'To drop-in or to adapt'

Total cost of ownership of renewables in heavy-duty trucks
A first overview of fuel/powertrain combinations

For Rijksdienst voor Ondernemend Nederland

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studio gear up

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List of abbreviations

Abbreviation	Meaning
CAPEX	Capital expenditures
CI	Compression-ignition
CNG	Compressed natural gas
CO_2e	Carbon dioxide equivalents
DFCI	Dual fuel compression-ignition
DME	Dimethyl ether
ED95	Ethanol with 5% cetane enhancer
ETD	Energy Taxation Directive
ETS	Emissions Trading System
FAME / B100	Fatty acid methyl ethers
FC	Fuel cell
FT diesel	Fischer-Tropsch diesel
GHG	Greenhouse gases
HBE	Hernieuwbare brandstofeenheden
HPDI	High-pressure direct injection
HPO	Hydrotreated pyrolysis oil
HVO	Hydrotreated vegetable oil
LNG	Liquefied natural gas
MtD	Methanol-to-Diesel
OEM	Original equipment manufacturer
OMEx	(Oligo-) Oxymethylene ether
OPEX	Operational expenditures
RFNBO	Renewable fuel of non-biological origin / e-fuel
RVO	Rijksdienst voor Ondernemend Nederland
SI	Spark-ignition
TCO	Total cost of ownership
TtW	Tank-to-wheel
VAT	Value added tax
WtW	Well-to-wheel

Content

- Background of the study
- Guidelines how to interpret TCO results
- TCO comparison for fuel/powertrain combinations
  - All considered options
  - Currently already marketed options
  - Drop-in options
  - Adaptations options
  - Mixed selection of drop-in and adaptation options
- Impacts of proposed Energy Tax Directive and the Emissions Trading System for Buildings and Road Transport
- GHG performance per fuel-engine-combination
- GHG abatement cost performance per fuel-engine-combination

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Background

- The regulator has limited the Annex IX B feedstock use that is predominantly used for HVO/FAME. This research looks at Annex IXA based fuel options that are able to scale for the heavy duty segment (40t trucks). Several fuel options require engine adaptations or new infrastructure, while some (drop-in) fuels are fully compatible with existing vehicles and existing infrastructure: "To drop-in or to adapt?"
- RVO commissioned a study from the Platform Hernieuwbare Brandstoffen to create insights for the sector whether "to drop-in or to adapt the engine". The Platform has asked studio Gear Up to compare the total cost of ownership (TCO) of various renewable fuel options in the heavy-duty road segment and inland shipping. The study results will be discussed with members of the working group road transport and shipping.
- This analysis focuses on 40t long-haul trucks and engines that are available on the market.
- Selection of fuel/powertrain combinations does not cover all potential options, but the study is a first scoping attempt to research renewable fuel alternatives besides FAME and HVO in the market.
- The total cost of ownership analysis is based on several assumptions, in the Annex of this report are a couple of slides included on the methodology and assumptions taken in this study .
- A TCO is time sensitive and thus this study provides insights for the current market situation. We have looked at the potential impact of upcoming new proposals for ETD/ETS.

Acknowledgements

- Platform Hernieuwbare Brandstoffen initiated a consortium of academia and industry, consisting of DAF (Alexander Wijn), HAN (Menno Merts), TNO (Stephan Janbroers & Peter van Gompel), TU Eindhoven (Bart Somers) and Westport Fuel Systems (Bas ten Broeke)

- Several industry and academia stakeholders outside the consortium were consulted, consisting of Iveco, ArenaRED (Paul Nooijen), Methanol Institute (Eelco Dekker), Nordsol (Niels de Regt), Ford (Werner Willems), RAI Vereniging (Wout Benning and other members) and others still to be confirmed

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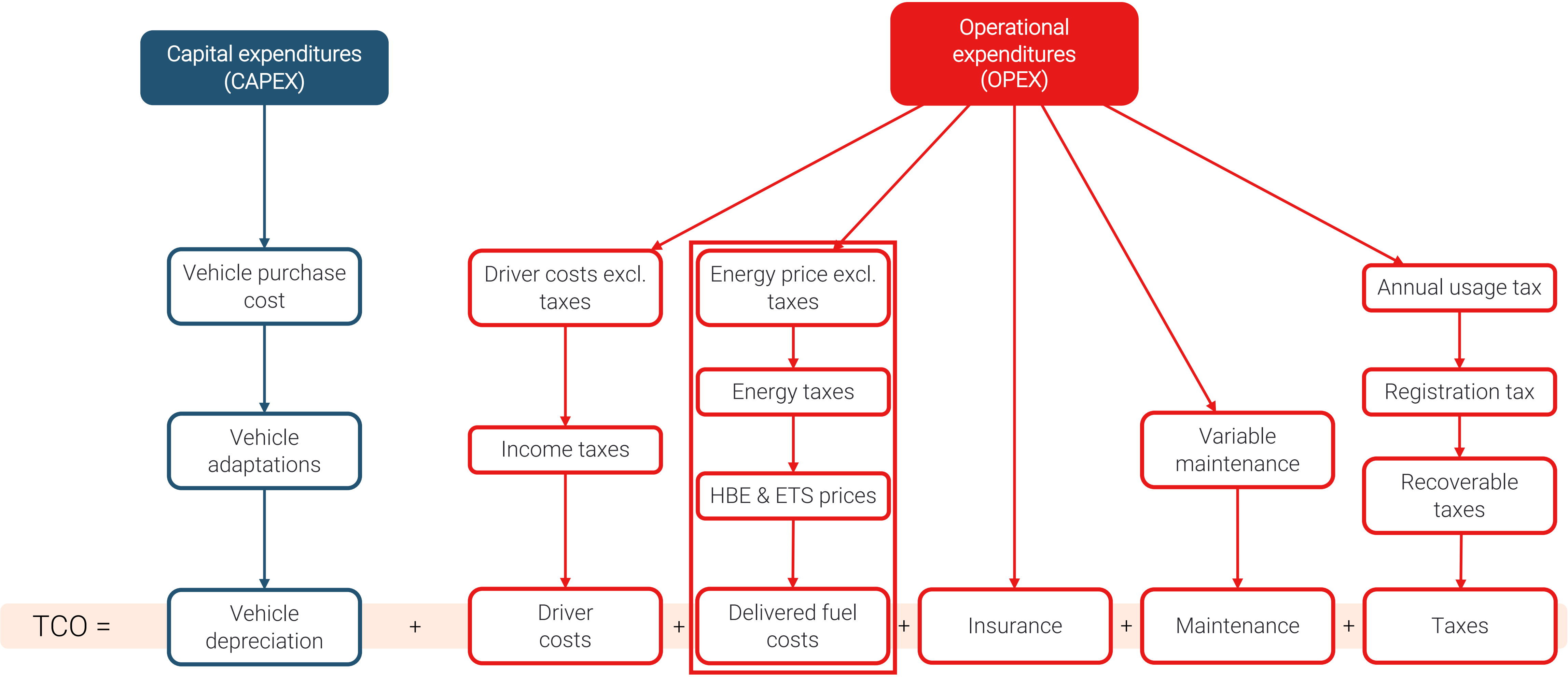
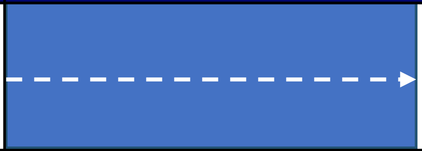
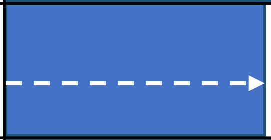
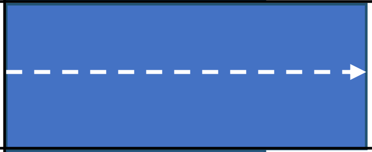
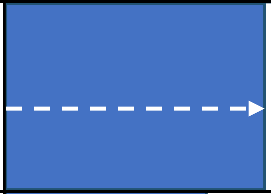
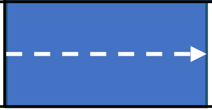
Elements of total costs of ownership (TCO)



Considered powertrains

- Compression-ignition trucks were assumed for diesel, drop-in fuels, FAME, ED95, DME and OMEx
- Dual fuel compression ignition trucks were assumed for a mix of HVO and methanol
- Spark-ignition trucks were assumed for hydrogen, methanol, CNG and LNG
- HPDI was assumed for hydrogen
- This slide will be updated with upcoming feedback from members regarding the status of certification of the different fuel/powertrain combinations

Powertrain long-haul transport	Readiness	Description
Compression-ignition engine (CI)		Ready, but not yet for non drop-ins. Currently dominant, but needs certification for non drop-ins
Dual fuel compression ignition (DFCI)		Most of the initiatives come from the shipping sector. It is theoretical ready for lower blends, but not the blend ratio that was taken into account in this study.
Spark-ignition engine (SI)		Ready, but less efficient, thus substituted by CI. Required for low cetane fuels and potential emissions benefits
High-pressure direct injection engine (HPDI)		Ready for methane, under investigation for hydrogen. Promising could scale when demand is there, highly efficient combustion technology, e.g. for hydrogen
Fuel cell (FC)		Expected to enter the market in the near future

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How to interpret the results?

- These results are indicative; most of the fuel/powertrain combinations are not widely available on the market. The results should be seen as a potential way of comparing multiple renewable options in the context of today. We have assumed for the renewable fuel options not yet on the market that they are produced on a large scale and that alternative powertrains have been certified.

- Ownership costs are annualised and shown per year. They only depict the current Dutch market conditions, without estimating any (near) future developments within or after the ownership period.

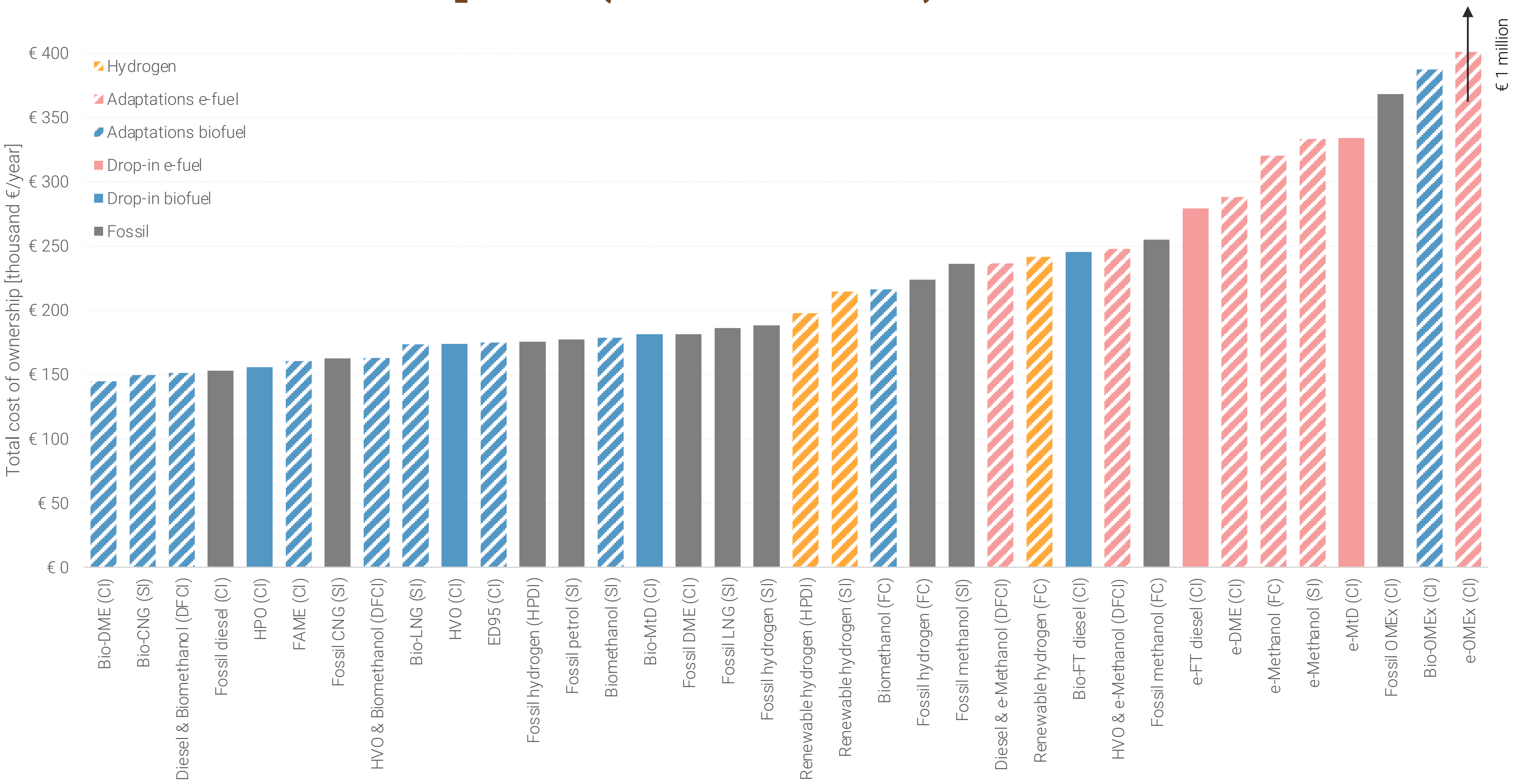
- Fuels and engines that are currently not marketed yet were assumed to be available at similar volumes as their already marketed counterparts. Therefore, the results depict an alternative 2022 in which all fuels and engines are present in comparable volumes and non-restricted by difficulties of selling in low volumes. The inflation of renewable energy products in the last few years has also been taken into account. For this, price developments of FAME and ethanol from January 2019 to February 2022 have been taken as a reference.
  - There are separate results for the currently already marketed options that do not require this assumption.

- Powertrain combinations that differ from the traditional long-haul truck (compression ignition) are considered as adaptations, e.g. bio-CNG in a spark-ignition will be in the category of adaptations. “Adaptations” is therefore to be understood as adaptations to the conventional truck fleet and fuel infrastructure.

- Results were generated before the steep increase of fuel prices caused by the war in Ukraine

- All biofuels are Annex IXA based fuels, gaseous or liquid. The option of biomethane through guarantees of origin is excluded in this research

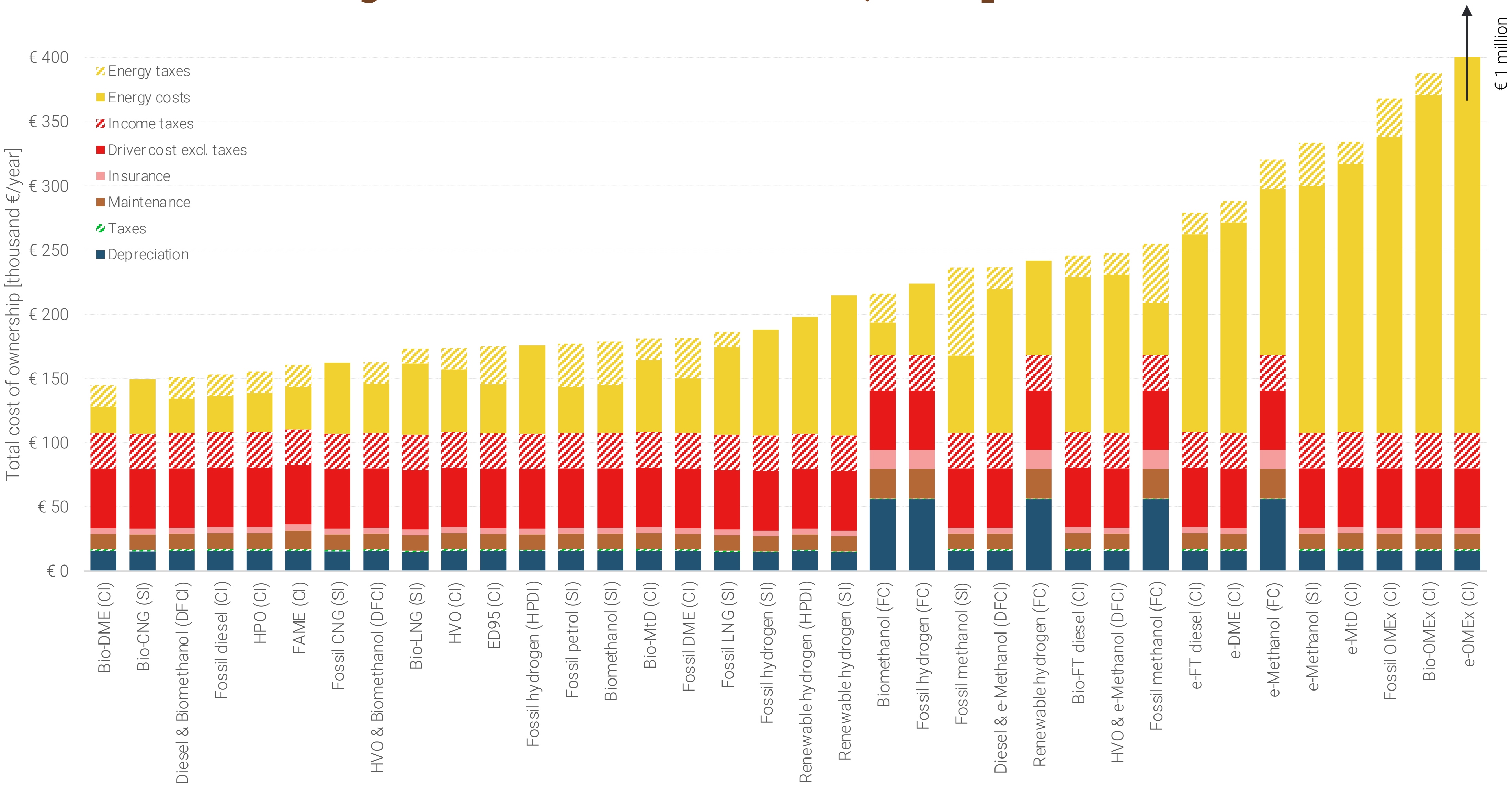
Overview of all considered options (not exhaustive)



* e-OMEx has been calculated with an assumed fuel price

CI = Compression ignition, DFCI = Dual fuel compression ignition, SI = Spark ignition, HPDI = High pressure direct injection, FC = Fuel cell.
* Note that all renewable fuels in the study are subject to energy content compensation for excise duties (Handboek Accijns 4.7.2)

Fuel costs cause the largest differences in costs, except for fuel cells



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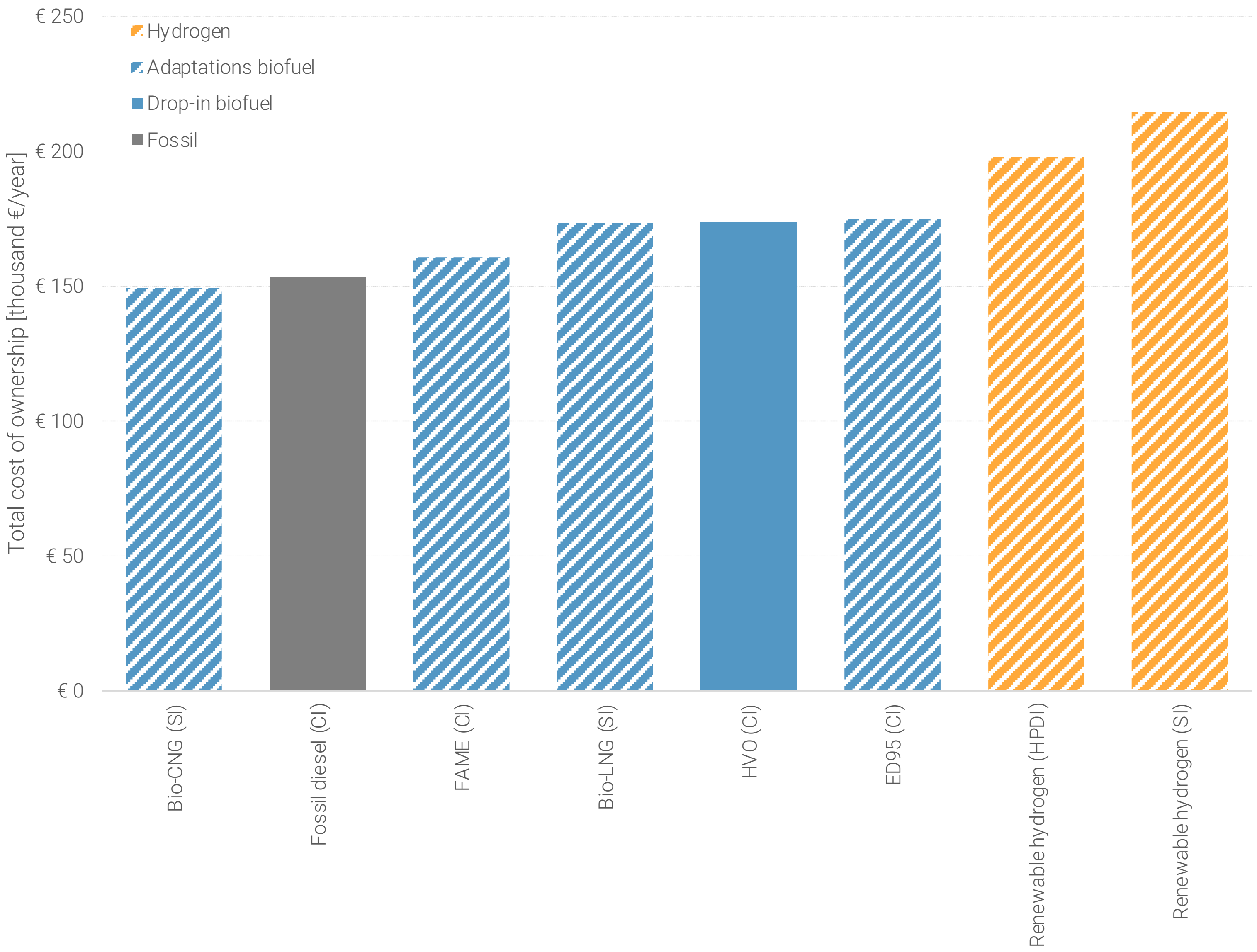
Comparison of currently marketed fuel-engine combinations in the EU

- Bio-CNG shows cost competitiveness with conventional diesel.
- Bio-LNG and FAME (B100) close in costs to coventional diesel.

- For bio-CNG and bio-LNG prices were provided by platform members.
- For diesel, HVO and hydrogen pump prices of February 2022 have been taken into account. For HVO a premium was added to make the price Annex IXA.
- For FAME a production price was taken and again a premium was added to make the price applicable for an Annex IXA fuel.
- ED95 was also derived from a production price. And again, an assumption was taken to arrive to a fuel price.

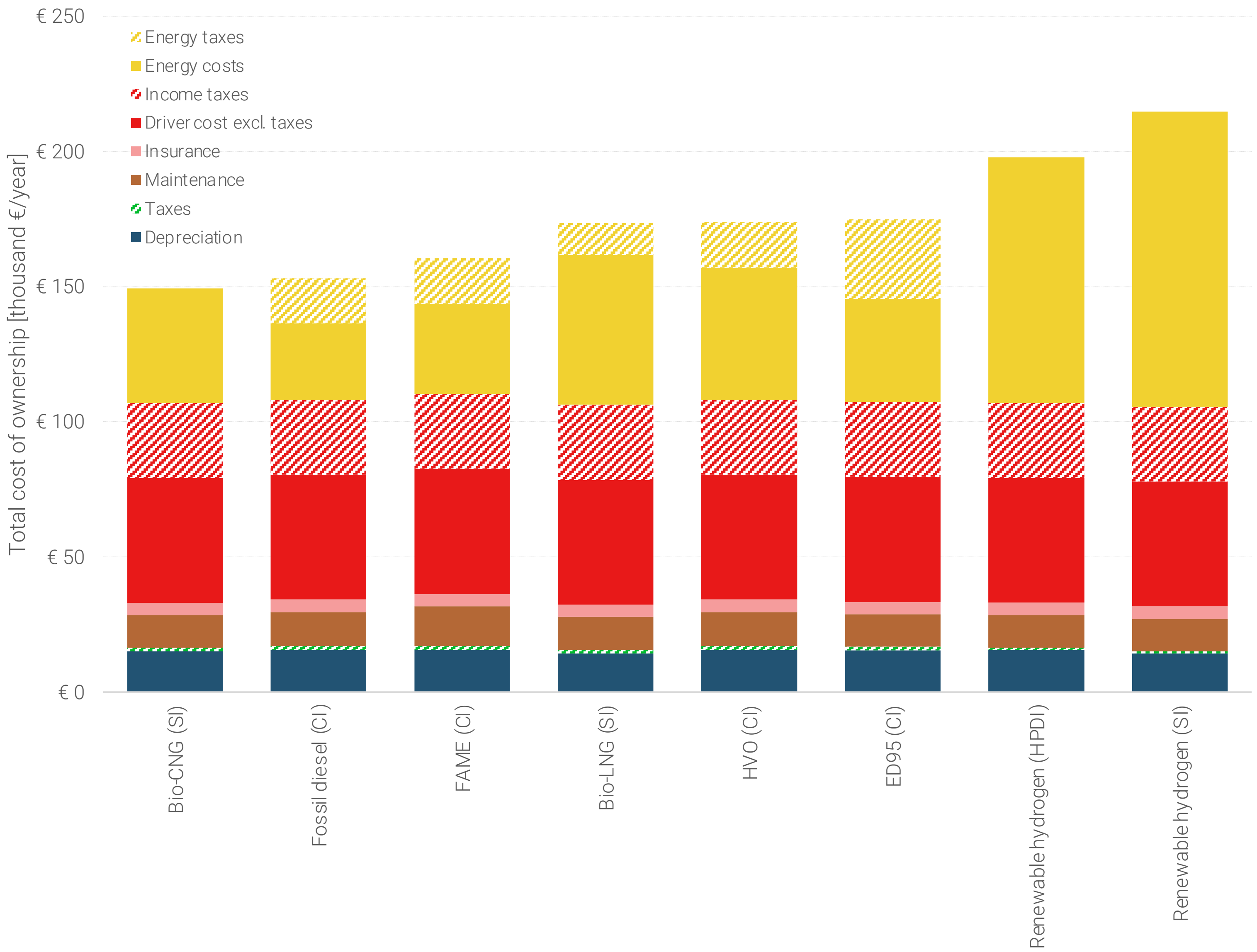
- Renewable hydrogen options are shown in a spark ignition and a high pressure direct injection system (variation spark ignition). Fuel cells are expected to enter the market soon.



SI = Spark ignition, CI = Compression ignition, HPDI = High pressure direct injection

Cost breakdown of currently marketed fuel-engine combinations in the EU

- For bio-CNG the higher fuel price compared to conventional diesel is counterbalanced by the exception of excise duties.
- FAME close to conventional diesel due to similar fuel costs.
- Bio-LNG close in costs to coventional diesel due to lower taxes, bur signficantly higher fuel costs.
- Fuel costs are the main driver of the differences between the fuel/powertrain combinations.
- Renewable hydrogen options come at a cost premium, but production prices are expected to drop in the future.



SI = Spark ignition, CI = Compression ignition, HPDI = High pressure direct injection

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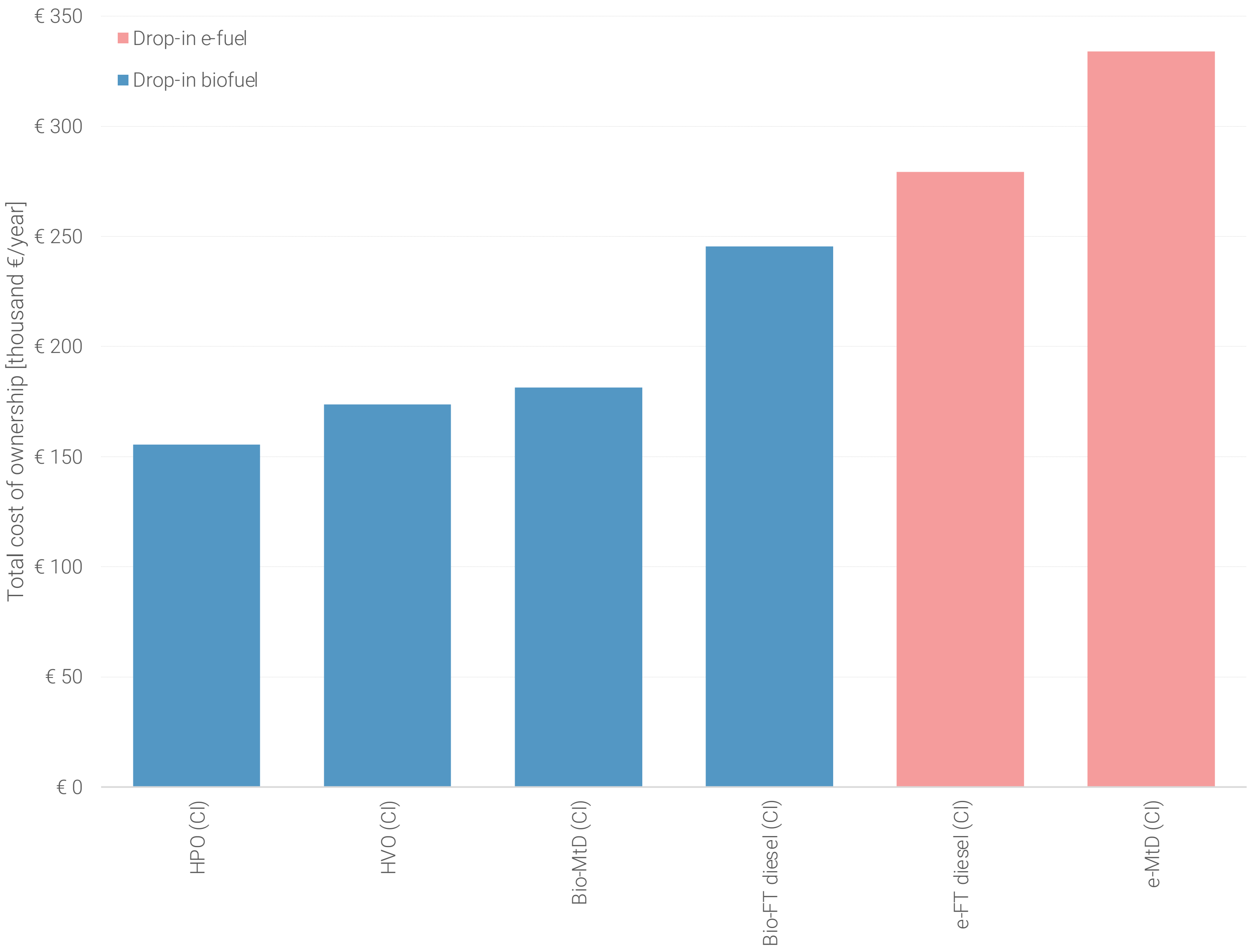
Drop-in e-fuels still result in higher costs than advanced drop-in biofuels

- Hydrotreated pyrolysis oil from forestry residues may become the most cost-competitve options of the renewable drop-ins.
- But also bio-Methanol-to-Diesel may achieve prices similar to HVO.
- Fischer-Tropsch diesel from biomass seems to be on the higher side amongst biofuel-options, though the details of economic performance depend on the business case of scale and renewable co-products.
- e-Fischer-Tropsch diesel may become cheaper than e-Methanol-to-diesel, showing a reverse correlation to their bio-counterparts.

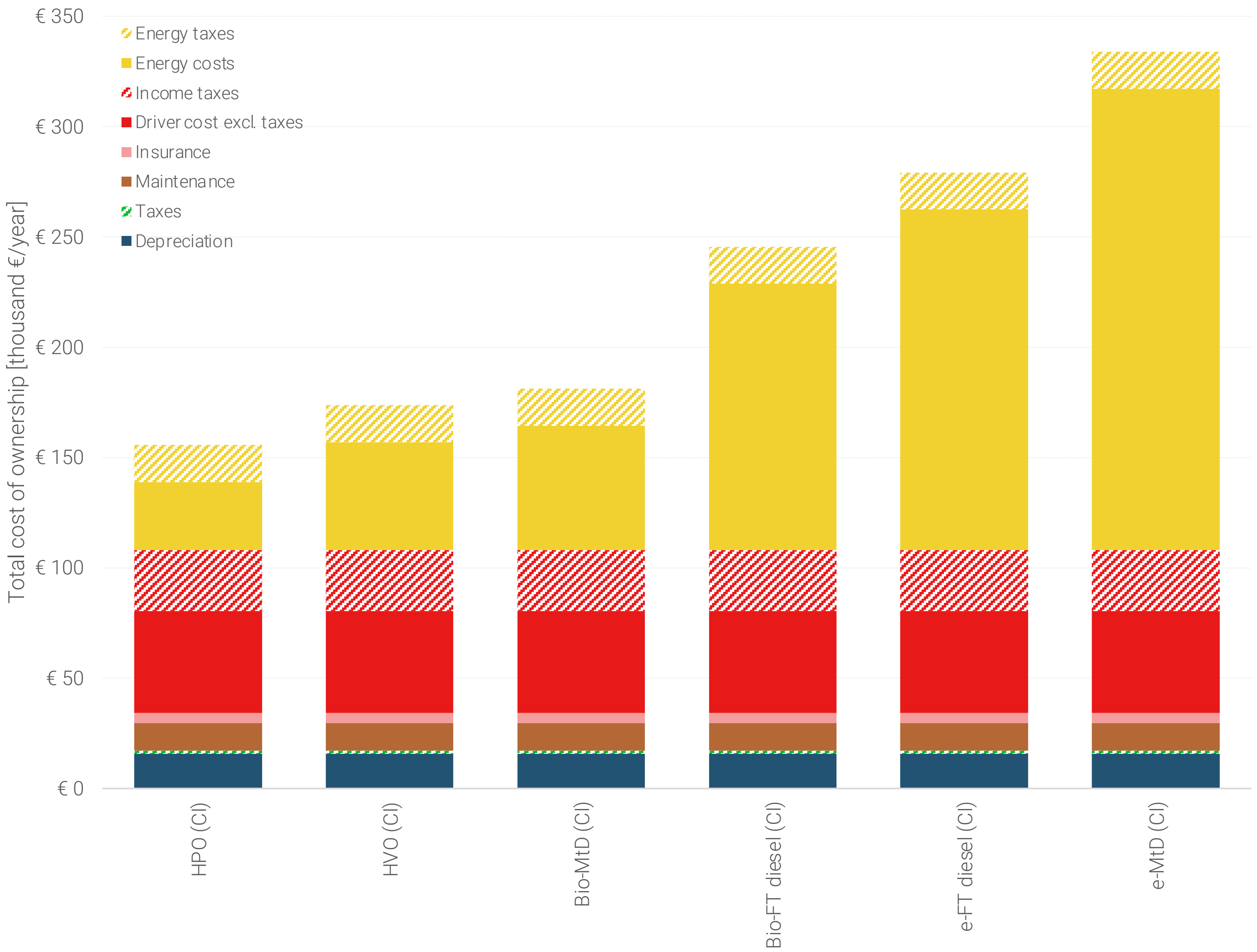


CI = Compression ignition

Drop-in options only differ in fuel prices

- The main difference in the costs of the several drop-in options are the fuel costs.

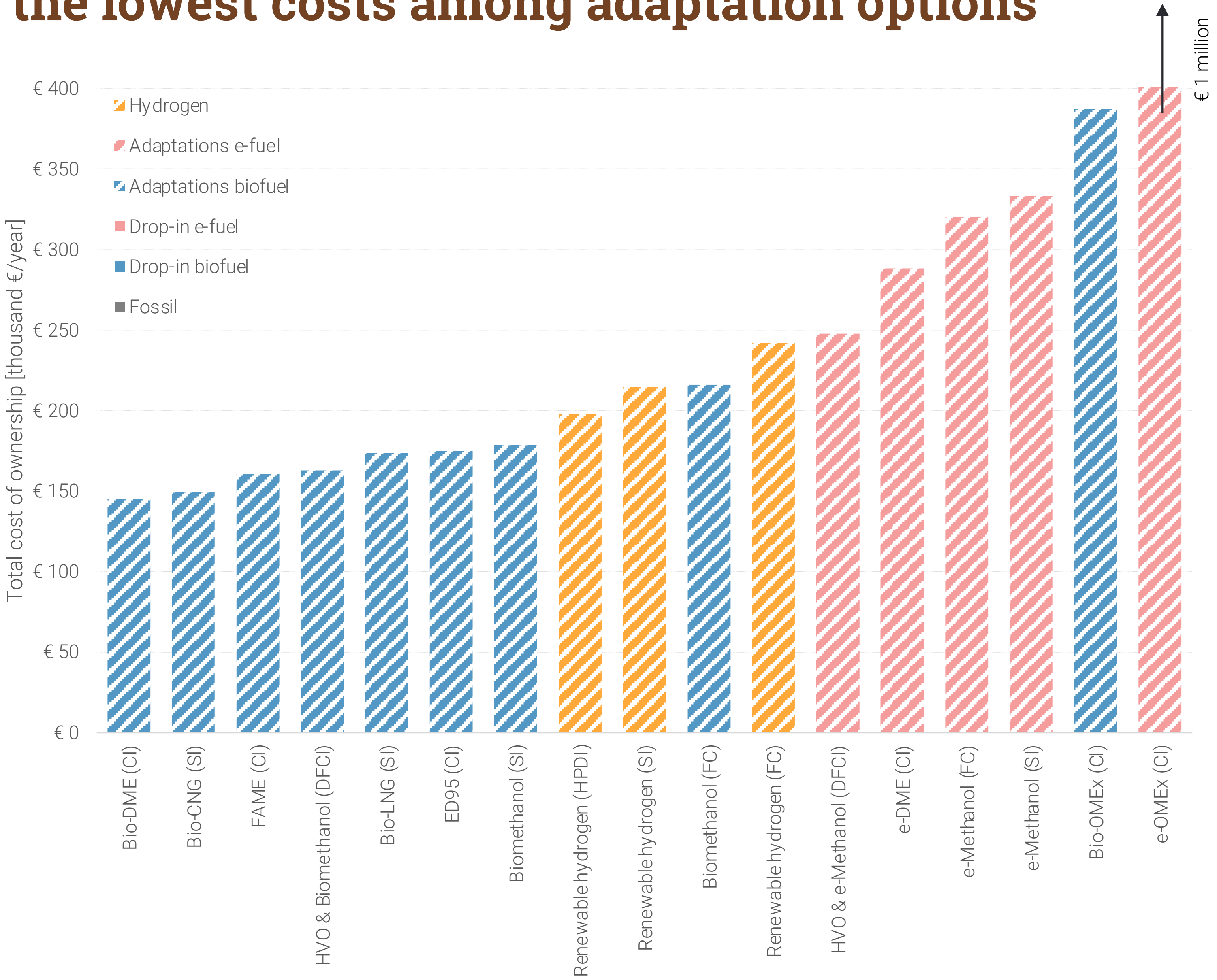
- Monitoring fuel costs developments is essential to understand how the different fuels and their associated costs will develop the upcoming years.



CI = Compression ignition

Bio-based options also have the lowest costs among adaptation options

- DME from lignocellulosic biowaste has the lowest TCO costs for fuel/powertrain combinations needing adaptations.
- Again, under current market conditions and assumptions taken, the biobased options perform the best on basis of a total cost of ownership.
- Hydrogen options expected to decrease in costs the upcoming years and come closer to the TCO of biobased options. Currently close to the TCO of biomethanol in a spark-ignition.
- Under the current assumptions there are seven options that can be used (now or in the future) by truck operators to reduce their emissions before the costs of hydrogen powertrain combinations decrease

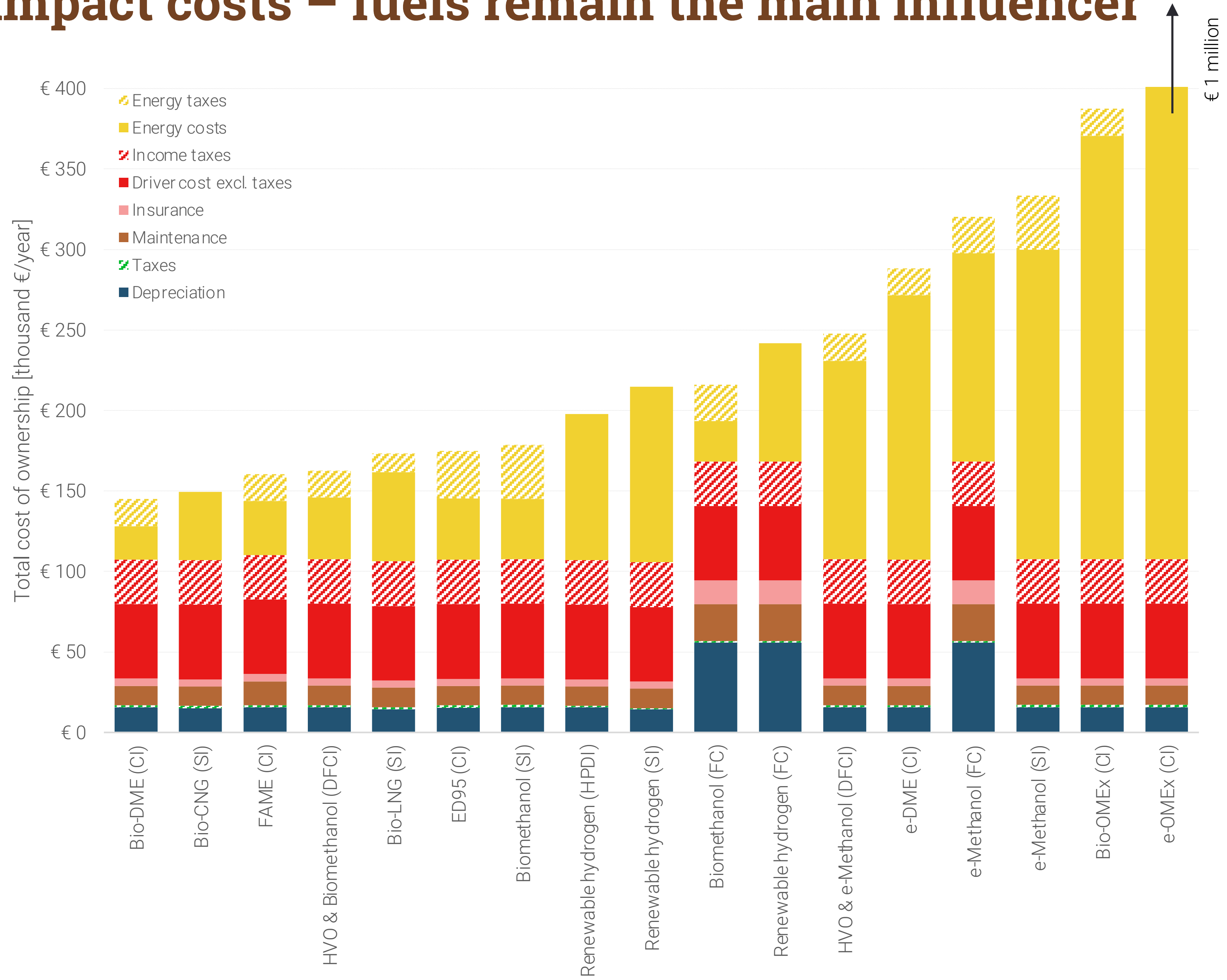


CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI = High pressure direct injection.

* e-OMEx has been calculated with an assumed fuel price

Adaptation costs limitedly impact costs – fuels remain the main influencer

- Adaptation costs are part of the depreciation costs and show a limited impact on the whole TCO.
- Except for the fuel cells, where the purchase costs result in a signficant higher depreciation compared to spark ignition, compression-ignition with adaptations or dual fuel compression ignitions.
- Fuel costs cause the main differences between the TCO's of the fuel/powertrain combinations requiring adaptations (except for the fuel cell).
- Fuel cell is a novel technology and it is expected to have lower purchase costs in the future, when the technology is more matured. Than it will become a very interesting option due to the high engine efficiency.



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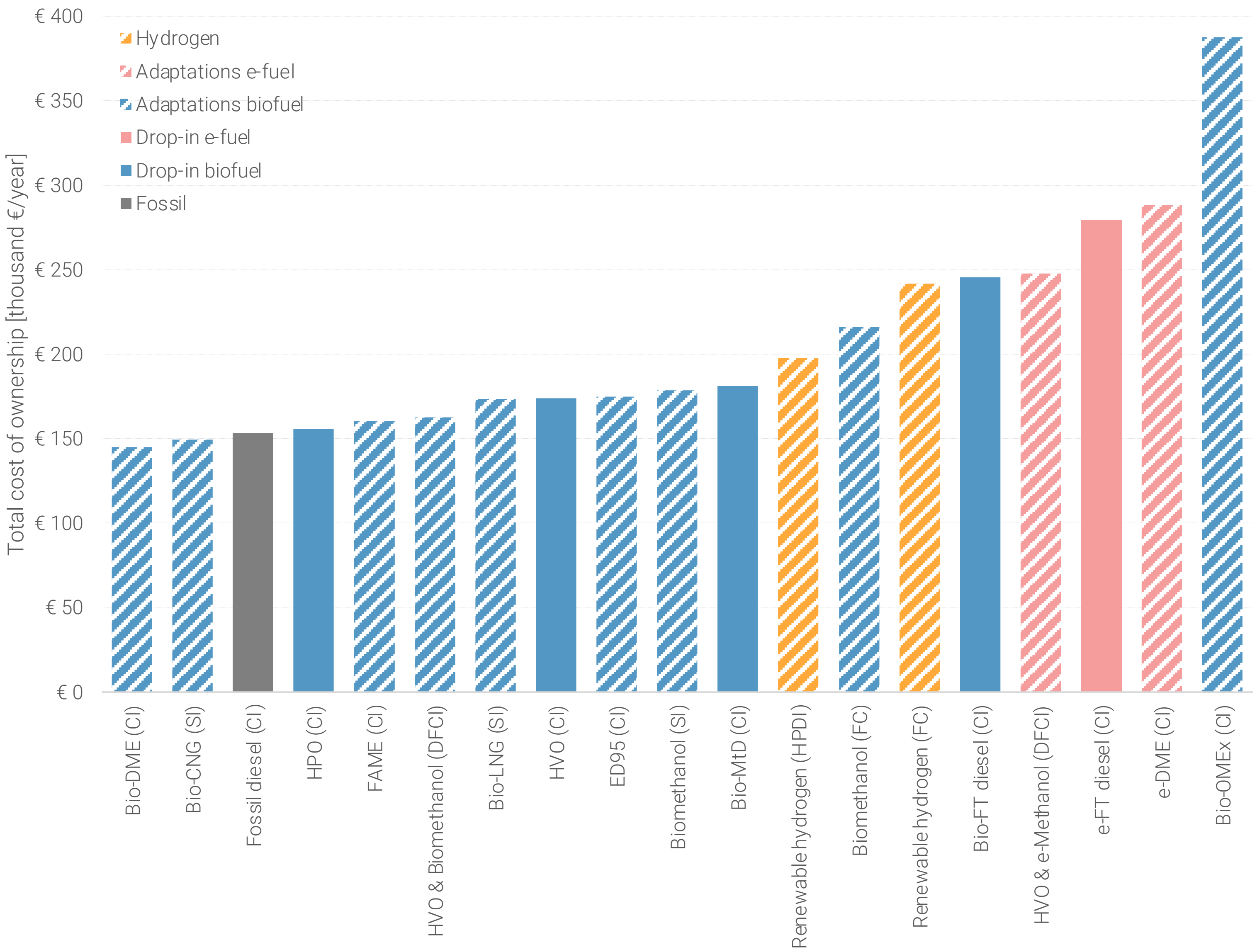
* e-OMEx has been calculated with an assumed fuel price

Potential portfolio of options (drop-ins or adaptations) available to reduce emissions without showing signficant increases in costs

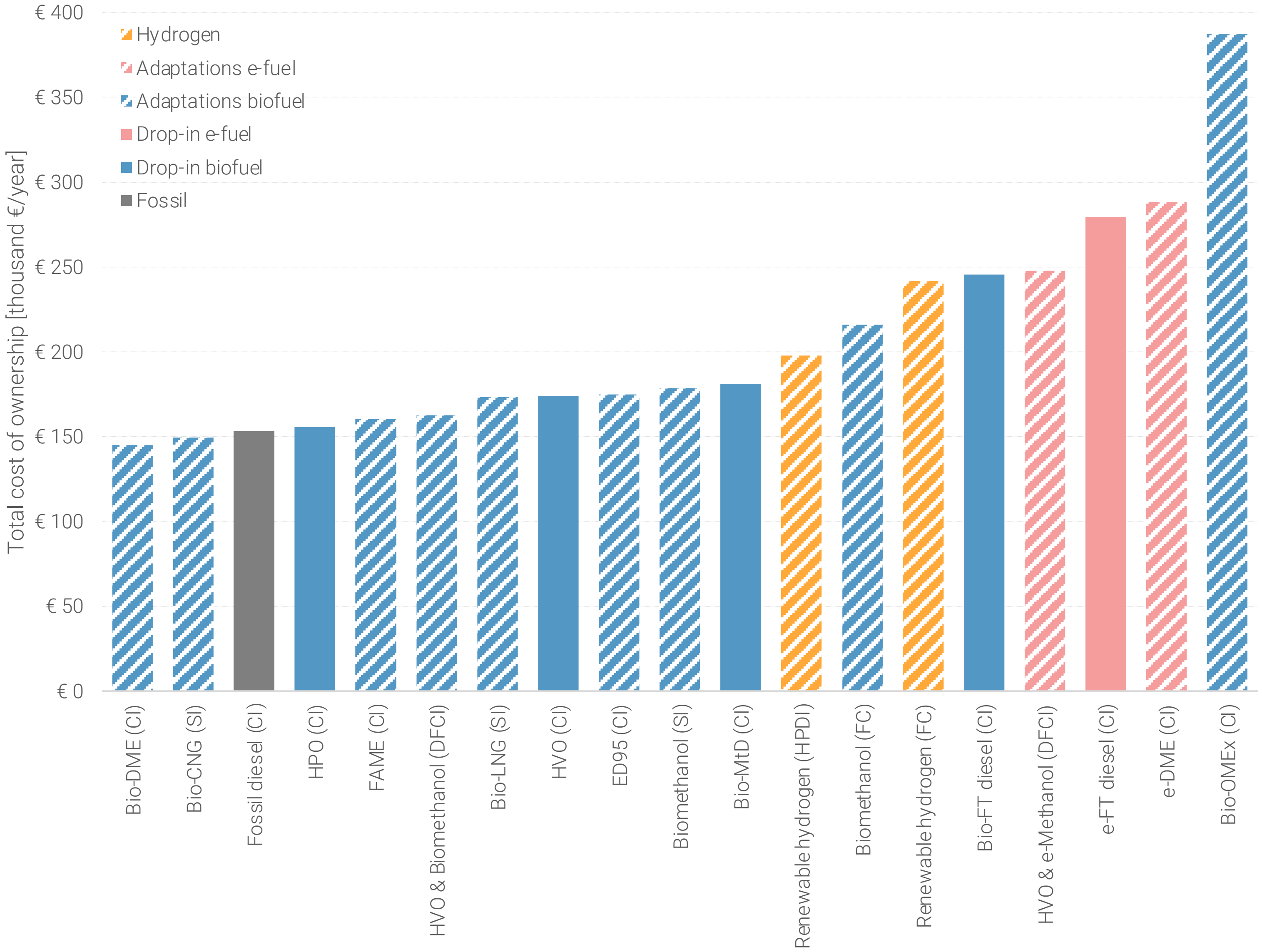
- Multiple options (requiring adaptations or drop-ins) show a potential to reduce emissions without signficantly increasing the TCO.
- Bio-based options are currently the options with the lowest costs (independent of drop-in fuels or fuels requiring adaptations).
- Five options show strong cost competitiveness with conventional diesel under current assumptions.
- Of which four requiring adaptions DME, CNG in a spark-ignition, FAME, and a mix of HVO and biomethanol in a dual fuel compression ignition.
- And one drop-in: HPO.



CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI = High pressure direct injection.

Potential portfolio of options (drop-ins or adaptations) available to reduce emissions without showing signficant increases in costs

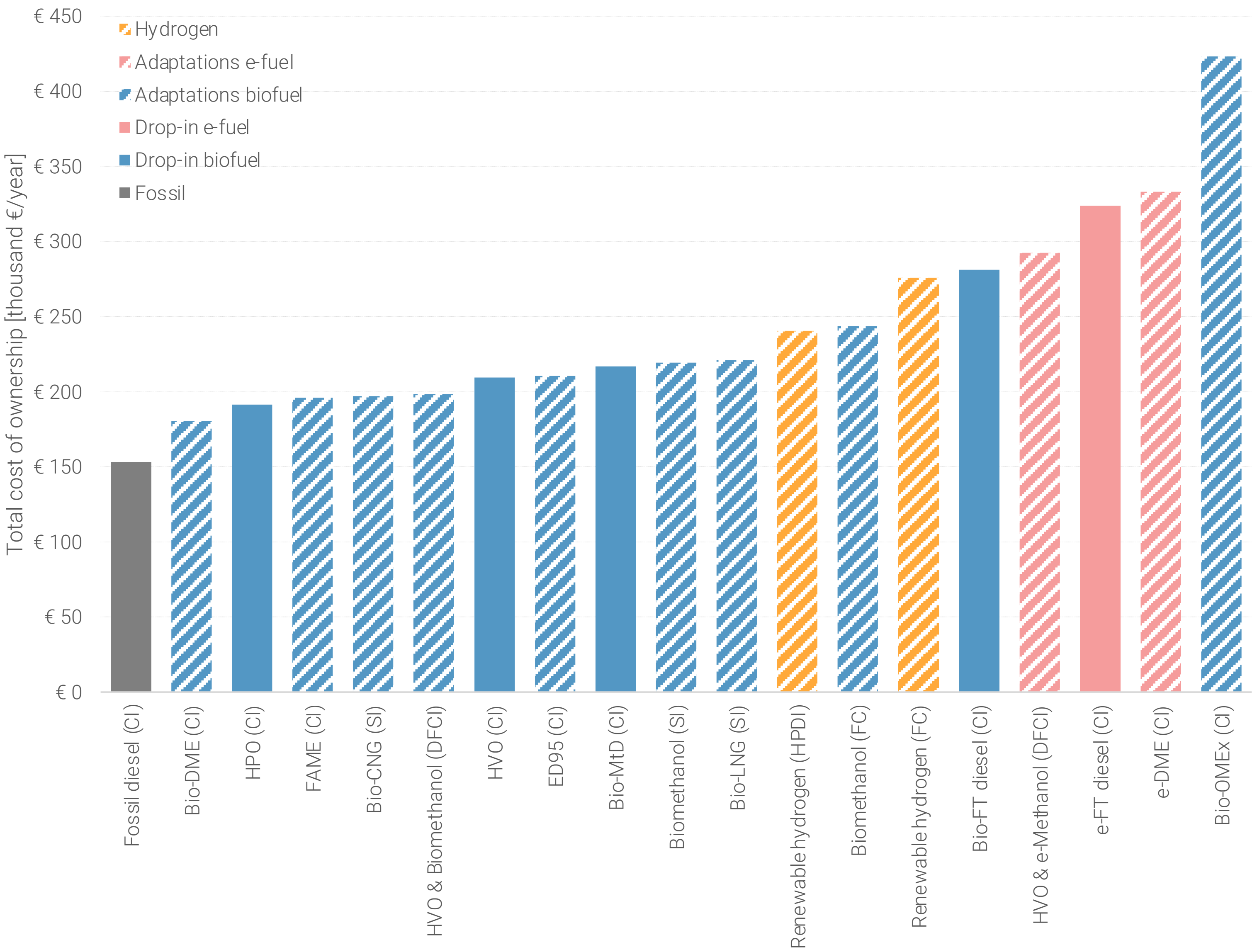
- TCO studies are based on multiple assumptions, and thus, this study is not able to conclude that these will be the definite TCO costs of the fuel/powertrain combinations for fleet operators.
- However, this graph shows there is a potential portfolio of fuel/powertrain combinations (now and in the future) available to reduce GHG emissions.
- The decision to drop-in or to adapt is influenced by the use profile and fuel costs of the fuel.



CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI = High pressure direct injection.

When excluding the HBE price system, fossil diesel becomes the cheapest option

- In the Dutch system fuel suppliers generate HBEs to compensate for the additional costs of renewable options.
- It is unclear how fuel suppliers use the HBE discount to market renewable fuels.
- In the previous graphs the overcompliance HBE price was substracted from the fuel costs of the renewable options.
- This graph shows that if the HBE prices are not included, fossil diesel is the cheapest option. This would render it difficult for fuel suppliers to comply with their yearly obligations.
- In other words, the HBE mechanism is found to be an effective market mechanism for equalising fossil fuel costs with renewable fuel costs.



CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI = High pressure direct injection.

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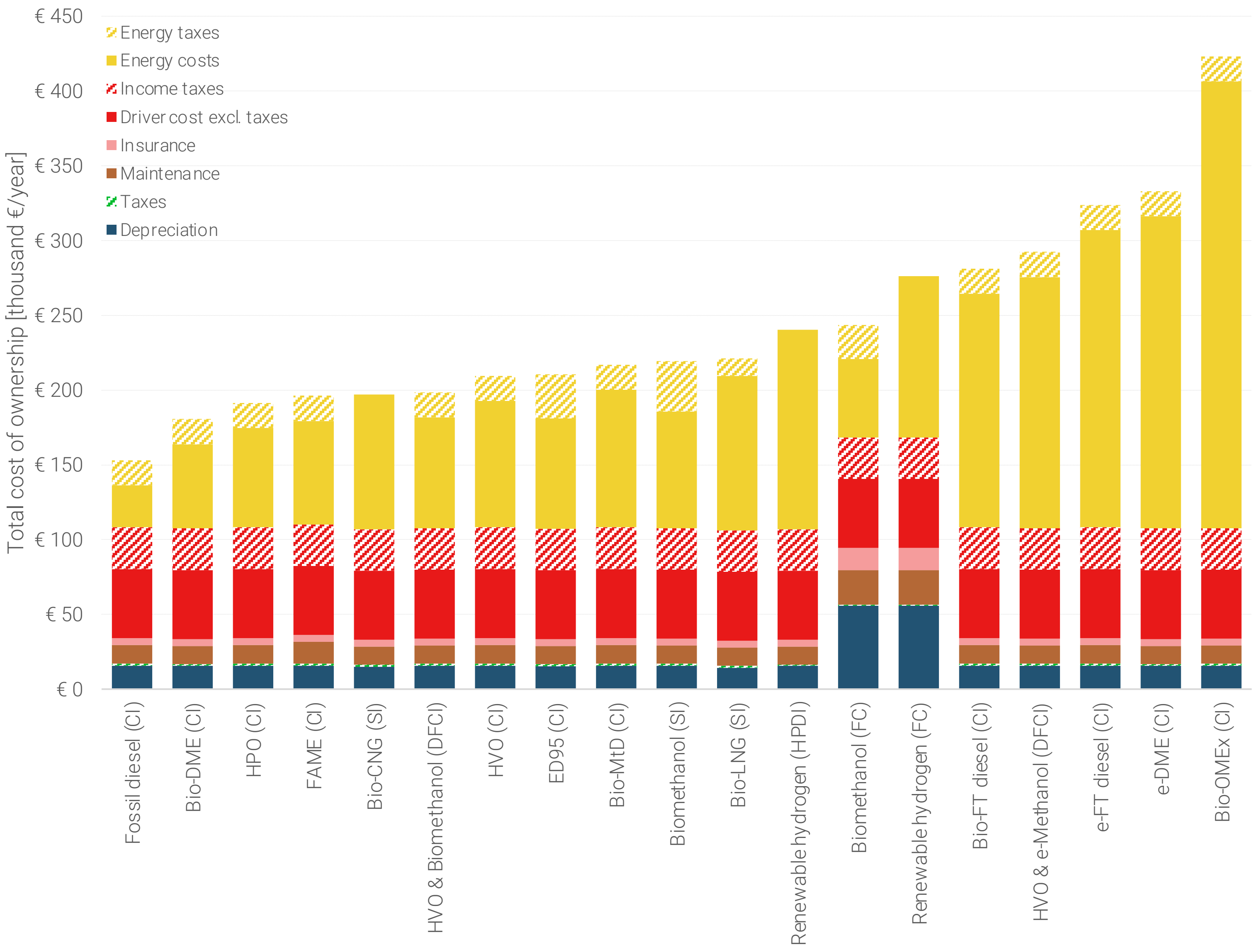
When excluding the HBE price system, fossil diesel is the cheapest option

- Fuel costs and taxes remain the cause of differences between the fuel/powertrain combinations (except for the fuel cells).
- Bio-DME remains in a relative good position compared to conventional diesel.
- The TCO of biomethanol in a spark-ignition is mainly influenced by the higher excise costs compared to other renewable options.

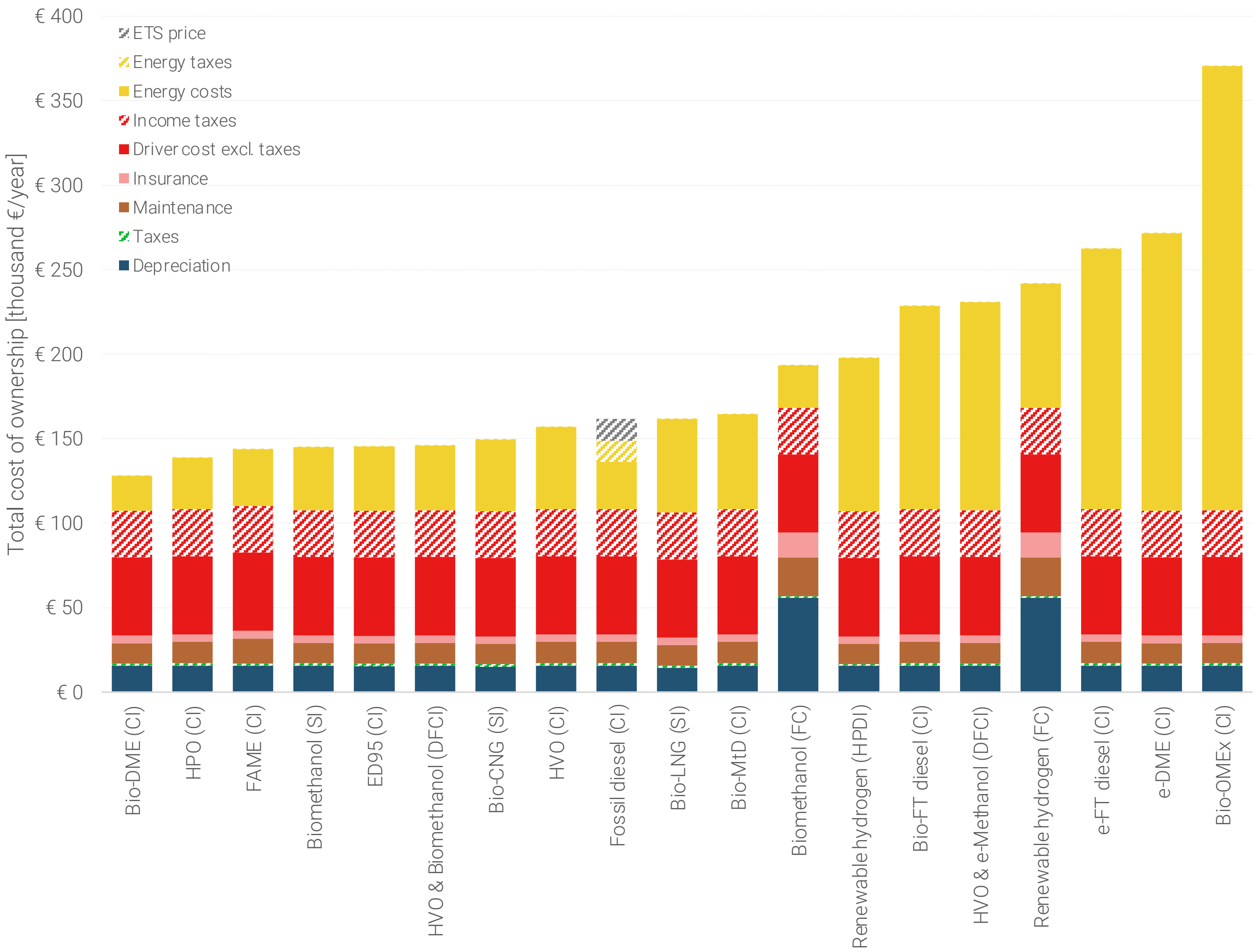


CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI = High pressure direct injection.

Impact ETS and ETD in 2033 (including HBE): even more renewable options could reach cost competitiveness

- The European Commission proposed an emission trading system (ETS) for the road sector together with the building sector. It is currently unknown how ETS prices might develop in the upcoming years. Here we have used an ETS price of 150 € could be lower or higher.
- It is also currently unclear how these directives will be implemented. The results show the impact of the proposed directives (changes can be announced in the near future).

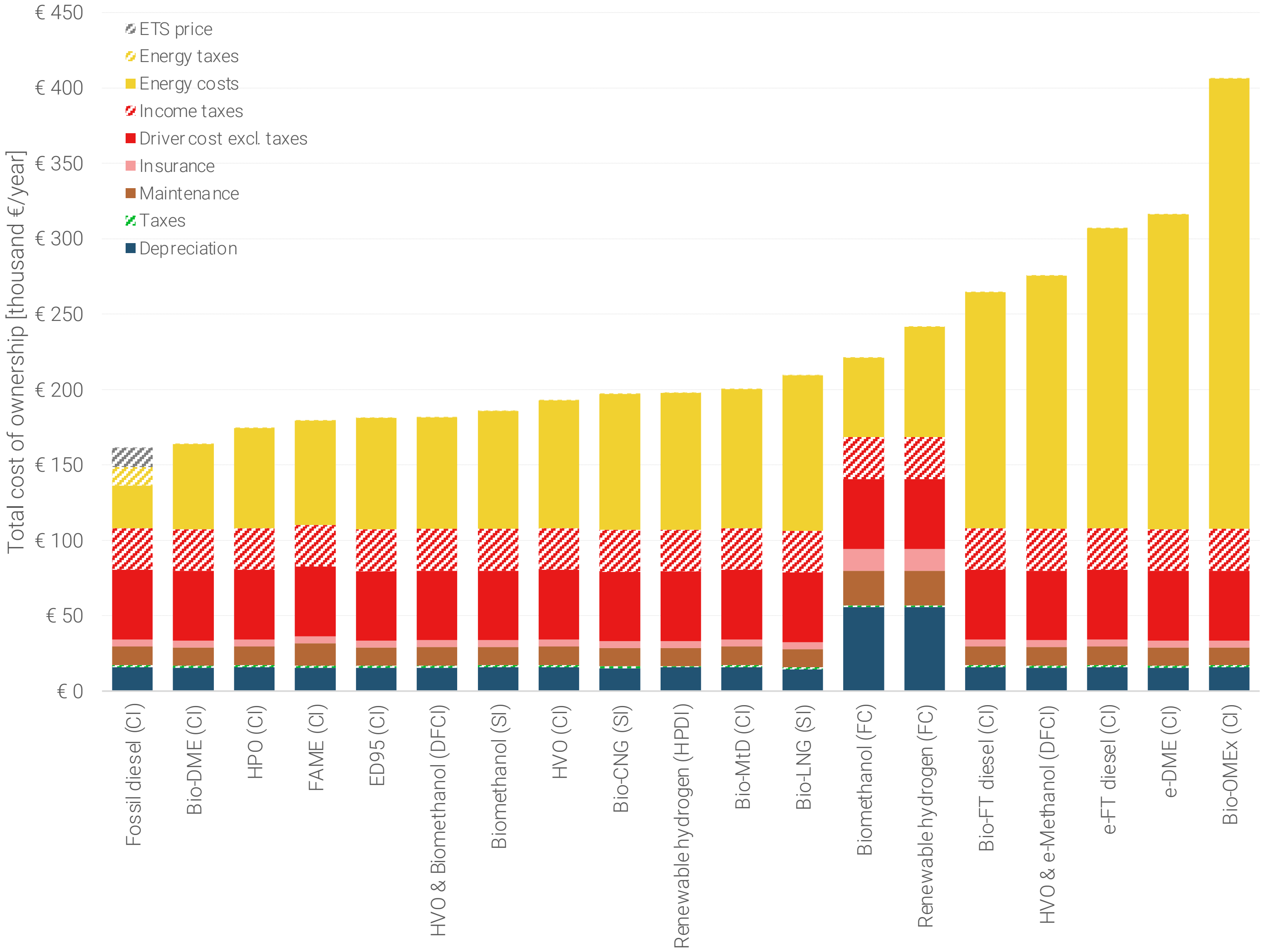
- The energy taxation directive (ETD) is expected to have a signifcant impact on the TCO of renewable options.
- Six more options have moved to the left side of the graph (HPO, FAME, bio-methanol in an SI, ED95, LNG, mix of HVO and bio-methanol in a DFCI and HVO) and show potential cost competitiveness with conventional diesel.
- Especially, the biomethanol option in a SI can benefit from these proposed directives.



CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI = High pressure direct injection.

Excluding HBE discount still shows the signficant impact of ETD and ETS in 2033

- In the previous graphs the HBE discount was substracted from the fuel costs of the renewable options.
- When exluding the HBE discount, ETD and ETS still bridge the gap from fossil to the first renewable fuel option (bio-DME).
- Also HPO, FAME, ED95 and biomethanol in a dual-fuel CI with HVO are in the close vicinity of the fossil fuel price.
- In general, the ETS and ETD are expected to provide fleet operators with more cost-competitive renewable options from 2030 onwards (with or without HBE discount). If! available in large supplies.,



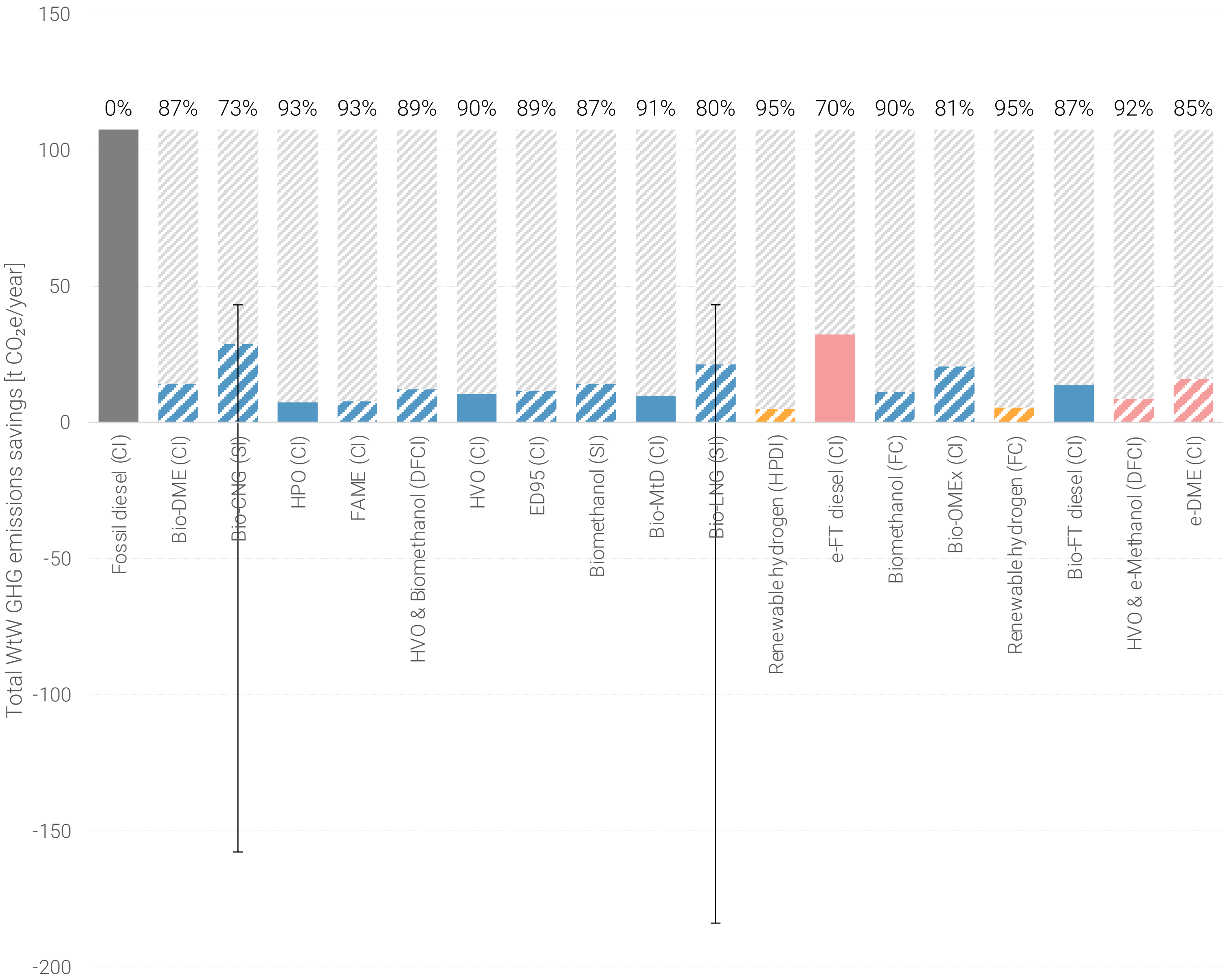
CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI = High pressure direct injection.

All renewable options achieve significant greenhouse gas reductions

- Previous graphs showed that there are multiple options available for fleet operators to move to more environmental friendly options, while not signficantly increasing their TCO.

- Here we see that all these options decrease GHG emissions drastically on a WtW basis.
- Renewable hydrogen reaches the highest GHG emission savings (95% compared to conventional diesel).

- Bio-CNG and bio-LNG are given a range of emission savings due to the feedstock determening the GHG savings signficantly, e.g. with a high share of manure negative emissions can be reached.



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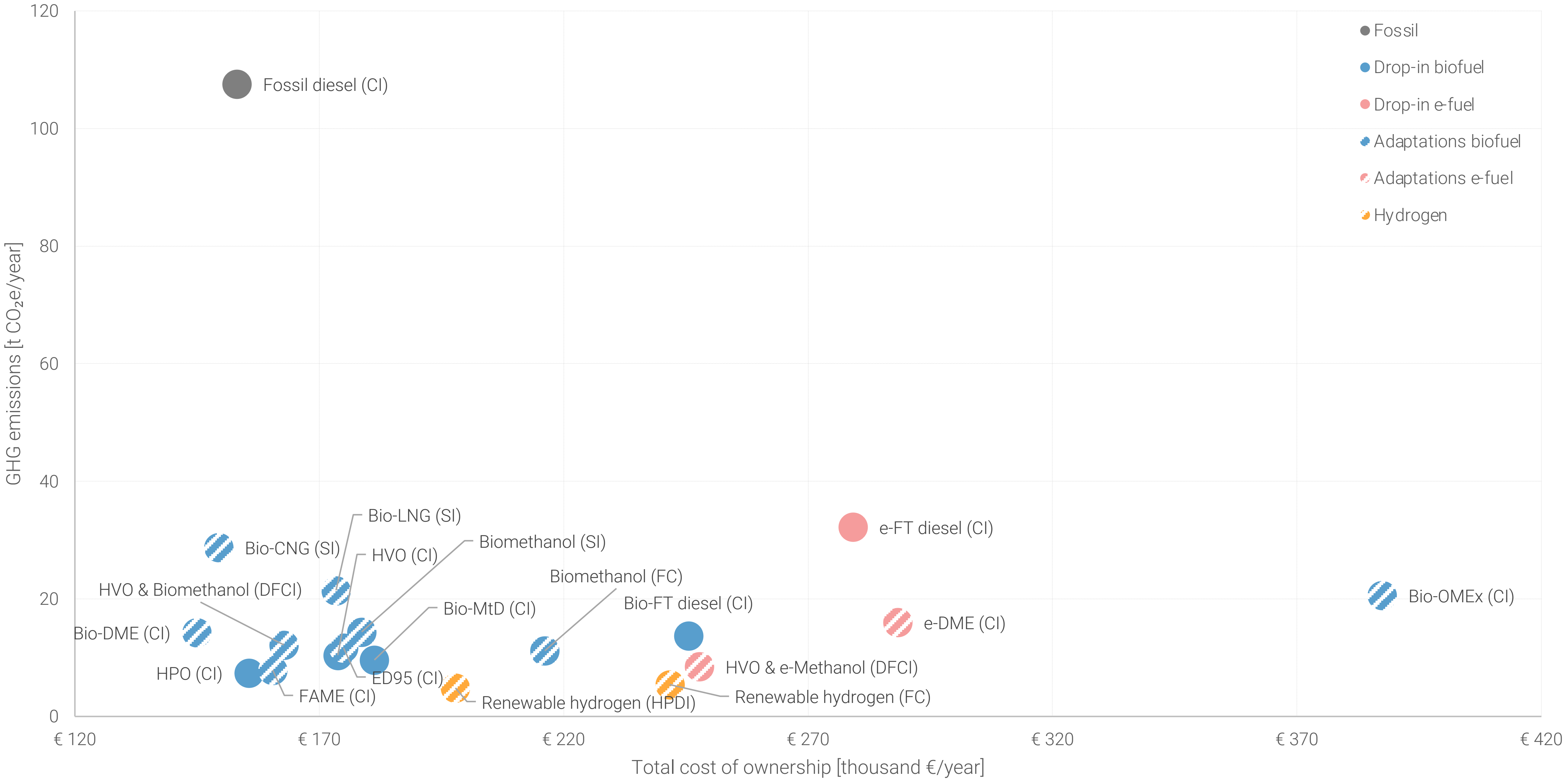
Biofuels show lowest abatement costs, renewable hydrogen could push down lifecycle GHG emissions even further (at a premium)



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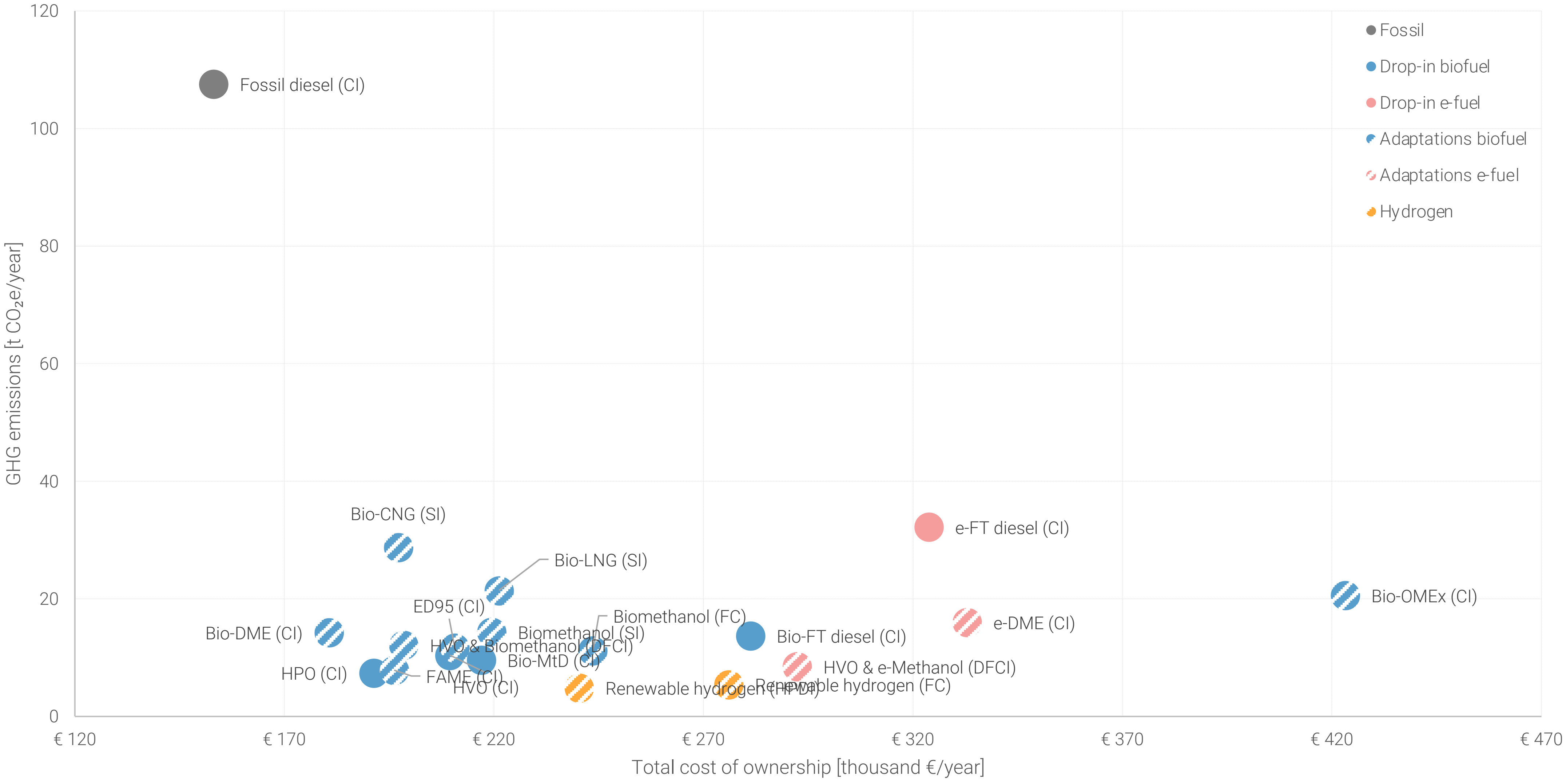
Even when the HBE discount is not given, many biofuel options remain interesting options for defossilising heavy-duty transport



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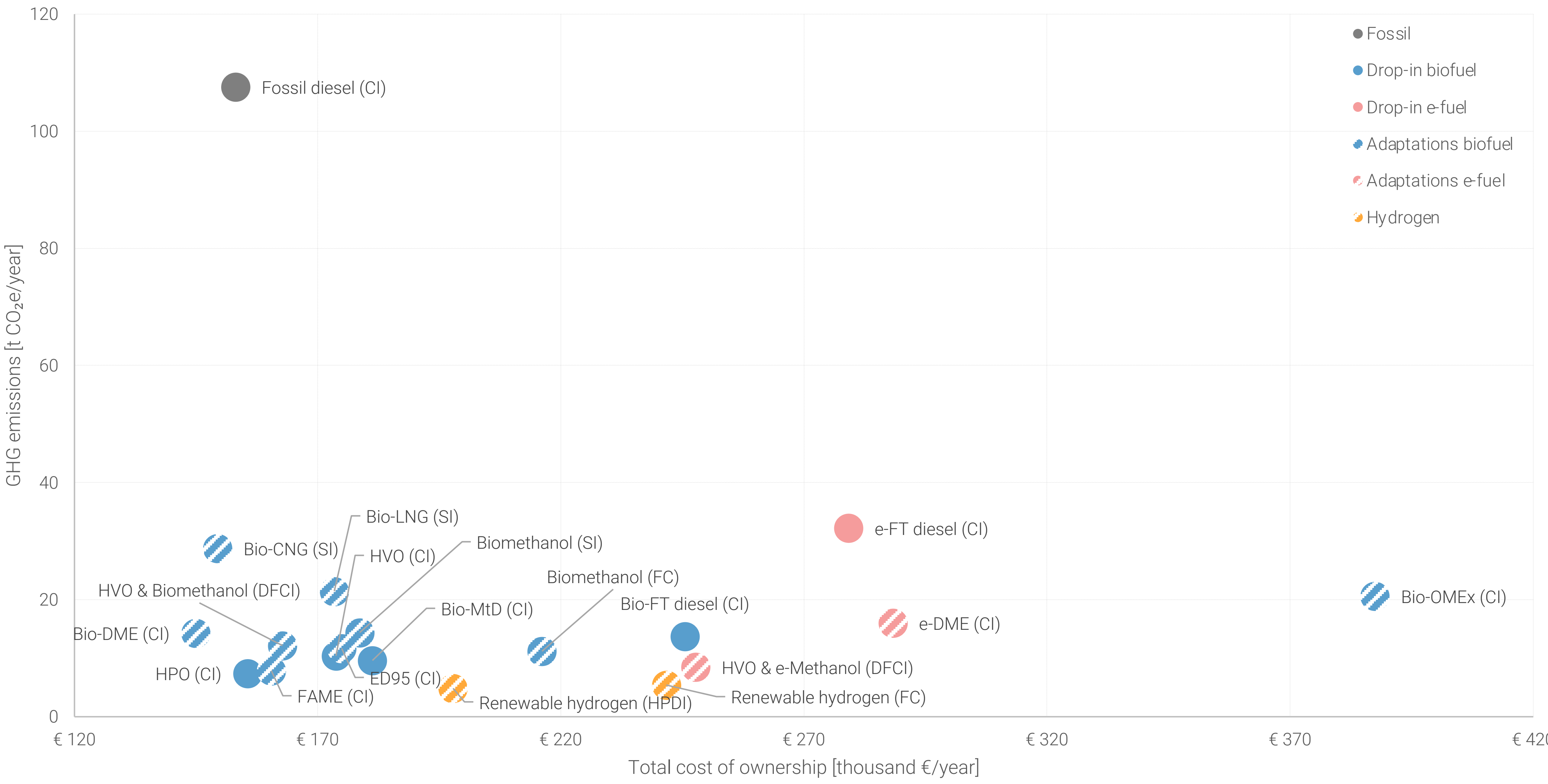
Potential portfolio to comply to the ETS and ETD



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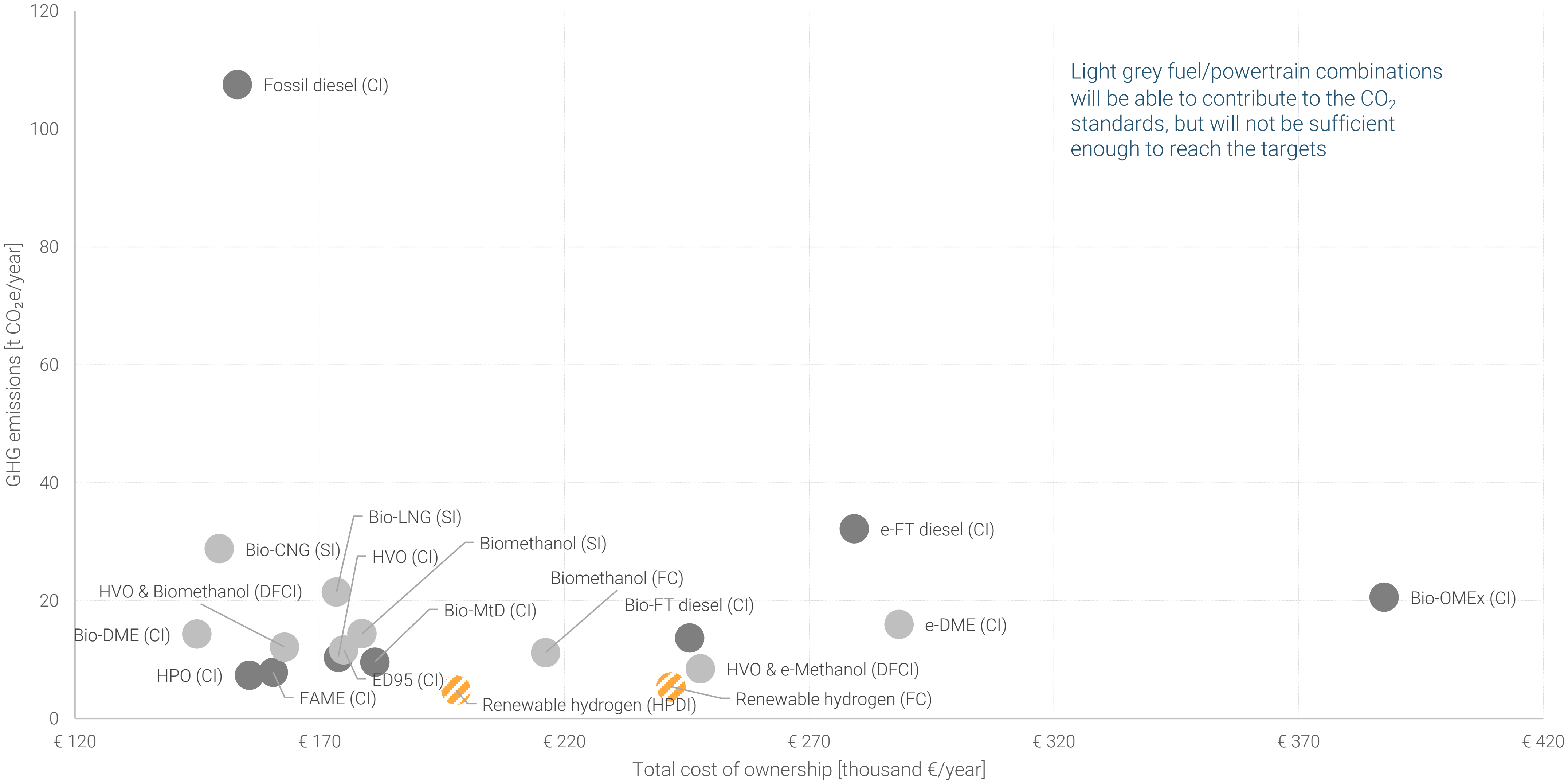
But, with the proposed CO_2 standards for heavy duty there might be a limited amount of renewable options available for fleet operators



CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI **= High pressure direct injection.**

Conclusions & recommendations 1/2

- Total cost of ownership results are built on many assumptions and outcomes are highly sensitive to market developments. The results are not fixed and can be influenced by policy makers, market developments etc.
  - The availability and scalability of these renewable options will be the most determining factor of their associated costs. This study has been done under the assumption that fuels and engines that are currently not yet marketed are available at similar volumes as their already marketed counterparts.
  - Secondly, not all powertrains are certified. This is a long and expensive process which OEMs do not usually bear solely for the Dutch market (as it is a relatively small market).

- This study does not conclude that there are renewable options lower in costs than conventional diesel, but this report aims to show that there are potential cost-effective options available in the current market and potentially even a wider portfolio of options in the (near) future. However, these options do require policy support to ensure availability and scalability of the fuel and the certification of the powertrains.
- Currently, most of the options close to conventional diesel are biobased options. These options are closer to technological maturity. For RFNBOs (e-fuels and hydrogen) this learning curve will continue and fuel prices might drop in the future. It is essential to keep supporting these options through policies, but we cannot expect them to be economically competitive in the near future. Support for the biobased options is needed to provide the heavy-duty segment with alternative options to reduce CO_2 emissions now.

- This report also shows that adaptations are not a major driver of the total cost of ownership. Mainly, the fuel prices determine the total cost of ownership.
- In general, the fuel/powertrain combination suitable for operations is determined by the use profile of the fleet operator, distance driven etc.

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Conclusions & recommendations 2/2

- Support a system providing a wide portfolio of renewable fuel options options for the heavy duty segment
  - The current proposed CO_2 emission standards (TtW focus) will leave the market with limited options that are still early in their technological development. These novel options still have high associated costs. It is recommended to move to a WtW approach providing the heavy-duty segment with high GHG savings with a potential limited impact on the associated costs. Including renewable fuels could support the Truck OEMs to reach the targets of the CO2 standards in a cost-effective way
  - With the upcoming ETS and the potential financial burden it brings to fleet operators we cannot wait for options with zero TtW emissions. This requires additional policy support for the biobased options and e-fuels to provide the market with renewable options to comply with the ETS.
  - This will leave room for technological improvements and decreasing costs for hydrogen and e-fuels.

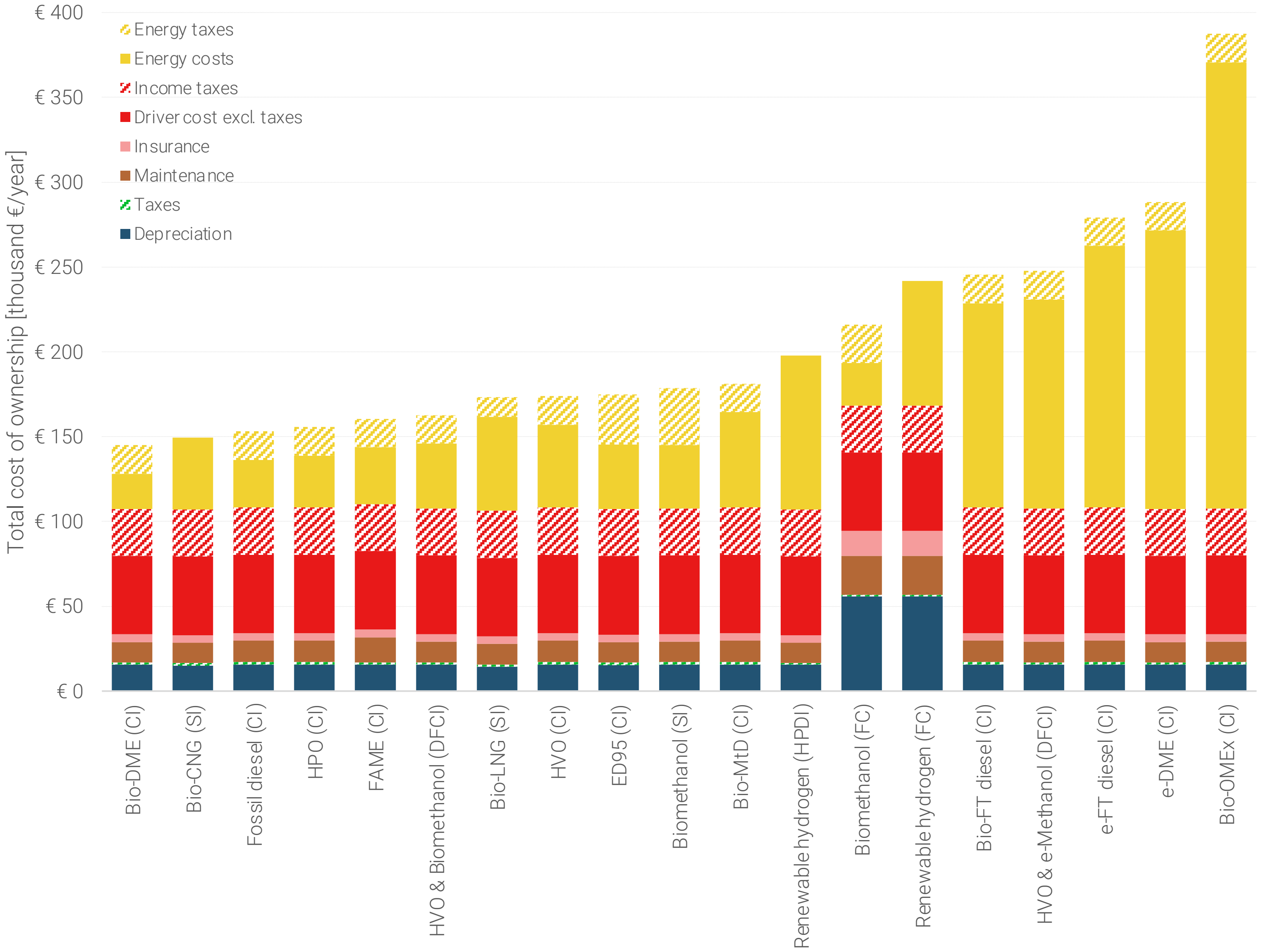
- All options will need support to provide tailormade solutions for truck operators
  - Starting with (drop-in) biobased options will lead to emission reductions now, rather than waiting for technological improvements and cost decreases. These are also options that require limited fuel certification, limited adaptations in the way of operating that end-users can take control over themselves.
  - Furthermore, policy support of the biobased technological pathways could benefit the e-fuel technological counterpart.
  - Supporting renewable fuels not yet on the market lead to a wider portfolio in the future. Making the adoption of GHG abatement options in the heavy duty segment easier, as it improves the ability to have fuel/powertrain combinations suitable for different use cases.
  - The upcoming Energy Taxation Directive (ETD) can provide this support by lowering taxation signficantly for renewable options.

Content Annex

- Detailed graph mixed options
- General assumptions
- Calculation method HBE discount and Annex IXA premium
- Energy inflation assumption
- Methodology CAPEX
- Powertrain efficiency
- Main sources

Potential portfolio of options (drop-ins or adaptations) available to reduce emissions without significantly increasing TCO

- Multiple options (requiring adaptations or drop-ins) show a potential to reduce emissions without significantly increasing the TCO
- Five options show strong cost competitiveness with conventional diesel under current assumptions
- Of which three requiring adaptions DME, CNG in a spark-ignition and FAME
- And one drop-in: HPO



CI = Compression ignition, SI = Spark ignition, DFCI = Dual fuel compression ignition HPDI **= High pressure direct injection.**

General assumptions

- Ownership period: 7 years [Panteia TCO]
- Depreciation over 7 years:* 77% [Panteia TCO]
- Annual mileage: 100,000 km [Panteia TCO]

- Maintenance:
  - Combustion engine trucks: 8 €ct/km [Panteia TCO] (except FAME: 10 €ct/km, based on assumption)
  - Fuel cell trucks: 19 €ct/km [Panteia TCO]
- Tyres (all trucks): 4 €ct/km [Panteia TCO]

- Registration tax for all trucks: 53 €/truck [ACEA Tax Guide 2021]
- Zware Motorrijtuigenbelasting: 750 €/truck/year [ACEA Tax Guide 2021]
- Motorrijtuigenbelasting: 632 €/truck/year (Fuel cell and Hydrogen trucks exempt) [ACEA Tax Guide 2021]
- Insurance: 3.2% of truck purchase cost per year [Panteia TCO]
- ETS price 150 €/ton CO_2 [Assumption]
- ETD price 0.15 €/GJ [Energy Taxation Directive]
- Fuel consumption diesel Euro VI truck 31.8 l/km [Panteia TCO]

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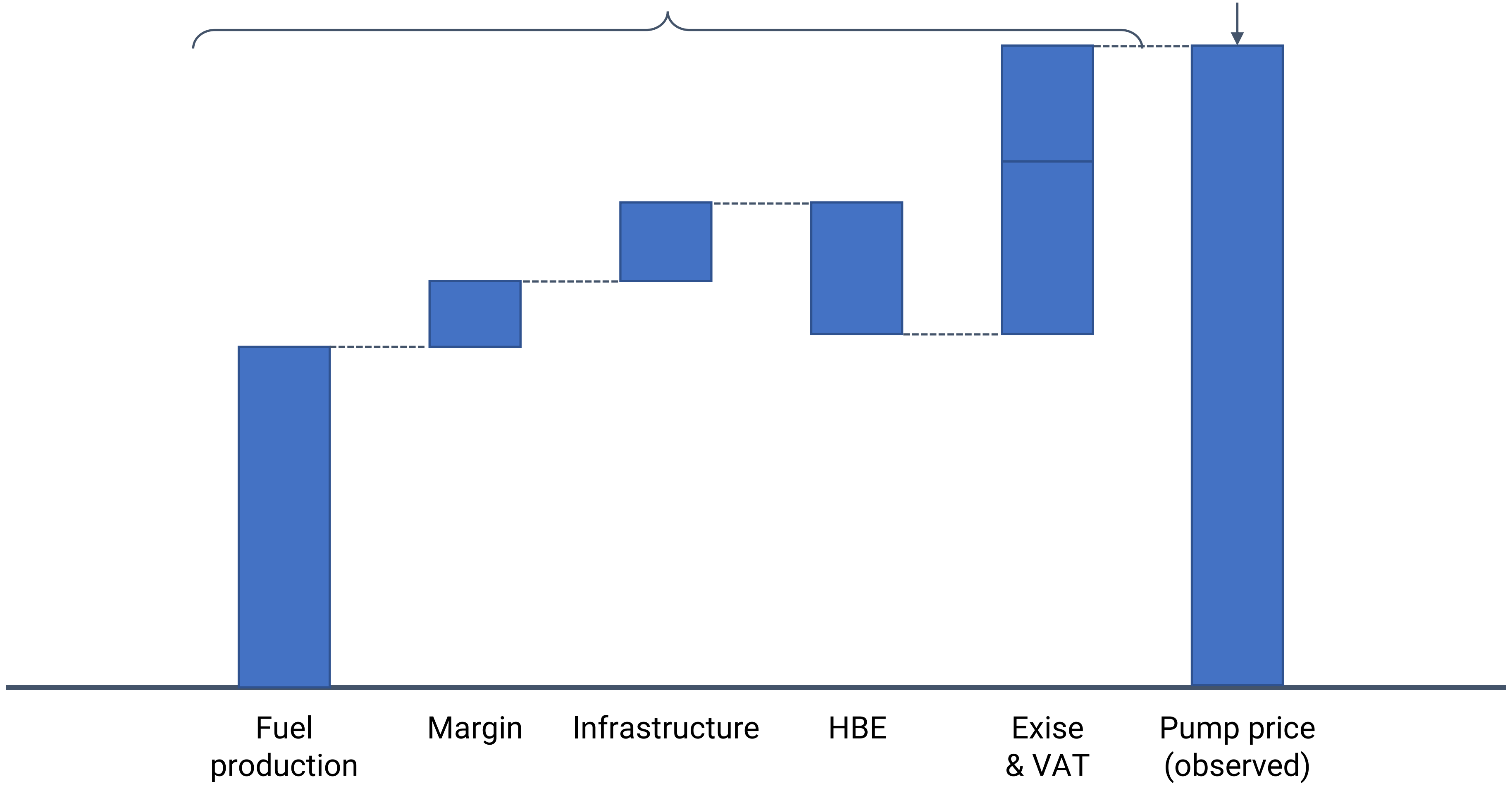
* Note that vehicles with strong and unpopular adaptations may depreciate stronger than conventional trucks. Nevertheless, even when assuming 100% depreciation, the impact was found to be small in comparison to the fuel costs over the ownership period of 7 years, and therefore does not significantly change the results or conclusions.

The cost for fuels in TCO calculations is the observed fuel price at the pump

In case of fuels that are not yet commercially available, the pump price is calculated from the production costs, margin, costs for infrastructure, HBE revenue, and taxes

If the fuel is already sold in the Netherlands, the observed pump price is used for TCO calculations



Prices of fuels (HBE impact and Annex IXA premium)

HBE price

- HBE price assumed is 19 euro/GJ, based on three sources in the fuels and HBE market:
  - HBE price during 2021 H2 ranged between 16.00 and 20.50 euro/GJ, with average of 18 Euro/GJ [information from trader]
  - End of december 2020, the HBE price was 19.50 euro/GJ [information from trader]
  - March 2022, the price of HBE is about 19 euro/GJ [information from fuel company]

Cost of fossil diesel

- Fossil diesel price at pump = 1.5464 Euro/l, including excise duty but excluding VAT [price in period 21-23 February 2022]
- This already includes costs to fulfil the obligation in the Netherlands
- This translates to a price of 28 euro/GJ before excise and VAT, including the effect of the obligation
- The obligation of 17.9% in 2022 [Besluit energie vervoer 3.1.a] implies that every GJ contains 0.179 GJ renewable fuel
- The cost of this is (maximally) equal to the cost of a single counting HBE, or 0.179 x 19 Euro/GJ = 3.4 Euro/GJ
- The cost of fossil diesel before tax and before complying with the obligation = 28 – 3.4 Euro/GJ = 24.6 euro/GJ

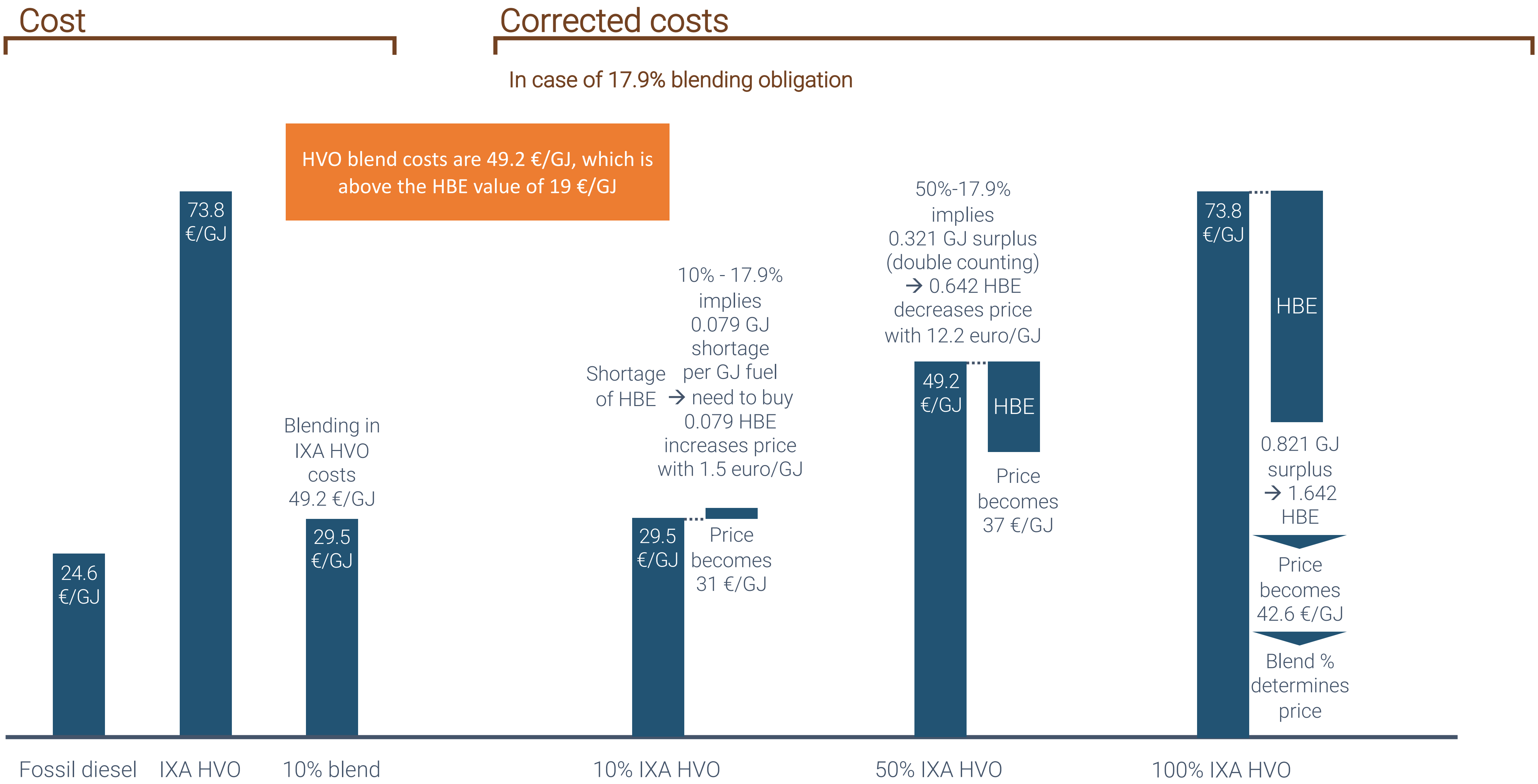
Cost of double counting Annex IXA type HVO

- The price of Annex IX B type HVO at pump = 1.7678 euro/l, including excise, excluding VAT [Fieten Olie website, 21 February 2022]
- The price of Annex IX A type HVO is typically 300 US$/tonne above that of Annex IX B type HVO [information from user]
- This translates to an Annex IX A HVO price of 73.8 euro/GJ excluding excise and VAT (also applied for FAME)
- The HVO pump price takes into account revenues from HBE surplus
- A 100% HVO has a surplus of 100 - 17.9 = 82.1%, which is double counting, so every GJ HVO generates 1.642 HBE
- This translates to an Annex IX A HVO price of 42.6 euro/GJ excluding excise and VAT, and before HBE revenues

:7

HBE impact depends on blend obligation *and* proximity HBE to additional costs

If the additional cost of a fuel are *above* the HBE value, higher blends *increase* the price (& higher blend obligation decreases the HBE returns and thus increases the price)



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Energy inflation assumption

- Recent commodity price insights of biofuels suggest that also all renewable options are affected by recent surges in energy prices

- Therefore, for all data that was **not** found for 2022, an “energy inflation factor” was applied. This harmonises recent price data with mid-recent data that is already outdated:
    - For prices from early-to-mid 2021, this factor was 160% [Calculated with F.O Licht data]
    - For prices from 2020, this factor was 174% [Calculated with F.O Licht data]
    - For prices from 2019, this factor was 200% [Calculated with F.O Licht data]

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Methodology – CAPEX

- Vehicle purchase cost were found from various literature sources and verified with experts from the consortium and industry

- The typical economic ownership period of a new truck was found to be about 7 years in Northwest Europe. This ownership period was assumed for all trucks. Similarly, 100,000 km/a was found to be a typical annual mileage for freight trucks, although this value can be higher or lower dependent on the location and application [Panteia TCO].

- The **depreciation** was taken from the Panteia model. It is 77% over 7 years, meaning that the truck has 23% of its initial purchase value left after 7 years.*

- Depreciation and adaptation costs together form the Capital Expenditures (CAPEX).

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* Note that vehicles with strong and unpopular adaptations may depreciate stronger than conventional trucks. Nevertheless, even when assuming 100% depreciation, the impact was found to be small in comparison to the fuel costs over the ownership period of 7 years, and therefore does not significantly change the results or conclusions.

Methodology – CAPEX

- **Adaptations and retrofit costs** were found in literature. They were verified, supplemented and complete via interviews with experts in industry and academia. They were assumed to be 0 € for all drop-in options as well as for specialised trucks that are already bought for a specific alternative fuel (e.g. LNG trucks), since the vehicle adaptation is already included in the purchase costs.

Adaptation category	Fuels	Range of adaptation costs [€]
No adaptations required	Drop-in biobased and e-fuels	0€
Light adaptation	FAME,OMEx, DME, ED95 and methanol in a DFCI	1,000 – 10,000 €
Heavy adaptation	LNG, CNG and hydrogen	20,000 – 45,000 €

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Methodology – Driver costs, Insurance, Maintenance, Taxes

- Total **driver costs** were taken from the Panteia model. To better understand the division in salary and income tax, income taxes were calculated via a generic brutto-net income calculator for the Netherlands.

- **Insurance** is a highly varying parameter that depends on the insurance provider, location / region, size of the company, transported goods, history of accidents etc. Generally, the insurance costs are dependent on the monetary value of the insured good. In accordance with the Panteia model, an annual insurance cost of 3.2% of the initial purchase cost of the truck was assumed.

- **Maintenance** was derived from the Panteia model, expressed in ct.€/km for conventional (CI) trucks, battery-electric trucks and fuel cell trucks. It was assumed that all combustion engine trucks have similar maintenance costs to the conventional (CI) truck. In addition, it was assumed that methanol fuel cell trucks have the same maintenance requirements as hydrogen fuel cell trucks. Furthermore, all fossil diesel and drop-in diesel trucks were subject to about 0.55 €/km costs of AdBlue consumption. The dual-fuel configurations with methanol and diesel (substitutes) were assumed to still consume 0.11 €/km AdBlue. FAME was assumed to consume more AdBlue and has 0.69 €/km AdBlue costs.

- **Taxes** are composed of vehicle registration tax, zware motorrijtuigenbelasting (heavy vehicle tax) and general motorrijtuigenbelasting. These were all determined by the latest version of the ACEA Tax Guide for the Netherlands. A typical 40 tonne freight truck for international, long-haul transport with air suspension was assumed. Fuel cell, battery-electric and hydrogen-combusting trucks count as zero-emission vehicles that are exempt from the general Motorrijtuigenbelasting

Powertrain efficiencies

- The efficiencies of the powertrain are here defined as power output (in mechanical power onto the axes) divided by power input by fuel consumption.

- For all fuels, the efficiencies of their powertrains are considered constant. Differences in fuel consumption within one group of powertrains are thus entirely based on the differences in heating values of these fuels.

- The gas engine (for bio-CNG and bio-LNG) is an exception to this rule, as data in literature suggested that the real-life efficiency is about 5 percent-points below the efficiency of a regular spark-ignition engine.

- The efficiency of the HPDI is only applicable for hydrogen and was given by a market player. The spark-ignition was given by the consortium of academia. The efficiency of the fuel cell was retrieved from Öko-institut. Other efficiencies were taken from the Panteia Model.

Powertrain	Energy efficiency [%]
Compression-ignition engine	40%
Spark-ignition engine	35%
Fuel cell	52%
High pressure direct injection engine	42%
Dual fuel compression-ignition engine	40%

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Main references

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- ACEA Tax Guide 2021
- F.O. Licht (2019-2022). Price and production costs ethanol & FAME.
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