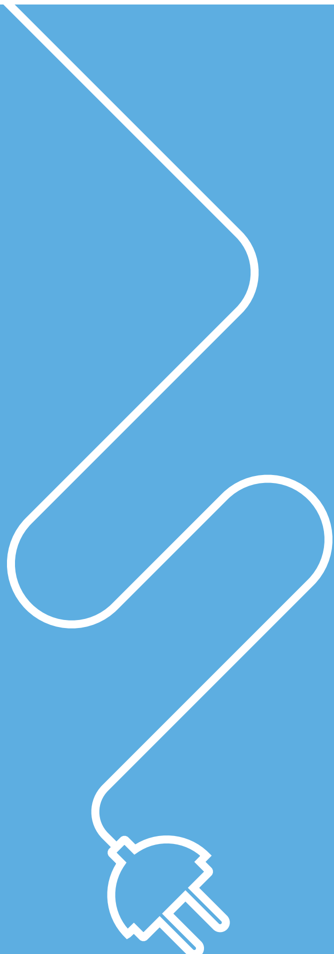
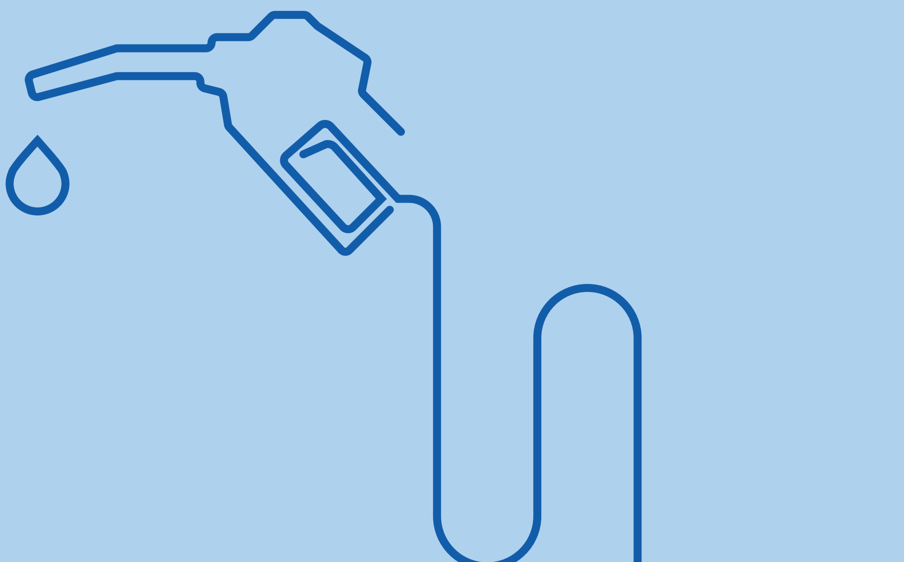


Key findings

A COMPARISON OF MASS ELECTRIC VEHICLES ADOPTION AND LOW-CARBON INTENSITY FUELS SCENARIOS

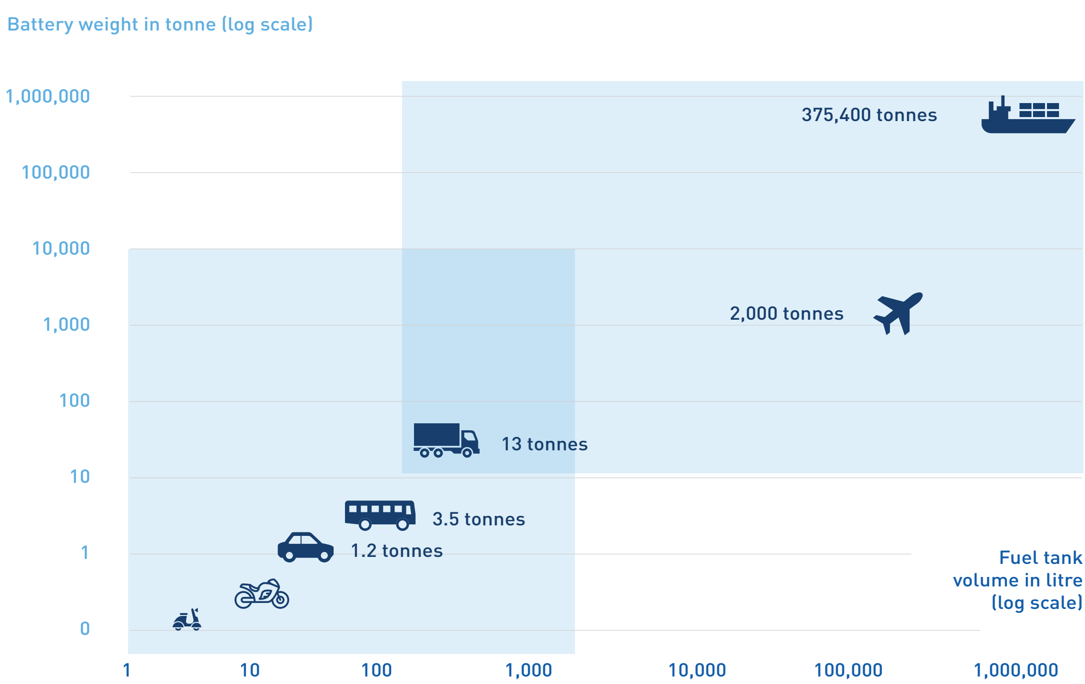


FuelsEurope
REFINING PRODUCTS FOR OUR EVERYDAY LIFE

There is a widespread view that all of light road transport, and much of other transport sectors, should be electrified in order to meet the European Union's (EU) climate objectives. But there is also a growing awareness that such electrification will be challenging, and that there is no single solution to build a low-carbon transport system.

Concawe[1] asked Ricardo[2] to carry out an extensive study to examine a scenario for near-complete electrification of cars and light commercial vehicles on the road in the EU by 2050 ("Full Electrification scenario"), with quantification of GHG reductions, total costs of ownership and infrastructure, battery materials and power requirements. And in addition, to evaluate in the same way a scenario with a combination of electrification and low-carbon liquid fuels into very efficient internal combustion engine (ICE)-based vehicles ("Low-Carbon Liquid Fuels scenario"). This in-depth study sets out the challenges and opportunities associated with such a range of alternative options.

LIMITED ELECTRIFICATION BEYOND THE BUS AND LIGHT TRUCK SEGMENT



It is widely accepted that low-carbon liquid fuels will be essential in the long-term for sectors that have limitations in using electricity directly, such as long distance heavy road transport, aviation, maritime, and petrochemicals. The Ricardo study in light road transport allows to compare "apples with apples", and also to explore how a combination of technologies could mitigate some of the biggest challenges of full electrification of light transport.

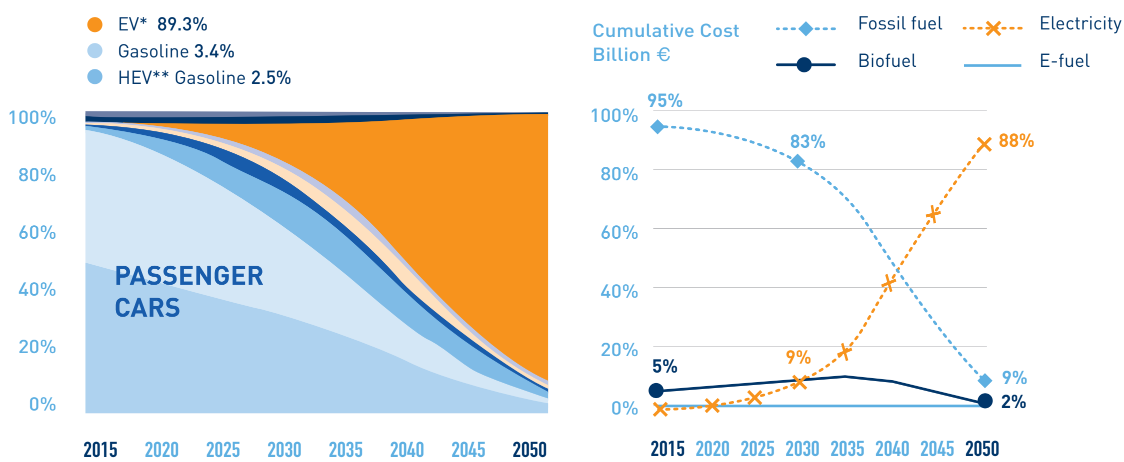
[1] The refining industry's scientific and technical body.

[2] Global strategic engineering and environmental consultancy that specialises in the transport, energy and scarce resources sectors.

1. Highlights of Full Electrification scenario

The High EV scenario in the study shows that full electrification of transport for passenger cars and light-duty vans in 2050 should reach 90% of the vehicle parc, on the basis of 100% registration of battery-electric vehicles from 2040 onward.

VEHICLE PARC IN THE HIGH EV SCENARIO

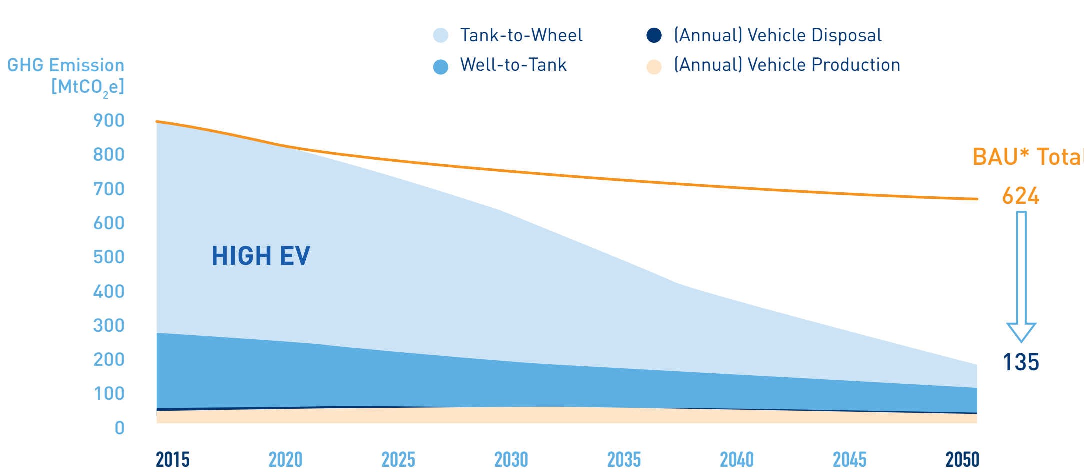


Source: Ricardo Energy & Environment SULTAN modelling and Analysis

*EV: Electric Vehicles, **HEV: Hybrid Electric Vehicles

The energy mix in this scenario shows a rapid decline in fossil fuel from 2030, a rapid rise in electricity use, and an end to biofuel use by 2050.

LIFE-CYCLE GHG EMISSIONS IN THE HIGH EV SCENARIO



Source: Ricardo Energy & Environment SULTAN modelling and Analysis

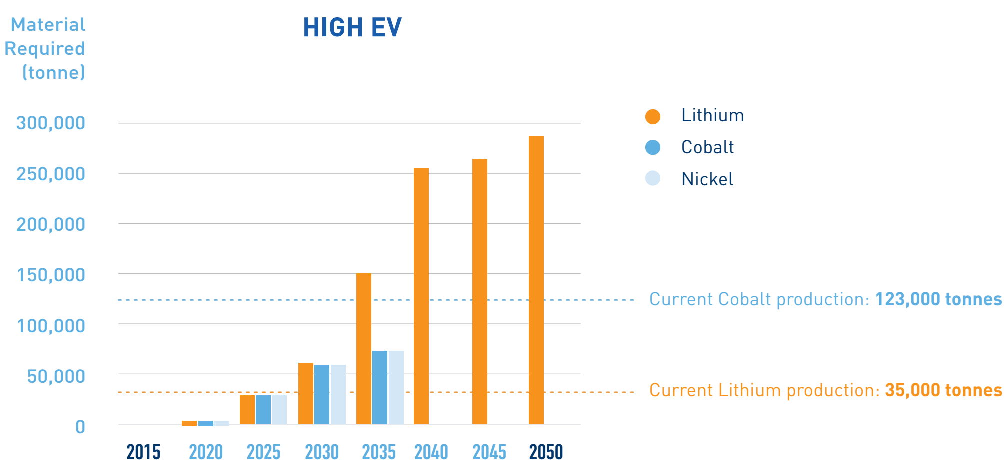
*Business-As-Usual

Whilst this scenario is expected to achieve by 2050 a reduction up to 87% of the 2015 GHG life-cycle emissions levels, the Full Electrification scenario entails a number of challenges:

- An estimated investment in EV charging and network infrastructure **between €630 billion and €830 billion to 2050.**
- Electricity demand for charging EVs is equal to 17,5% of the overall EU's 2015 electricity generation.
- Addressing **the annual loss of €66 billion in fiscal revenue** from fuel sales.
- The construction of **15 giga-factories to supply batteries** to the European EV market (550TWh).
- The installation of **increased peak power of 115GWh** (15% of current installed peak power generation) to meet electricity demand.
- Resources requirements for cobalt, nickel and lithium would increase very substantially over the period to 2050, posing a potential availability risk and creating a new import dependency of the EU.

Given that the majority of lithium and cobalt is located in a few countries, there is furthermore a potential risk for prices and security of supply.

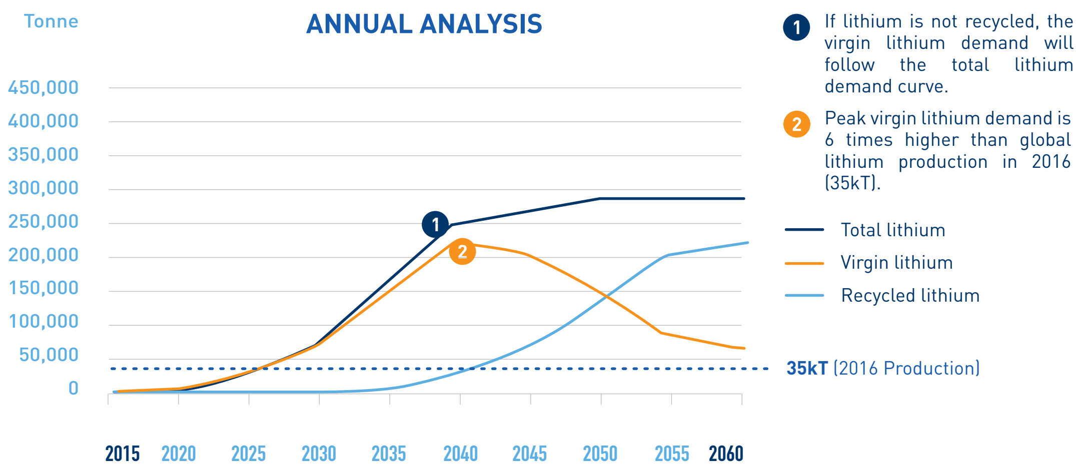
KEY BATTERY MATERIALS ANNUAL DEMAND IN THE HIGH EV SCENARIO



Source: Ricardo Energy & Environment SULTAN modelling and Analysis

For example, **increased lithium extraction** just for the full electrification of the European cars and vans, is **estimated at 6 times the 2016 worldwide lithium production**.

LITHIUM MATERIAL ANNUAL ANALYSIS IN THE HIGH EV SCENARIO



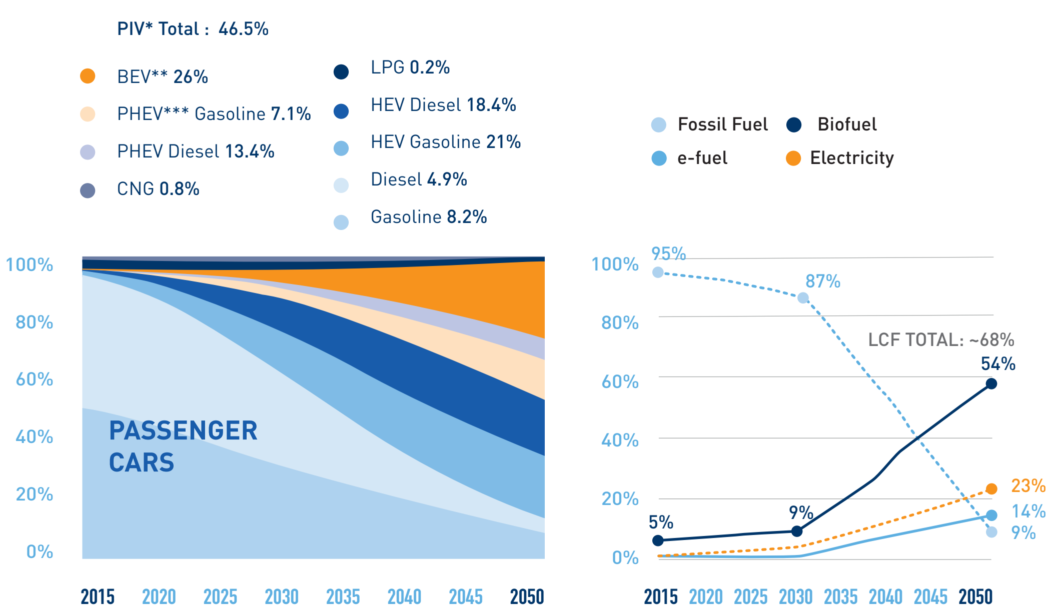
Source: Ricardo Energy & Environment SULTAN modelling and Analysis

Construction of an **equally large battery recycling industry** will be needed, with unknown power requirements and environmental impact.

2. Highlights of Low-Carbon Liquid Fuels scenario

The Low-Carbon Liquid Fuels scenario assumes that in 2050 the vehicle parc will consist of very efficient ICE vehicles, with a high penetration of low-carbon fuels (68%) complemented by 23% electricity and a minor quota of fossil fuels.

VEHICLE PARC IN THE LOW-CARBON LIQUID FUELS SCENARIO



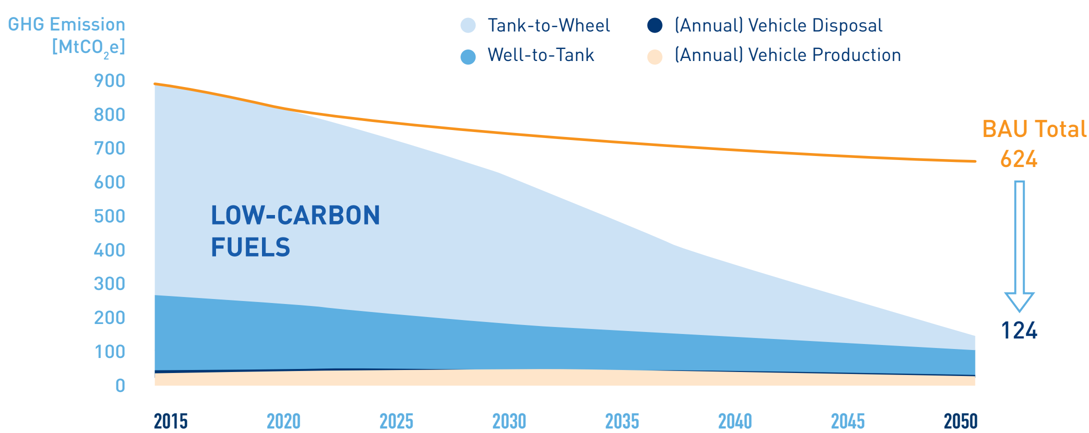
Source: Ricardo Energy & Environment SULTAN modelling and Analysis

*PIV: Plug-in Vehicle, **BEV: Battery Electric Vehicle, ***PHEV: Plug-in Hybrid Electric Vehicle

The energy mix in the Low-Carbon Liquid Fuels scenario shows a similar use from 2050, a steady rise in electricity use and a similar rise in biofuels and e-fuels.

It is expected that this scenario will reduce, by 2050, the 2015 life-cycle GHG emissions' level by 87 %, equivalent to the Full Electrification scenario.

LIFE-CYCLE GHG EMISSIONS IN THE LOW-CARBON FUELS SCENARIO



Source: Ricardo Energy & Environment SULTAN modelling and Analysis

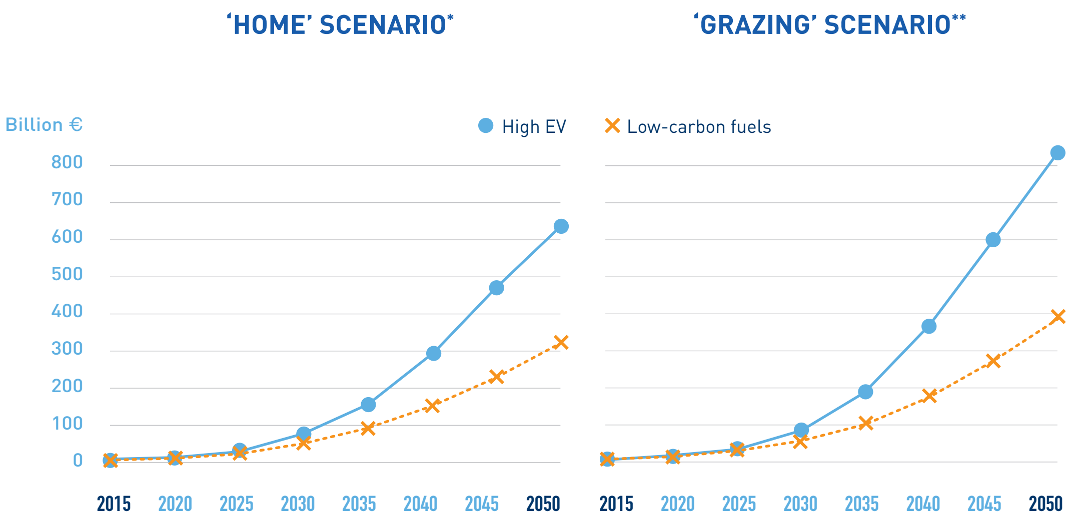
The Low-Carbon Liquid Fuels scenario can offer benefits such as:

- A sustainable alternative for other transport segments such as aviation, marine and heavy-duty road transport.
- The opportunity to supply the ICE-based existing light-duty fleet as these low-carbon fuels appear on the market, thereby enabling a wider GHG reduction compared to the progressive fleet renewal scenario.
- Requiring significantly lower infrastructure investments, since only 50% of the recharging capacity of the High EV scenario will be needed (**€326 to 390 billion**).
- Only requiring half of the peak power generation compared to the High EV scenario.
- Only requiring 5 or 6 giga-factories for battery production and significantly limiting demand for raw materials to less than half of the High EV scenario requirements.

The Low-Carbon Liquid Fuels scenario estimates that the amount of required biofuels for light transport is around 35% of today's (petrol and diesel) fuel volumes. This results from the significant efficiency gains of the ICE, reducing the total volumetric demand by 60% compared to today's volumes[3].

[3] In the Full Electrification scenario, no further development of the ICE powertrain is assumed beyond 2025, as carmakers would be expected to invest solely in electrification technologies.

COMPARISON OF CUMULATIVE ELECTRIC CHARGING AND NETWORK INFRASTRUCTURE COST



Source: Ricardo Energy & Environment SULTAN modelling and Analysis

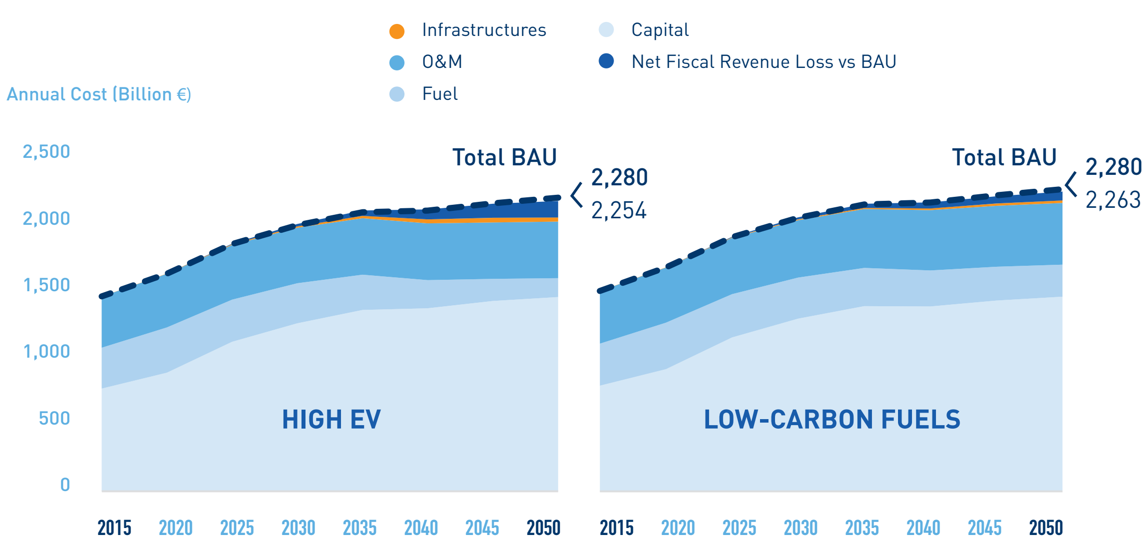
* In the "home" recharging scenario EV users charge mainly using off-street home or on-street residential recharging infrastructure.

** In the "grazing" recharging scenario, it is assumed that EV users charge little and often, mainly using charging points away from the home.

3. Total annual costs of both scenarios

The study shows that, contrary to conclusions from recent studies, the total parc annual costs of vehicles under the High EV scenario or under the Low-Carbon Liquid Fuels scenario is likely to be very similar with no competitive advantage for the EV vs the ICE:

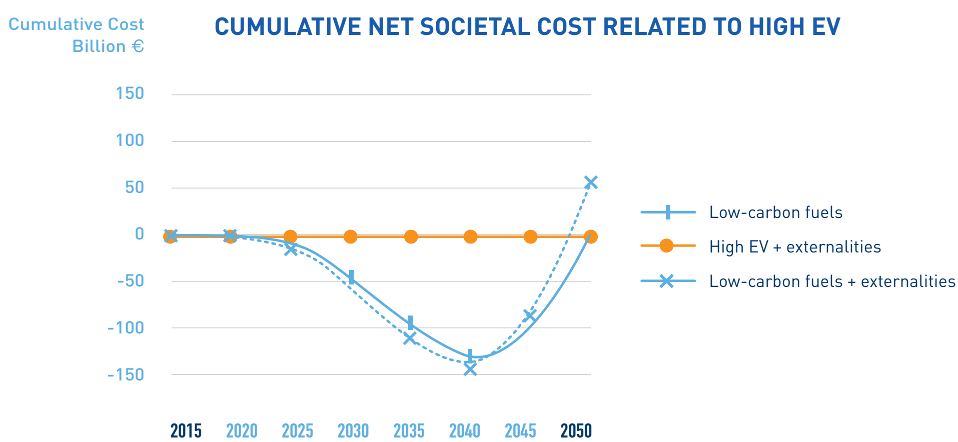
TOTAL PARC ANNUAL COSTS TO END-USER FOR ALL LIGHT DUTY VEHICLES



Source: Ricardo Energy & Environment SULTAN modelling and Analysis

Ricardo also assessed the cost of each scenario after inclusion of externalities[4]. From the graph we can see that externalities related to the Low-Carbon Liquid Fuels scenario are similar to the full electrification scenario, represented as the reference scenario in this comparison.

CUMULATIVE NET SOCIETAL COST (RELATED TO HIGH EV)



Source: Ricardo Energy & Environment SULTAN modelling and Analysis

4. Conclusion

- Low-carbon liquid fuels offer **a sustainable alternative to full electrification of light duty vehicles, and an attractive solution for other transport segments** such as aviation, marine and heavy-duty road transport.
- Low-carbon liquid fuels offer the **opportunity to be supplied to the entire existing fleet** as they appear on the market and by doing so, enable a wider GHG reduction compared to the gradual penetration of EVs.
- The vision of significant **deployment of low-carbon liquid fuels** is very ambitious but expert work shows it **is achievable and very beneficial**.
- The vision for full electrification is also very ambitious and has **major challenges, plus significant uncertainties on the key assumptions, which need to be addressed**.
- The technologies for the production of low-carbon liquid fuels are as essential as electrification, and deserve a **similarly strong policy support** – they need to be part of the Vision for 2050 of the EU, Member States, industry, their investors and customers.
- **Both sets of technologies are complementary and require the adoption of policies based on a neutral approach to technology support: this will lead to the best choices and decisions for the future of the EU**.

[4] External costs (or 'externalities') are the monetary value attached to the impacts of GHG, air quality pollutant emissions and other impacts such as noise and congestion due to indirect effects, for example on public health and other elements.