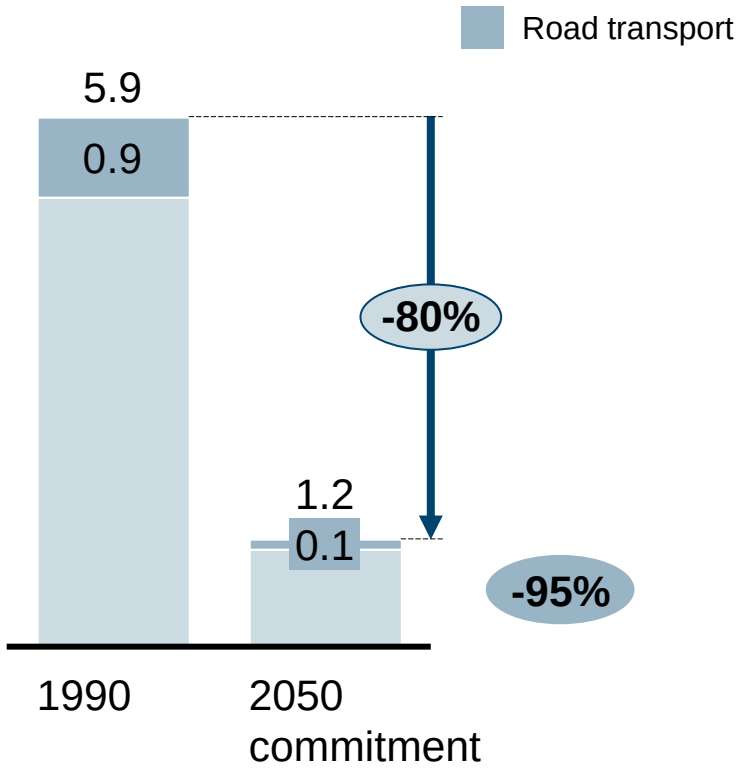
A fact-based analysis of the role of diesel hybrid, hydrogen fuel cell, trolley and electric powertrains

Programme Review
28 & 29 November 2012

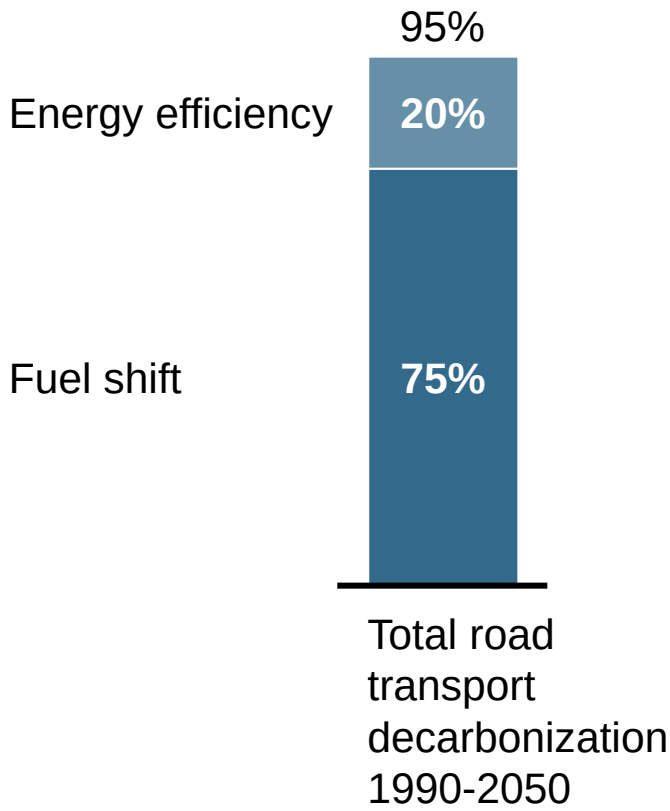
Carlos Navas, FCH JU
Project Manager

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

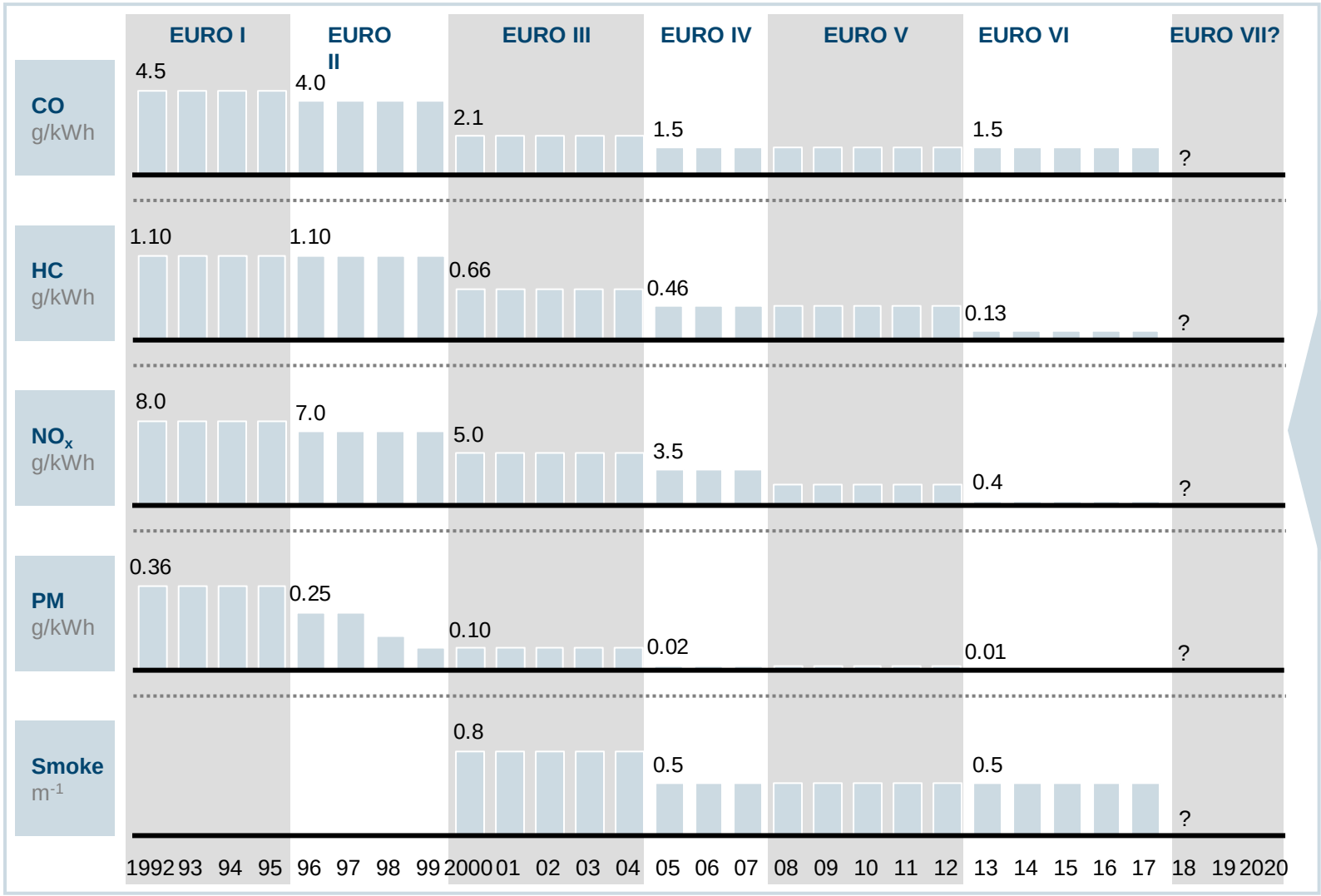


Majority decarbonization needs to come from fuel shift



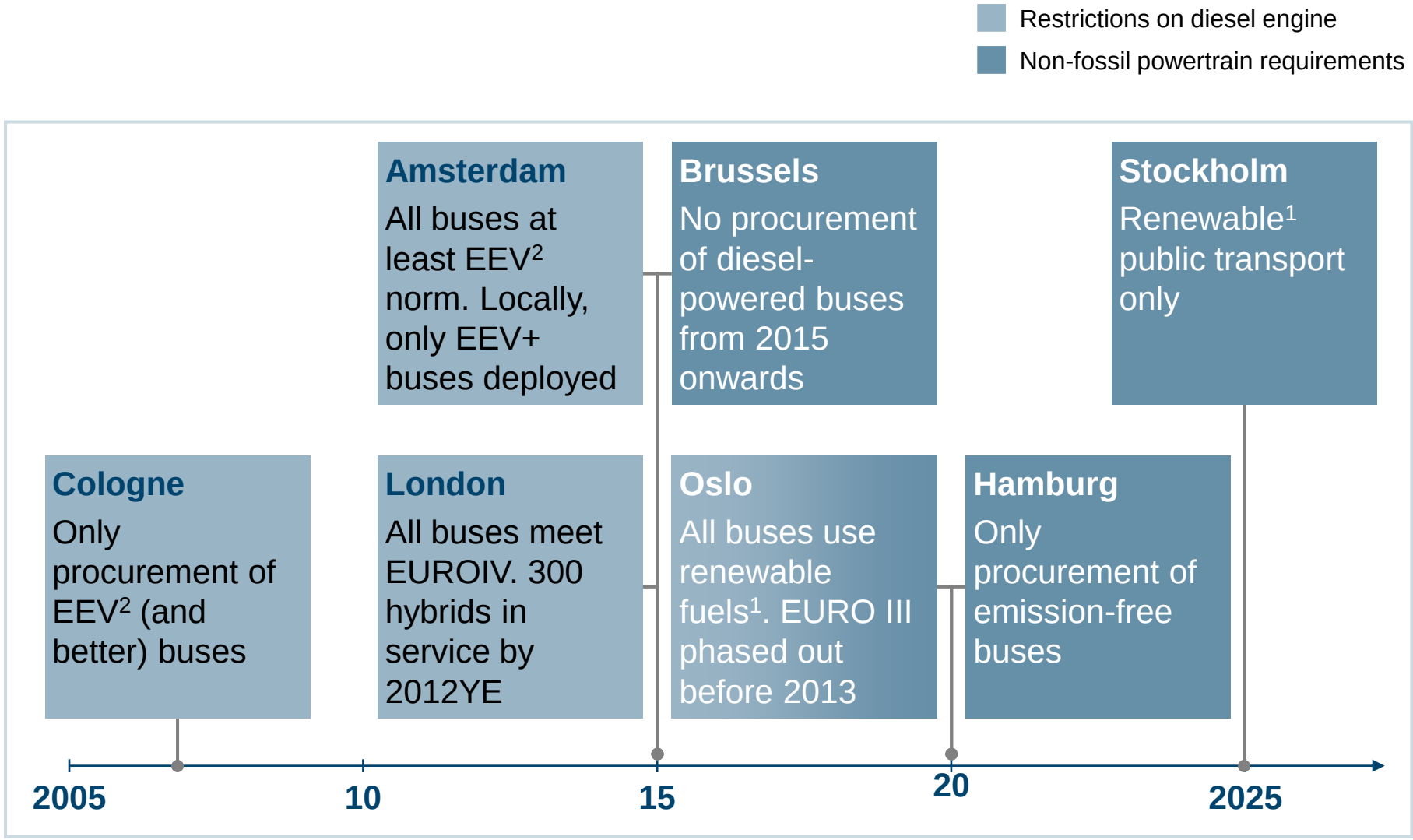
Source: Roadmap 2050

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



SOURCE: Dieselnet; team analysis

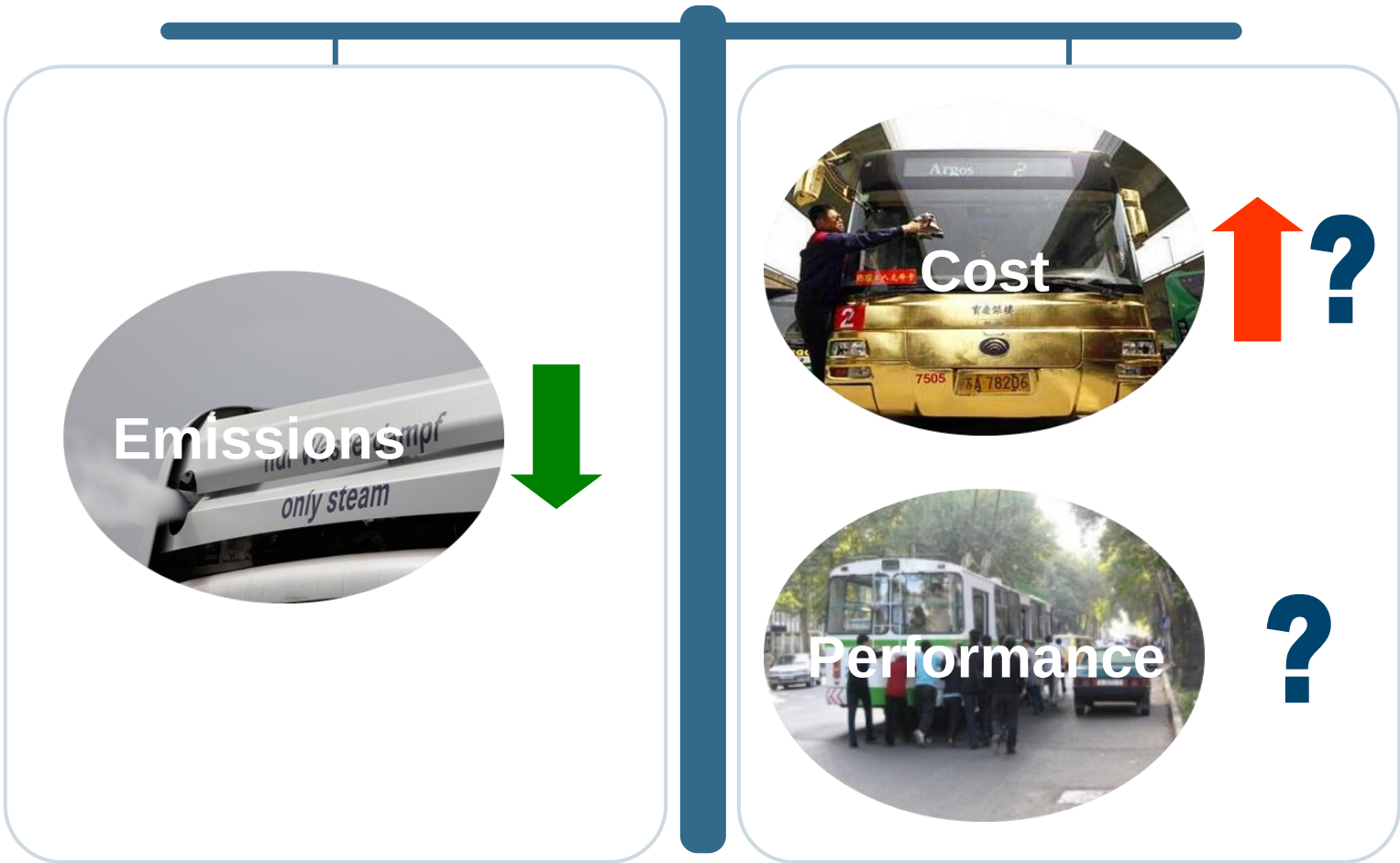
Result is that European cities focus on getting newest diesel engines until 2015 but, beyond that, seem to demand powertrains with lower emissions



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

Fact-based evaluation of conventional and most promising alternative **powertrain technologies for urban buses**

Approach

- **Large coalition including all relevant stakeholders**
- Assessment on **cost, emissions**, and **performance**
- **Proprietary industry** data **objectivity** and **confidentiality** collected by a external '**clean team**'

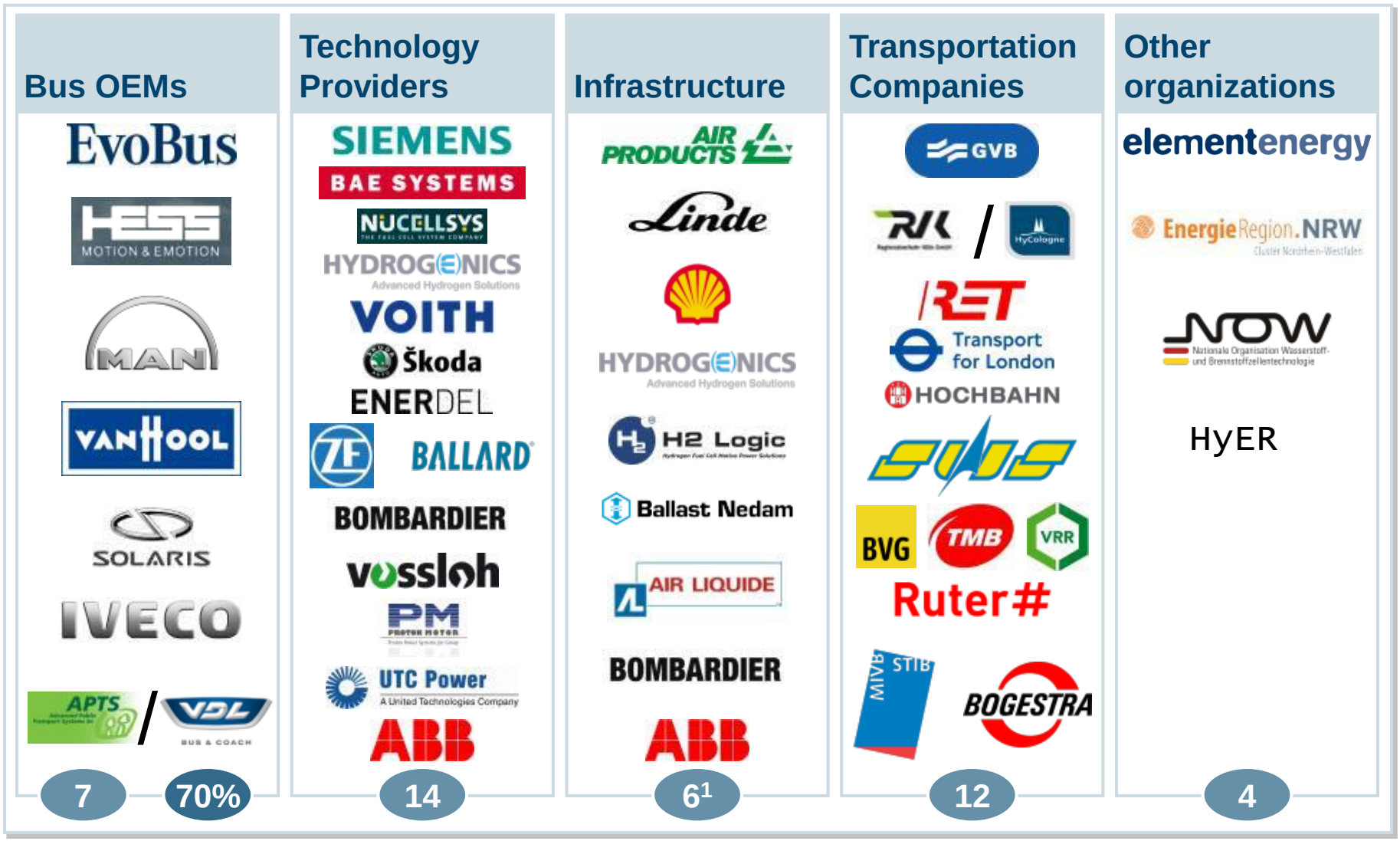
Scope

- 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



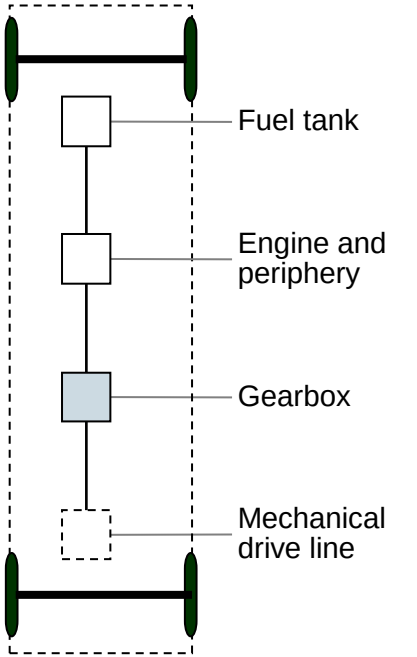
1 Bombardier, Hydrogenics and ABB participate in both the Technology Providers and the Infrastructure working groups

SOURCE: FCH JU; McKinsey

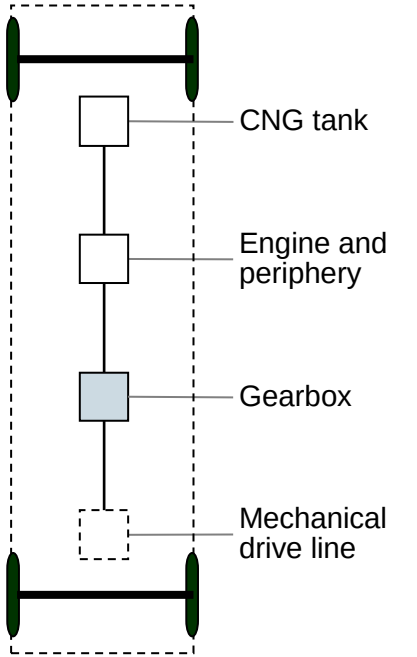
Diesel, CNG and diesel hybrids are powertrains in scope which rely (partly) on a conventional engine

ICE powertrain | Transmission | Electric powertrain | Battery or supercaps

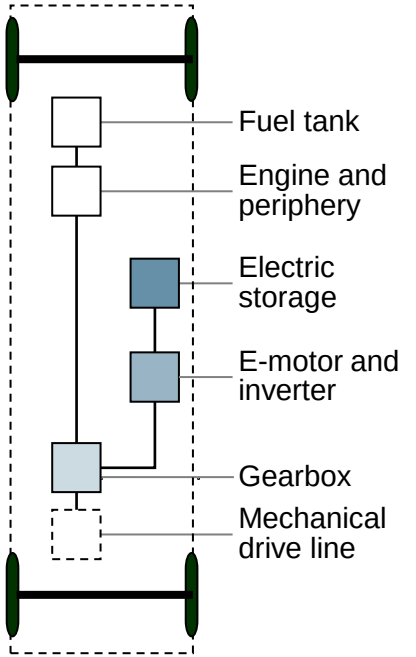
Diesel powertrain



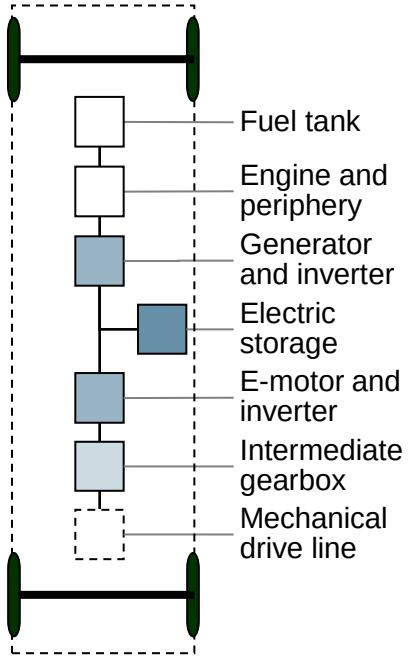
CNG powertrain



Parallel hybrid powertrain



Serial hybrid powertrain

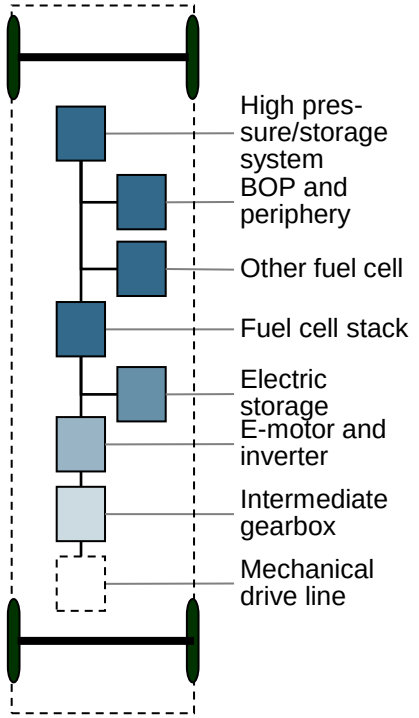


SOURCE: Study analysis; EvoBus; MAN; Iveco Irisbus

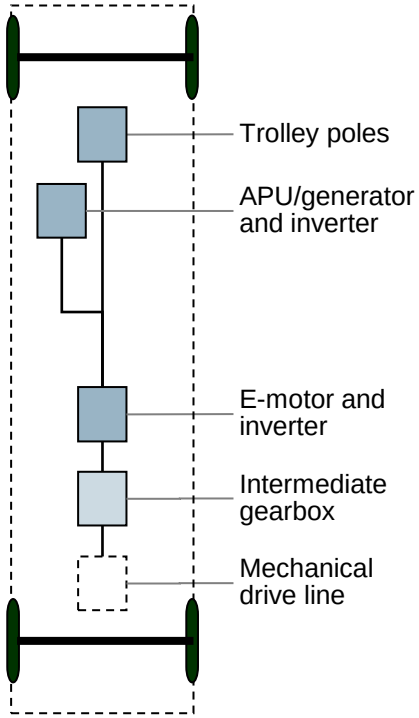
Hydrogen fuel cell, trolley and two e-buses are powertrains in scope with zero local emissions

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

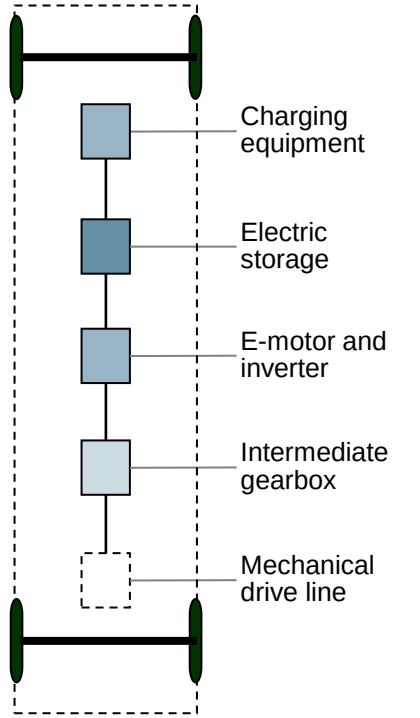
Hydrogen fuel cell powertrain



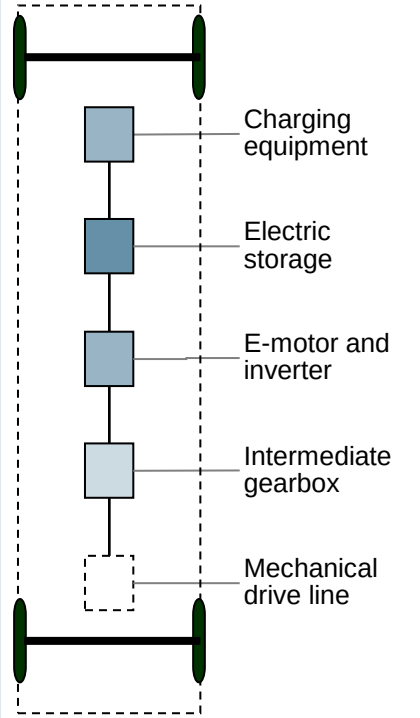
Trolley powertrain



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

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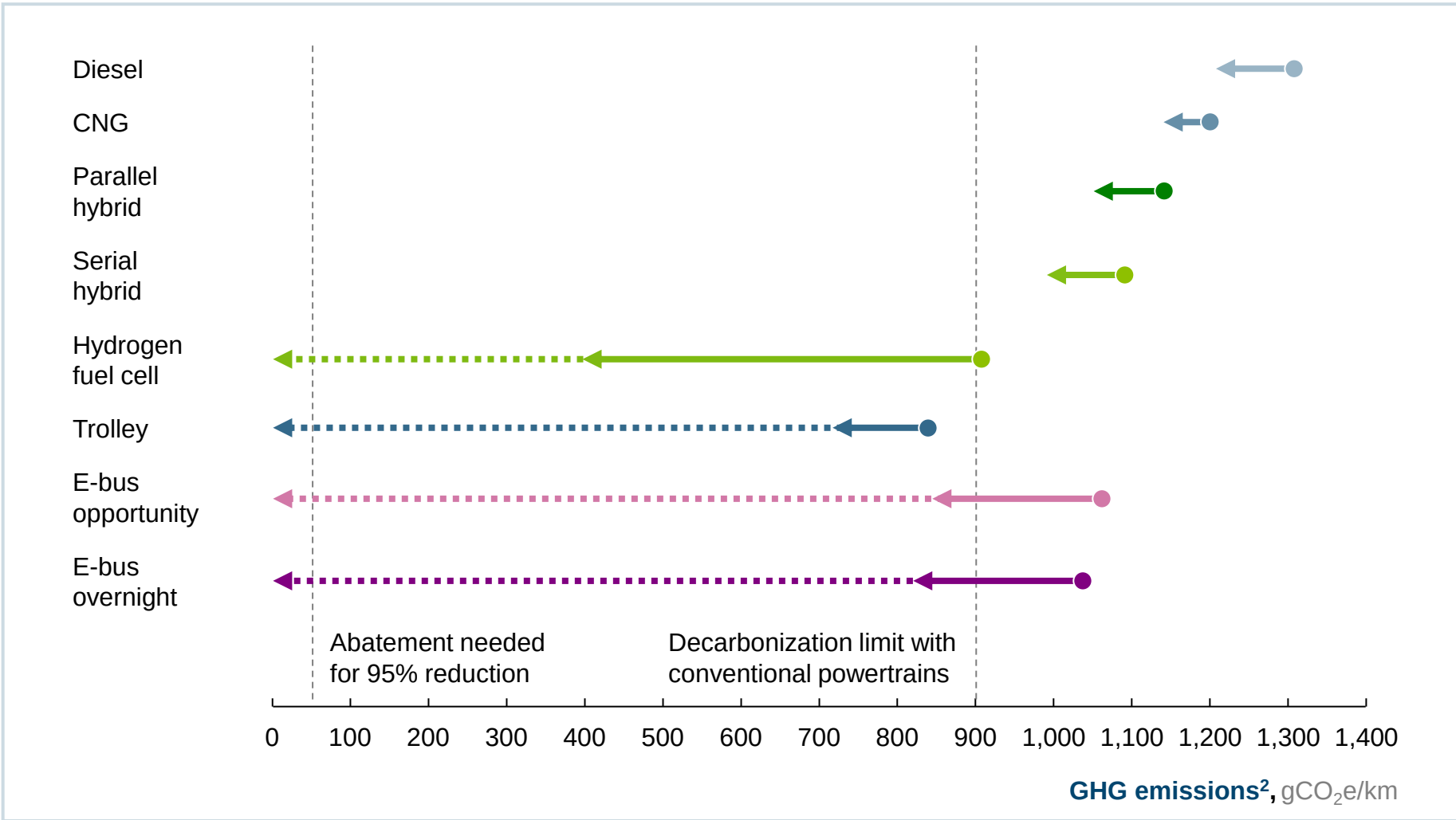
Only the hydrogen, e-bus and trolley buses have the potential to drastically reduce well-to-wheel emissions…

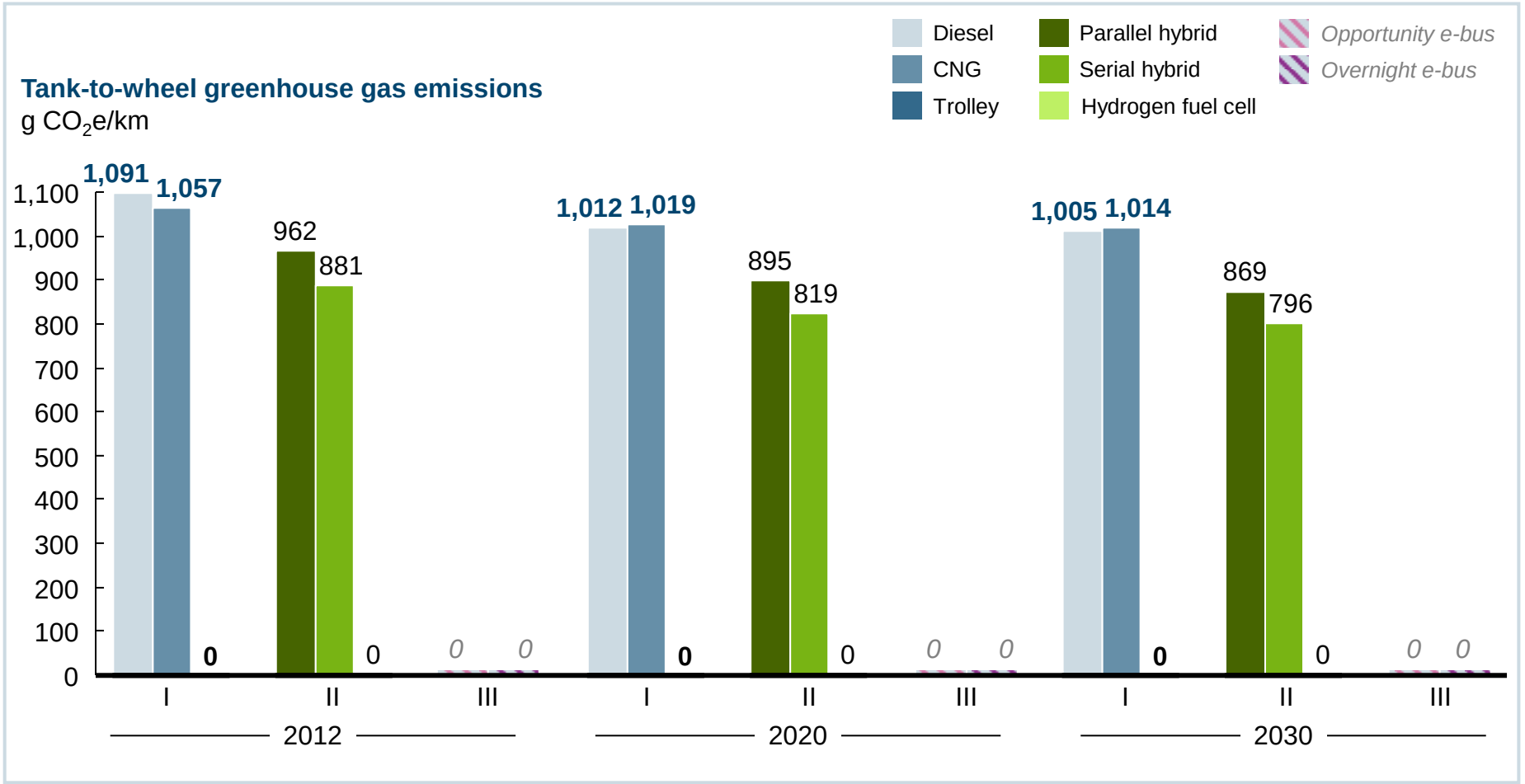
WELL-TO-WHEEL | 12 METER BUS



SOURCE: Study analysis

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

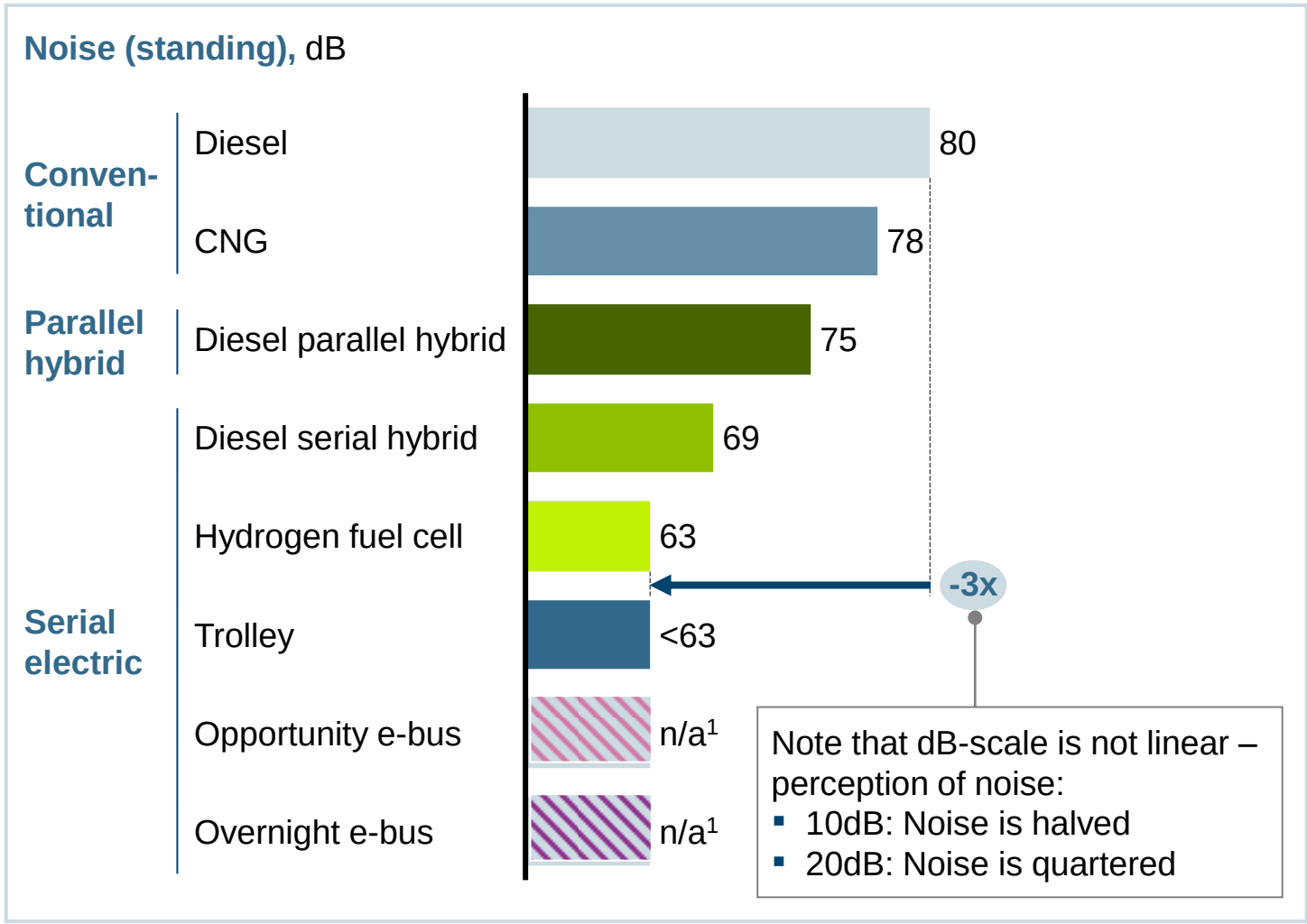
TANK-TO-WHEEL | 12 METER BUS



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
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Performance of the hydrogen bus is similar to conventional powertrains

12 M BUS | 2030

Similar performance

Passenger capacity

Curb weight
(12 m bus)

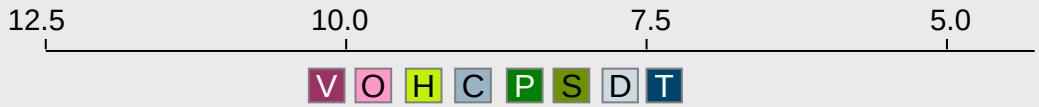
Lowest:
Diesel (11.6 tonnes)

Highest:
Overnight e-bus (13.5 tonnes)

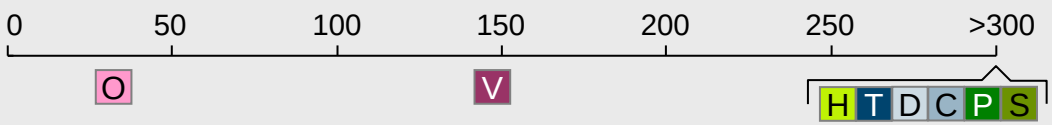
Differentiated performance

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

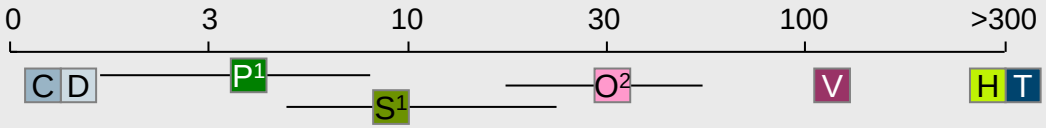
Acceleration, time to accelerate to 30 km/h in s



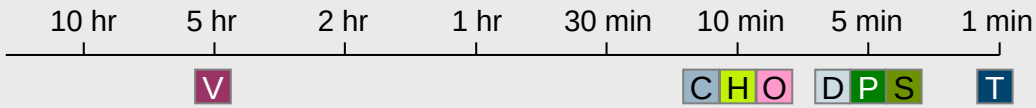
Range, in km



Range in pure-electric mode, km (logarithmic scale)



Refuelling time, (logarithmic scale)



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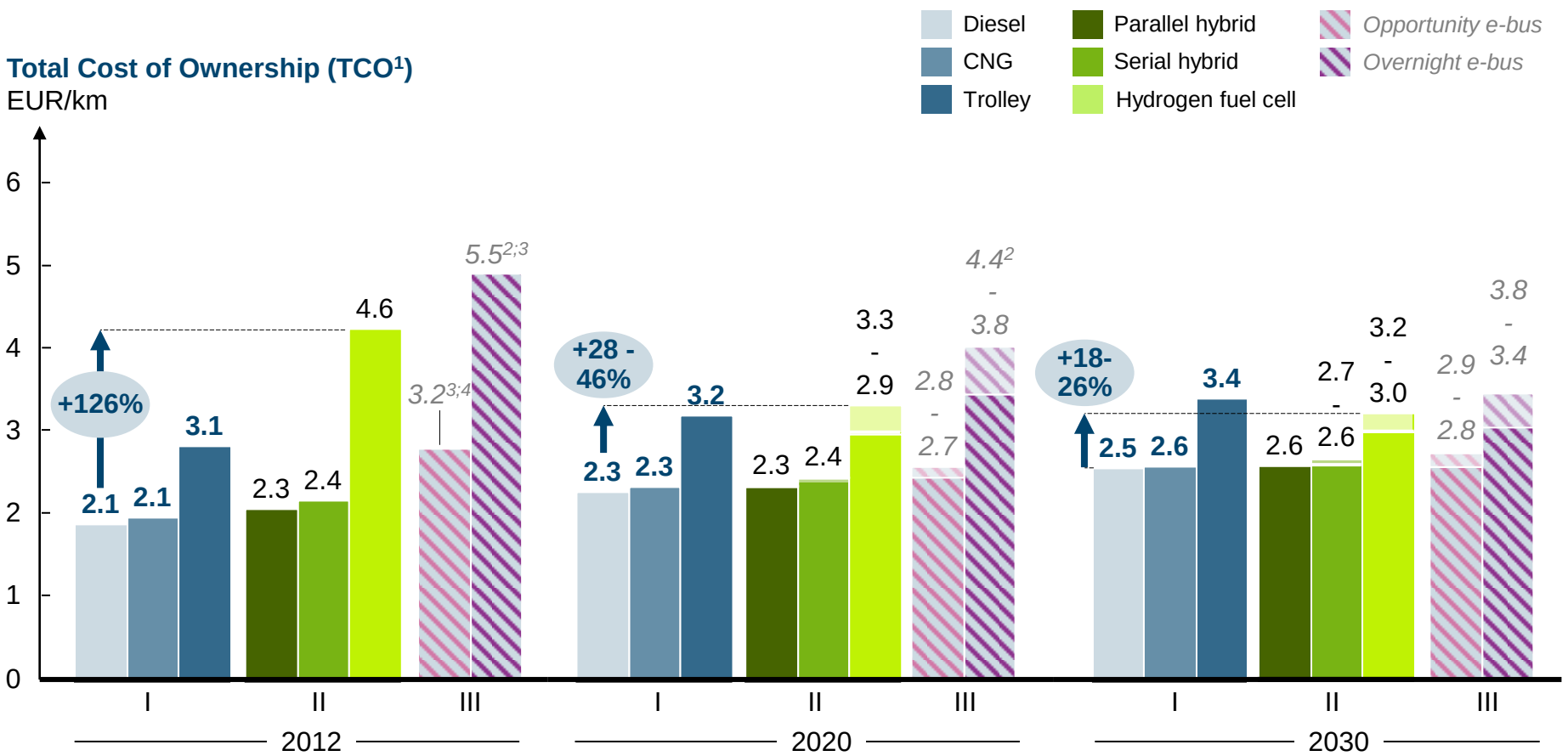
The price premium for a hydrogen fuel cell bus will decrease from 125% to only 15-25%

12 METER BUS



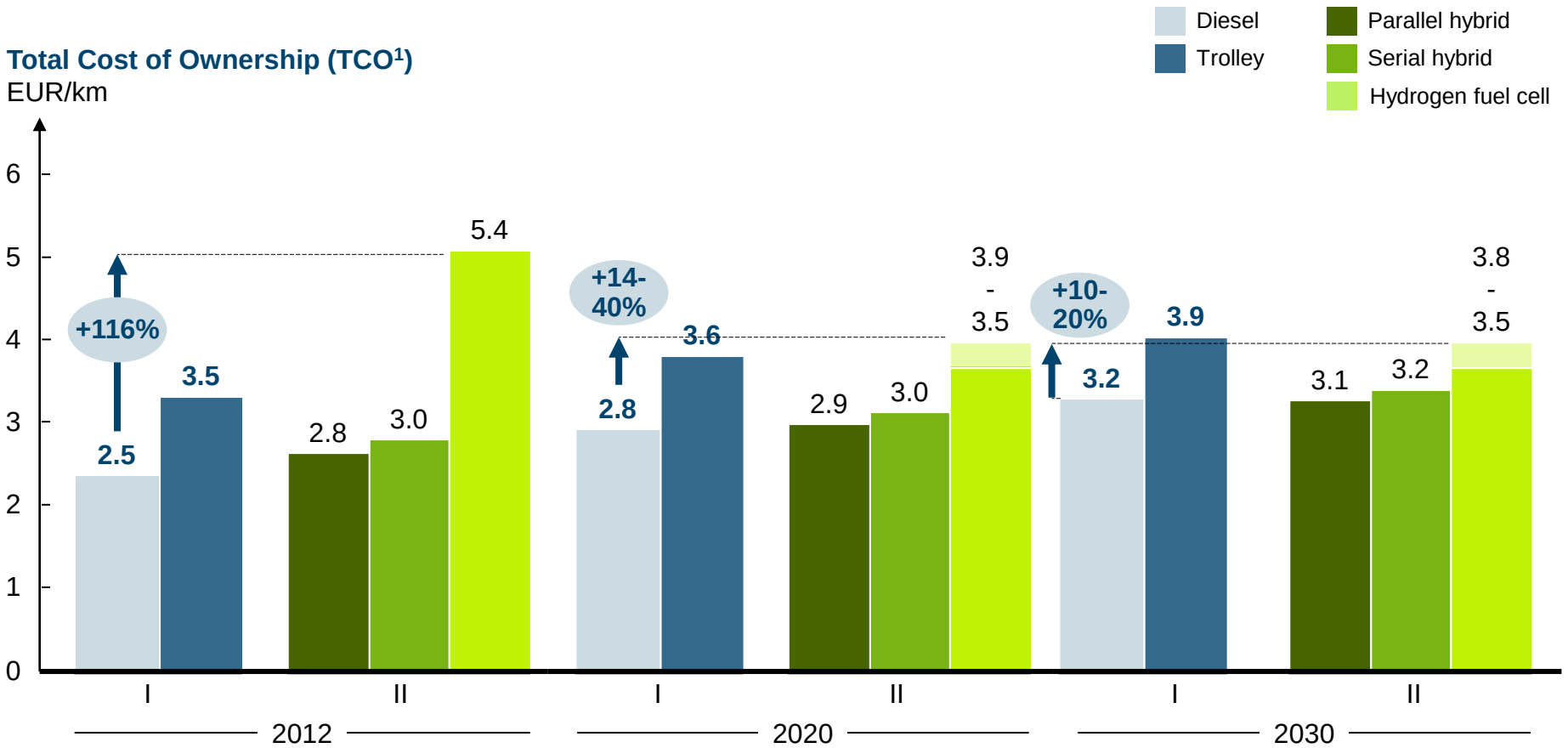
Upper bound figures = **'production-at-scale'** scenario
Lower bound figures = **'cross-industry'** scenario

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

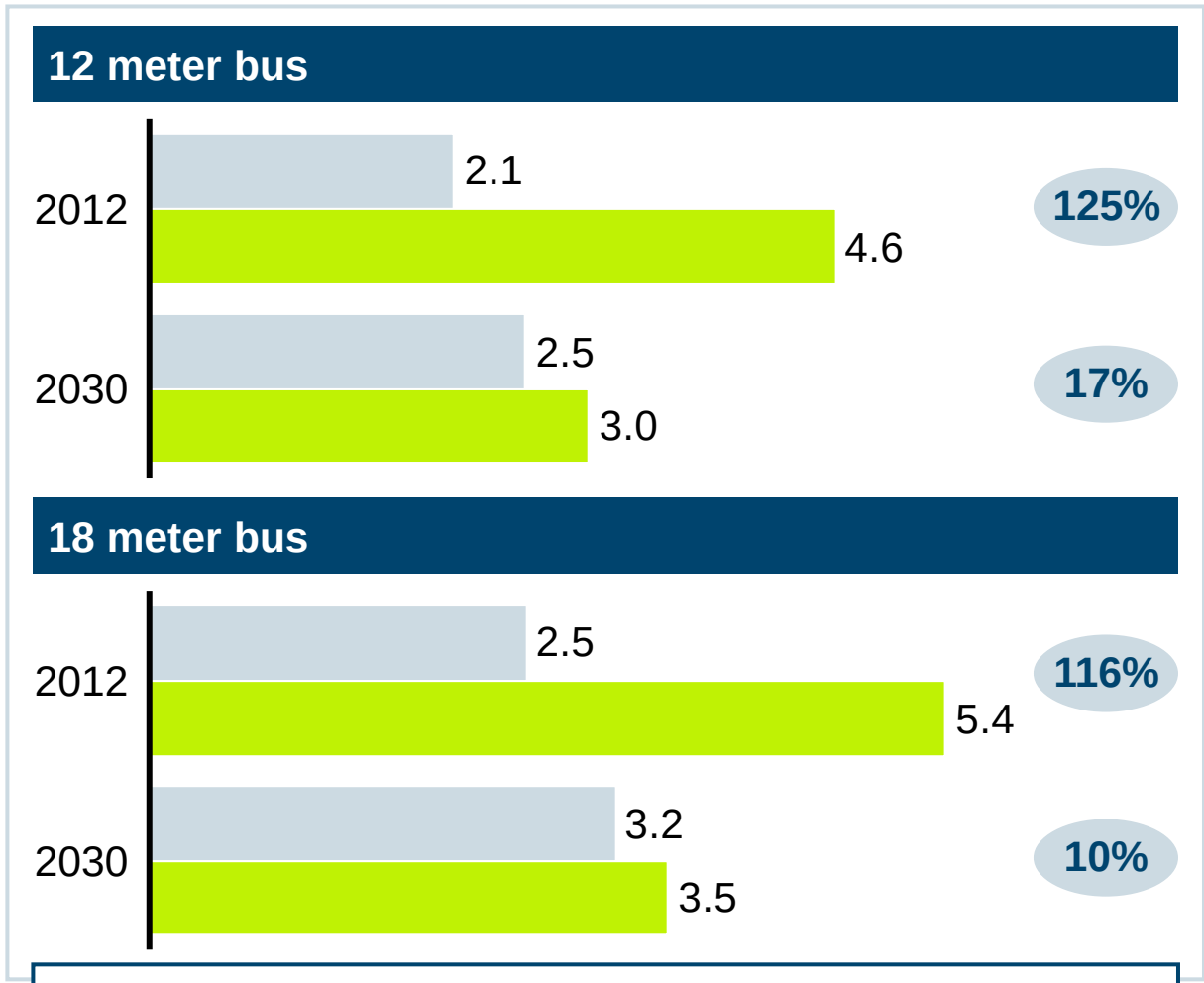
1 Based on 12 years' bus lifetime, 60,000 km annual mileage

SOURCE: Study analysis

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

TCO, EUR/km

INDUSTRY-WIDE SCENARIO

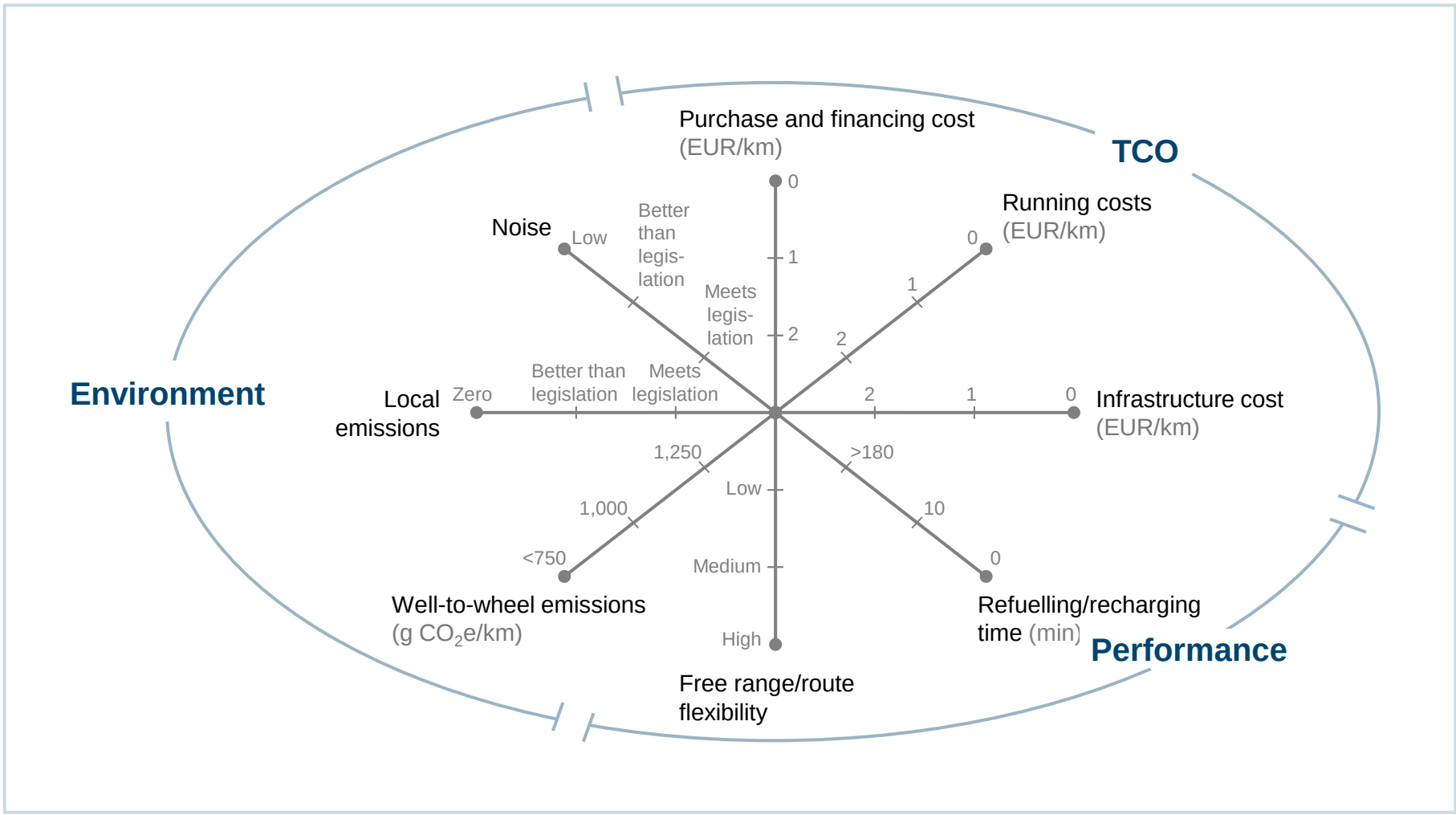


The hydrogen fuel cell bus only has a small premium over conventional diesel by 2030

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

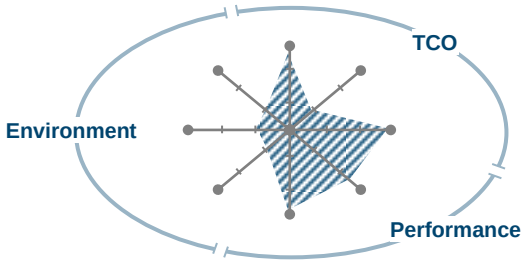


SOURCE: Study analysis

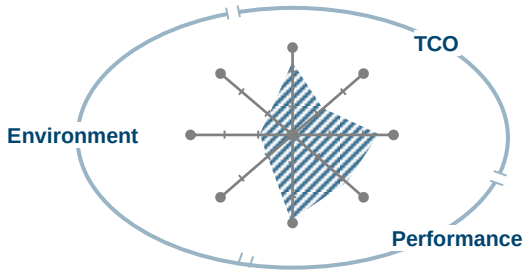
For the powertrains based on a combustion engine, the hybrids outperform the standard combustion engines

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

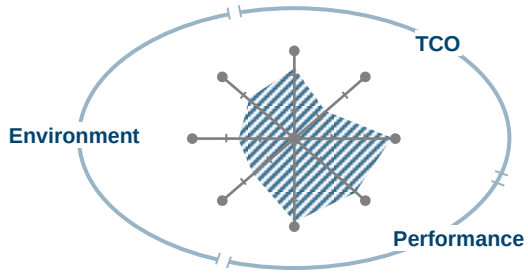
A Conventional diesel



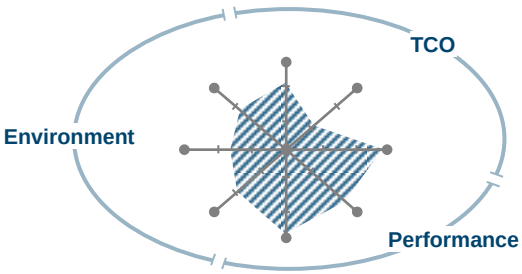
B CNG



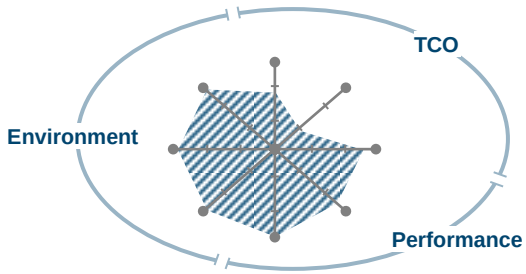
C Diesel parallel hybrid



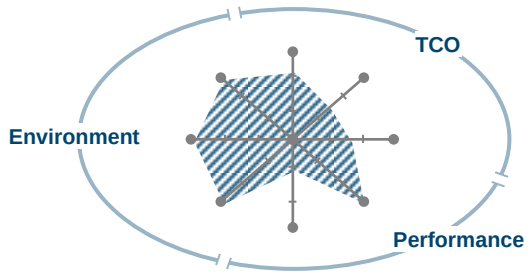
D Diesel serial hybrid



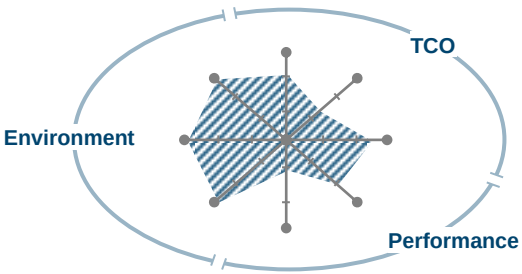
E Hydrogen fuel cell



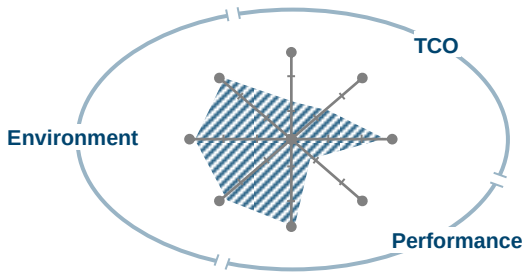
F Trolley



G Opportunity e-bus



H Overnight e-bus



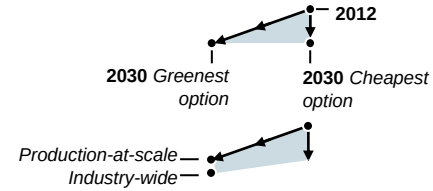
SOURCE: Study analysis

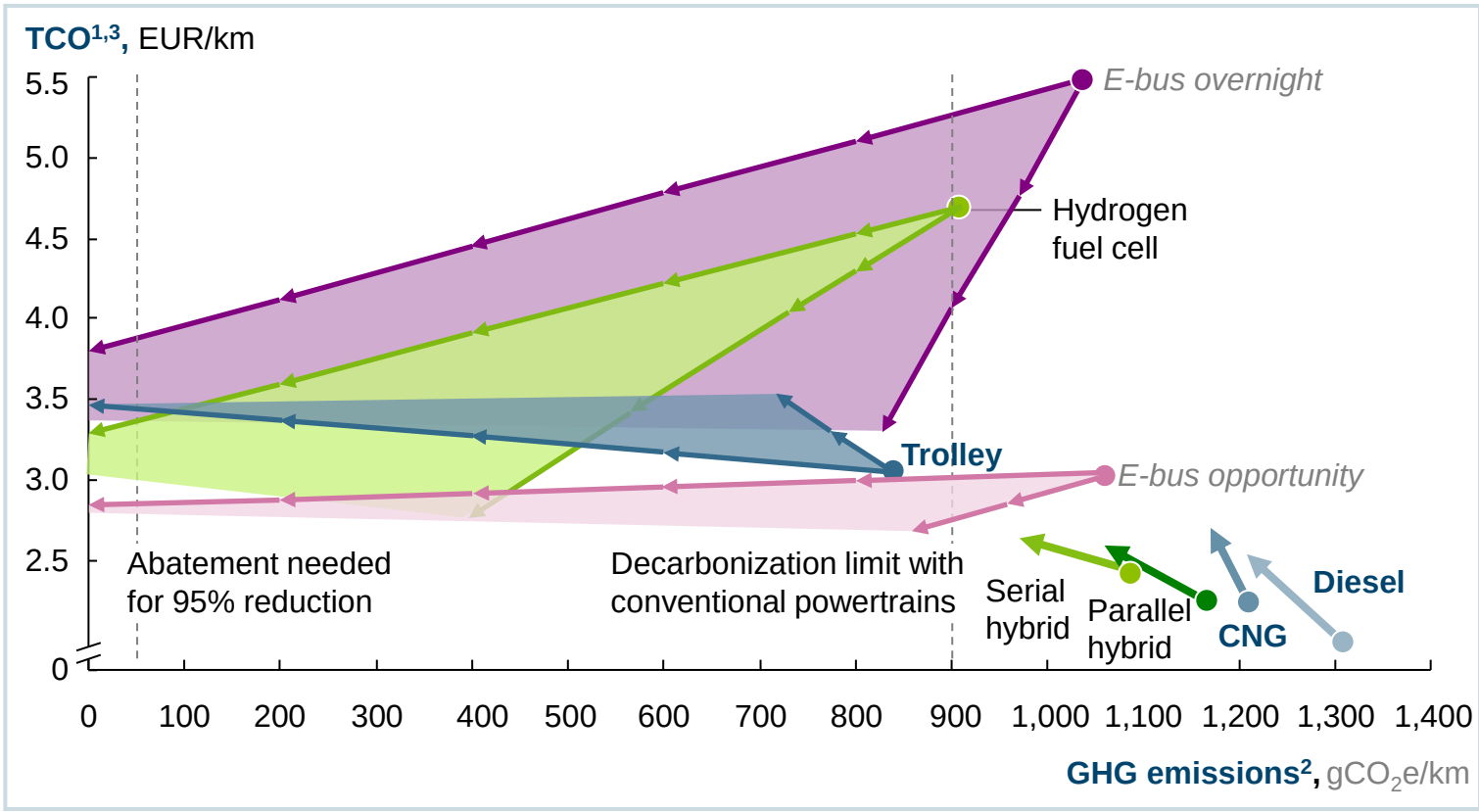
Only four powertrains can deliver a real decarbonisation; among those four, two are the cheapest

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?