Impact Analysis of Mass EV Adoption and Low Carbon Intensity Fuels Scenarios

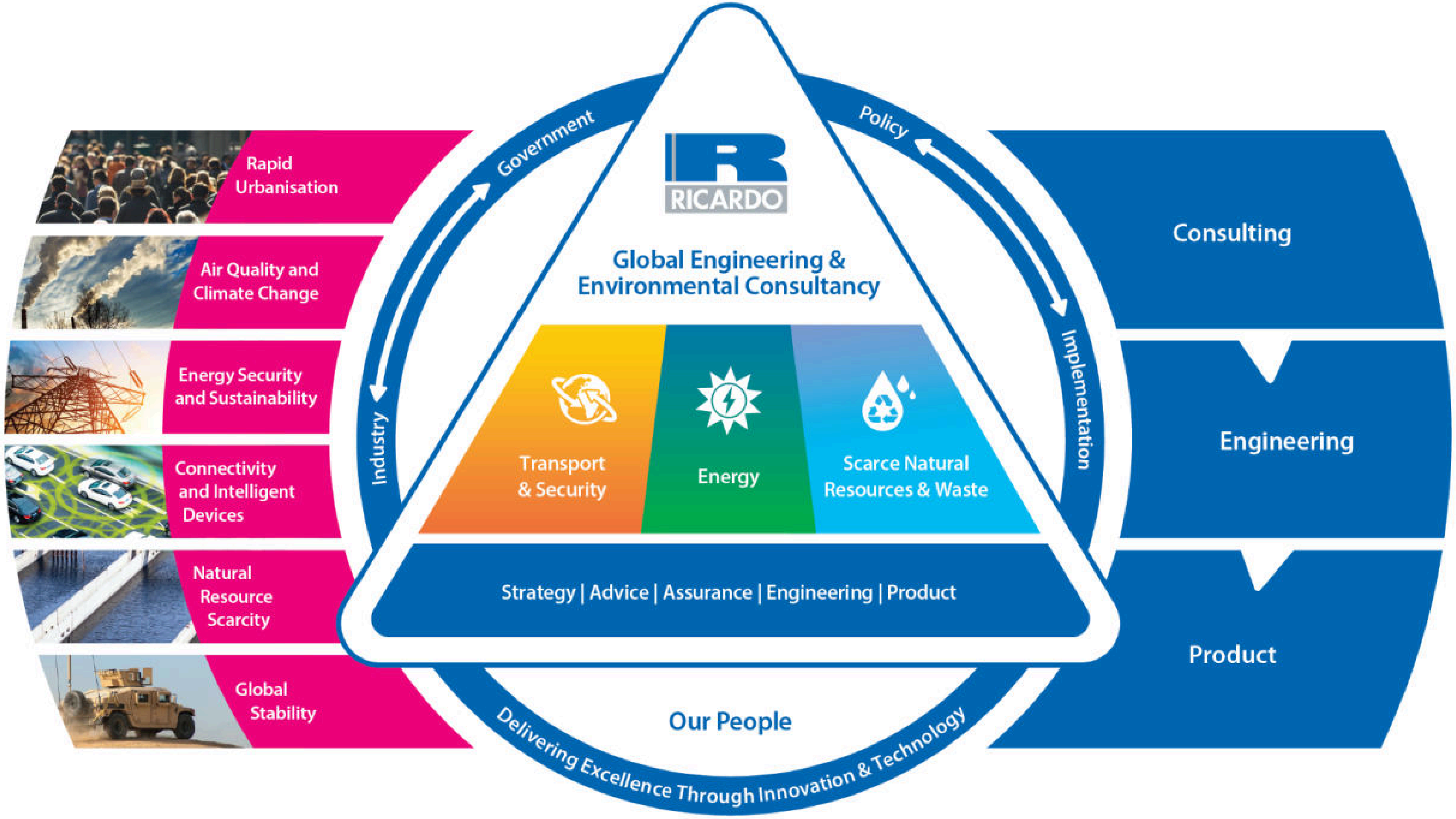
By Nikolas Hill and Nick Powell, Ricardo

Ricardo
Energy & Environment

Ricardo is a Global Engineering & Environmental Consultancy with over 3000 employees: engineers, scientists and consultants in all major regions

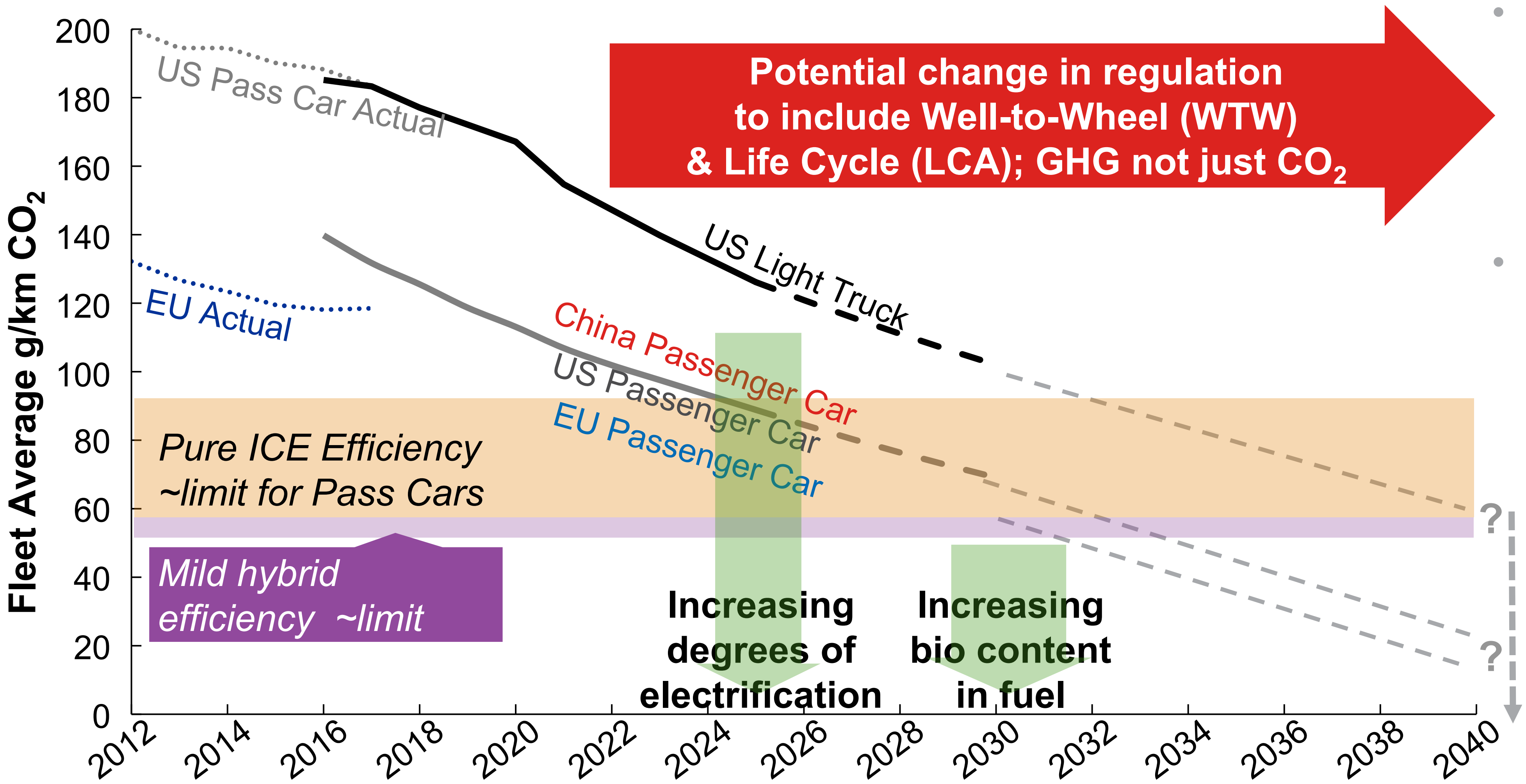
Sectors

- Automotive
- Commercial Vehicles
- Defence
- Energy & Environment
- Motorsport
- Motorcycle
- Off-Highway Vehicles
- Rail



Due to Energy/Climate challenge vehicle GHG reductions beyond 2025 are required – Only real options are low carbon electricity or lower carbon fuels

EU, US and China LD legislated and expected GHG average fleet trajectories



- Policymakers increasingly focused on "Zero" emissions for road transport
- Reducing carbon intensity in other sectors perceived to be more difficult

Source: Ricardo Analysis and Ricardo Vehicle Simulation, EEA (80), EPA (81) | All EU CO_2 results are reported as NEDC equivalent although CO_2 vehicle tests are RDE and WLTC since 2017

The impact of two scenarios: ‘High EV Adoption’ & ‘Low Carbon Fuels’ on GHG emissions, infrastructure, costs & resources are compared

- Concawe commissioned Ricardo to conduct research and provide analysis of the wider potential implications of high EV uptake and alternative scenarios

High EV Scenario

Low Carbon Fuels Scenario

CO_2

1. What are the Greenhouse Gas (GHG) emissions, including life cycle emissions?

2. What are the implications for energy supply and electricity infrastructure?

3. What are the cost implications?

4. What are the implications on materials and natural resources?

Note: * The scenarios consider the European light duty vehicle fleet only. L-category vehicles, buses, and medium and heavy duty trucks have not been included in the analysis
Low Carbon Fuels include biofuels and eFuels generated from renewable energy sources

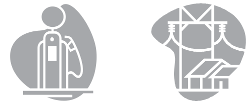
The analysis considered the whole life of the vehicle, Well-to-Wheel (WTW) fuel production and use and embedded GHG emissions

RICARDO

Vehicle Life Cycle

Well-to-Wheel (WTW) Analysis - Life Cycle Assessment of the fuel or electricity used to power the vehicle

Vehicle cycle "Embedded" emissions result from from vehicle production; fluid, filter and component replacement during life; and end-of-life activities. A **"cradle-to-gate"** LCA study may only consider vehicle or component production



Fuel & Electricity Production

Assessment of (WTT) environmental impact of producing the energy vector(s) from primary energy source to point of distribution (e.g. refuelling station)

Study Boundary:

Analysis of the **whole vehicle life lifecycle** included embedded emissions from vehicle production, maintenance and servicing, and end-of-life activities, and WTW (WTT+TTW) emissions from production and use of the fuel / energy in operating the vehicle

Vehicle Production

Assessment of **'Cradle-to-Gate'** environmental impact of producing the vehicle including extract of raw materials, processing, component manufacture, logistics, vehicle assembly and painting

Use/Operation

- Environmental impact of driving (TTW emissions)
- Impact from maintenance and servicing

End-of-Life

Adds assessment of environmental impact of "end of life" scenario (i.e. -to-Grave). Can include: **re-using** or **re-purposing** components, **recycling** materials, energy recovery, and disposal to landfill

Quantitative analysis of impacts was conducted using SULTAN model with defined inputs, and post-processing of the results

RICARDO

Overview of the SULTAN* modelling analysis

Input Data / Pre-processing → **Scenario Modelling Calculations** → **Output Data / Post-processing**

Input Data / Pre-processing

Activity by mode

Vehicle Energy Consumption [MJ/km]
- By mode, model year, powertrain type *

Vehicle stock
- Fleet # projection by mode
- Survival rates
- % share of new vehicles by powertrain *

GHG Emission Factors [CO_2e/MJ]
- By fuel / energy carrier **
- TTW and WTW

AQP Emission Factors
- By mode fuel / powertrain
- Direct emission factors for NOx, SOx, PM

Cost Data
- Fuel costs (excl./incl. tax) **
- Capital costs by powertrain
- O&M costs

Scenario Modelling Calculations

SULTAN Scenario Database and Calculation Engine

↓

Results Database and SULTAN Results Viewer

Notes:
* Key input variable, set by the scenarios developed for this study
** Input variable to sensitivity scenarios for this study, e.g. electricity CO_2e/kWh, energy prices, etc.
*** Input data for calculations informed by Literature Review and Deep Dive analysis

Output Data / Post-processing

SULTAN Outputs
- Fleet numbers / mix by powertrain
- Energy consumption by fuel
- TTW, WTW, AQP emissions
- Energy Security metrics
- Economic outputs (social, end-user)
  - TCO: Capital, Fuel and O&M costs
  - Net fiscal revenue impact
  - External costs of emissions
  - Cumulative costs

Vehicle numbers by powertrain

↓

Additional Post-Processing ***
- GHG emissions from vehicle production and disposal
- Alternative fuel infrastructure requirements (# by type, share of energy cons., costs)
- Resource requirements

↓

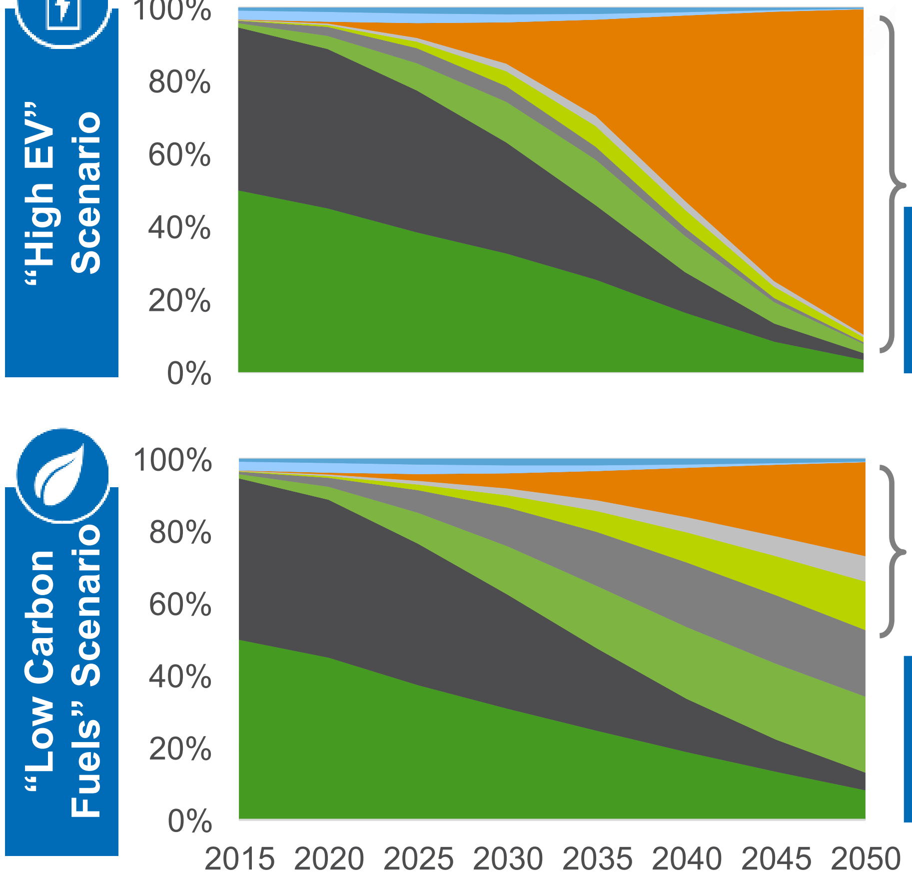
Additional Final Results, e.g.
- Total life cycle GHG emissions
- Total costs including infrastructure

Source: Ricardo Energy & Environment. * SULTAN is a Ricardo tool developed for the European Commission as a transport policy modelling tool, with the ability to evaluate the medium- and long-term (to 2050) impacts of new vehicle technologies

Two contrasting scenario options : What if all cars were electric? What if the share of Low Carbon Fuels was significantly increased?

- Both scenarios were scoped to deliver Tank-to-Wheel (TTW) GHG savings of 90 percent compared with 1990 figures

EU Passenger Car Vehicle Parc

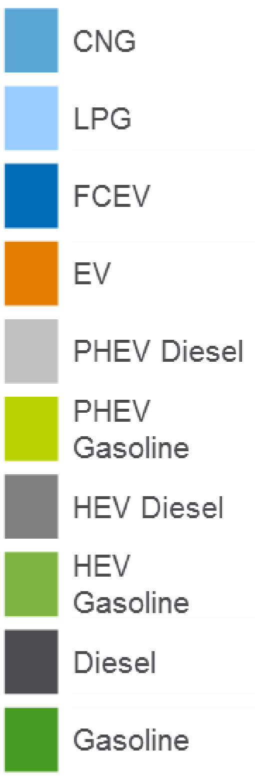


Plug-in Share: 91.3 %

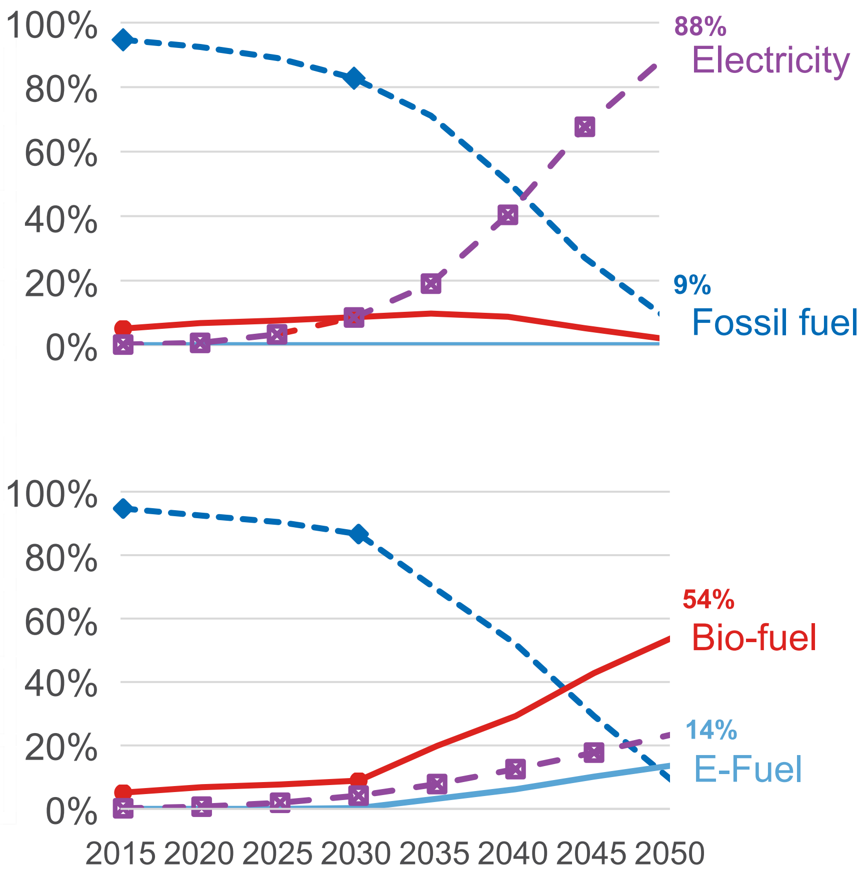
88% of energy from Electricity in 2050

Plug-in Share: 46.5 %

68% of energy from Low Carbon Fuels in 2050

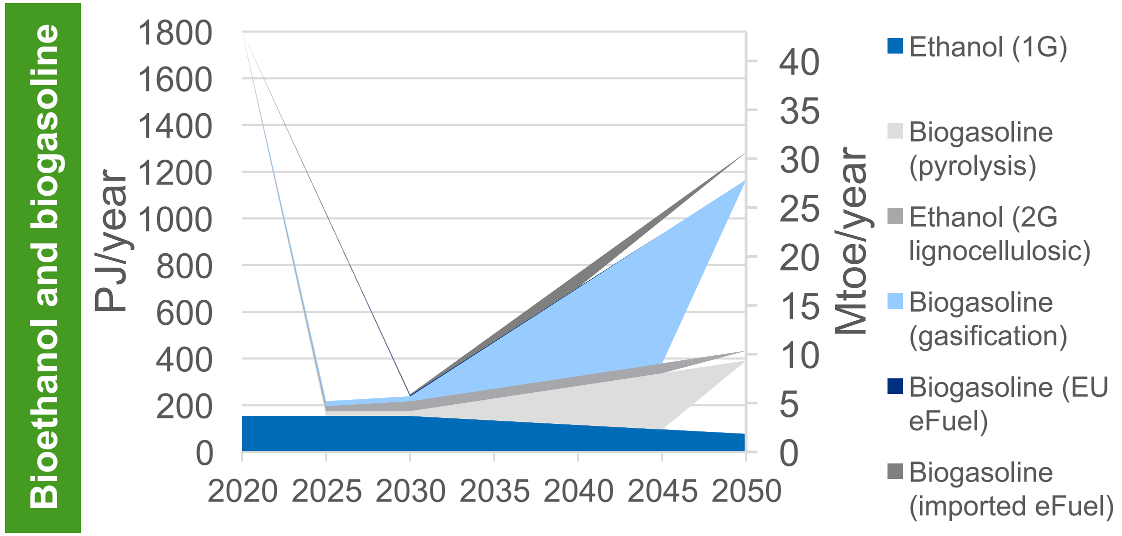


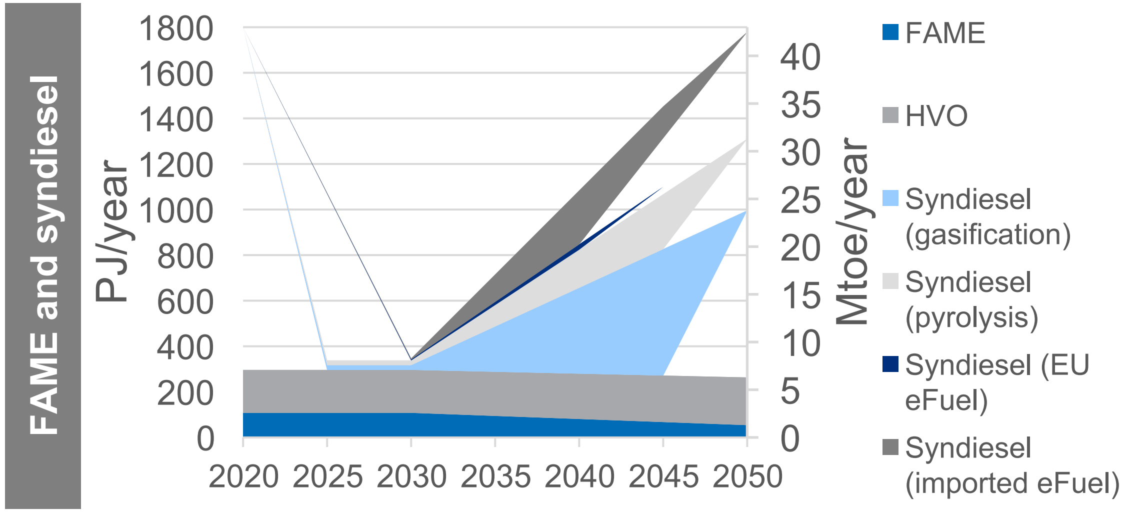
EU % Fuel Share by Energy Type



Note: New registrations & vehicle parc profiles calibrated to data and projections from European Commission modelling -Impact Analysis of Mass EV Adoption and Low Carbon Intensity Fuels Scenarios, Ricardo report for CONCAWE August 2018, https://www.concawe.eu/publications

The energy available from biofuels and eFuels for European light duty vehicles has been estimated from other research sources





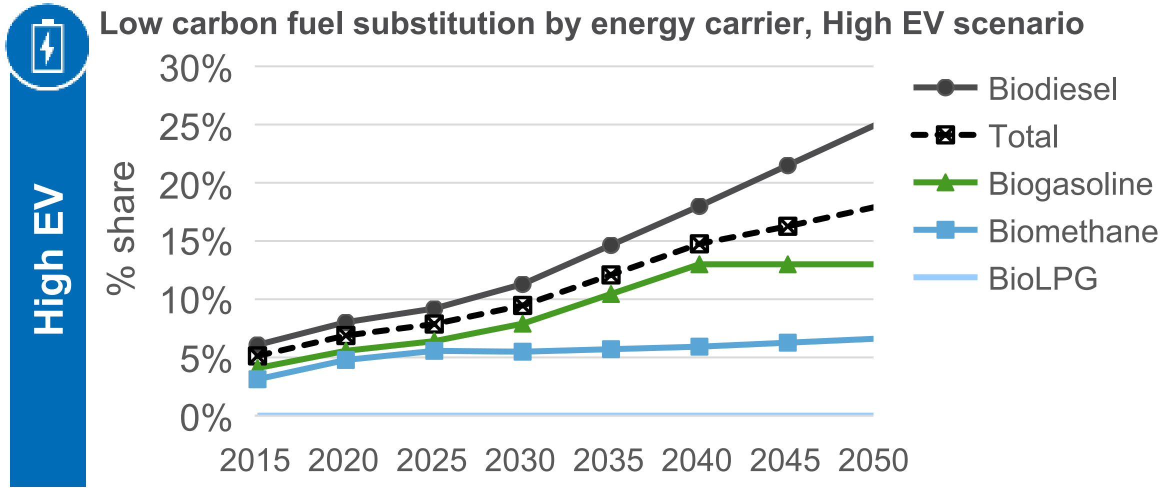
- Availability of Low Carbon Fuel is intended to reflect scenario where the whole biomass supply chain is optimised to maximise use of bioenergy
- Quantities available to LDVs allow for similar substitution levels in other road transport (e.g. HDVs)
- Use in other transport modes is not considered explicitly

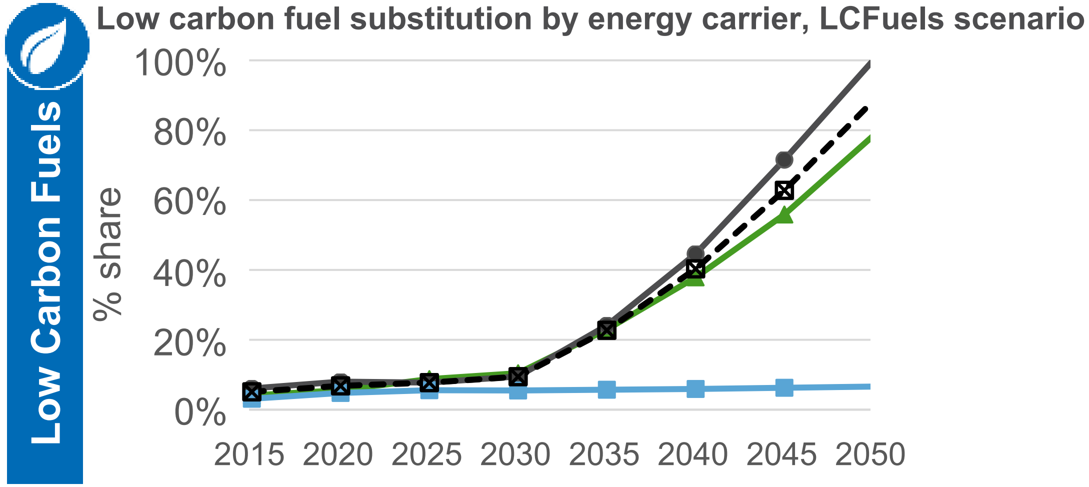
Source: Directorate-General for Research and Innovation (European Commission), "Research and innovation perspective of the mid-and long-term potential for advanced biofuels in Europe," 2018;
K. Sub Group on Advanced Biofuels Sustainable Transport Forum, Maniatis, I. Landälv, L. Waldheim, E. Van Den Heuvel, and S. Kalligeros, "Final Report, Building Up the Future," 2017;
dena (German Energy Agency), "«E-FUELS» STUDY - The potential of electricity-based fuels for low-emission transport in the EU - VDA," 2017;
H. D. C. Hamje et al., "EU renewable energy targets in 2020: Revised analysis of scenarios for transport fuels."

Both scenarios feature substitution of conventional liquid fuels by biofuels, with a higher share in the Low Carbon Fuels scenario

The total volume of bio-fuels is within that assumed to be available for LDVs

European scenarios for biofuel and other low carbon fuel uptake



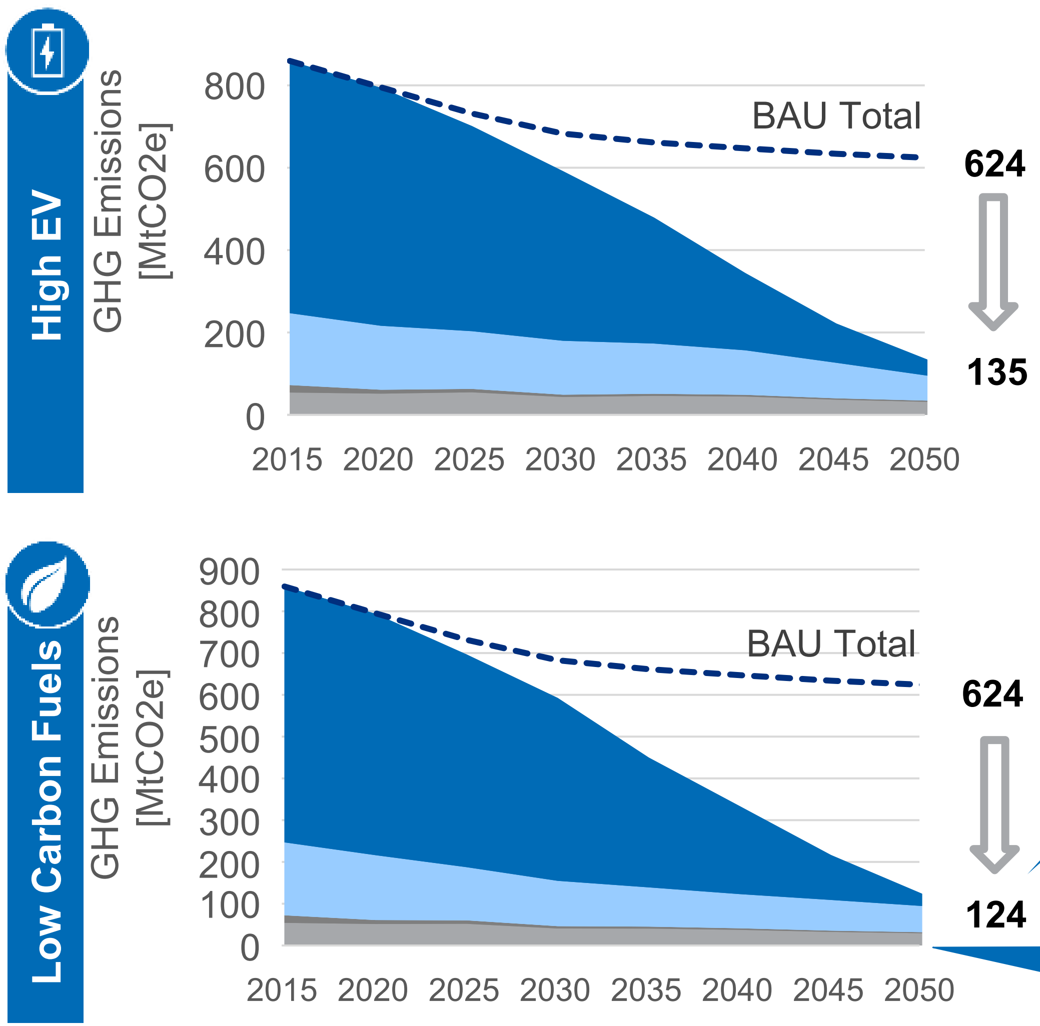


- Net GHG reduction for biofuels is assumed to reach ~85% by 2050
- After 2020: assumed that the share of low/no-ILUC biofuel (i.e. from waste or non-crop feedstocks) will increase to >95% share by 2050
- For the Low carbon fuels scenario:
  - It is assumed that the majority of biodiesel used post-2025 will be drop -in fuels (including syn-diesel, eFuels and HVO) and by 2050 substitution reaches 100%
  - Gasoline is also mainly replaced by advanced biofuels (synthetic gasoline) and substitution nears 80% by 2050

Source: Analysis by Ricardo Energy & Environment based on previous work for the EC and other European projects, and the availability (in PJ) of low carbon fuels developed by CONCAWE

Both scenarios result in a similar and significant reduction in GHG emissions to 2050, with WTW GHG savings reduced 92% vs 1990

EU Light Duty Vehicle Emissions (Well-to-Wheel + Embedded)



Both scenarios result in significant reduction from Business-As-Usual (BAU) EU reference

Embedded emissions from production and disposal rises to ~25% by 2050 for both the Low Carbon Fuels and the High-EV scenario

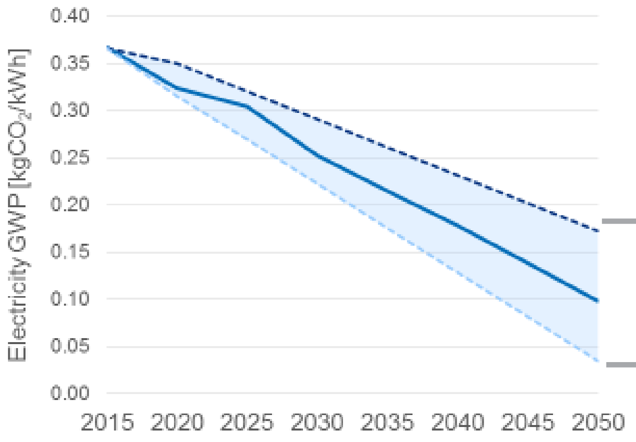
Source: Ricardo Energy & Environment SULTAN modelling and analysis

* BAU scenario as used by European Commission as a baseline for quantifying the impact of future policy changes

Sensitivities on electricity GHG intensity affect which scenario results in lower GHG emissions

Sensitivities on Electricity GHG intensity vs base High EV scenario

Electricity Global Warming Potential (GWP) [$kgCO_2/kWh$]



Total GHG emissions

+33 $MtCO_2e$

"High" electricity GHG intensity

High EV Scenario produces 33Mt CO_2 **MORE** than the Low Carbon Fuels Scenario

-8 $MtCO_2e$

"Low" electricity GHG intensity

High EV Scenario produces 8Mt CO_2 **LESS** than the Low Carbon Fuels Scenario

- High EV Scenario
- Low Carbon Fuels Scenario

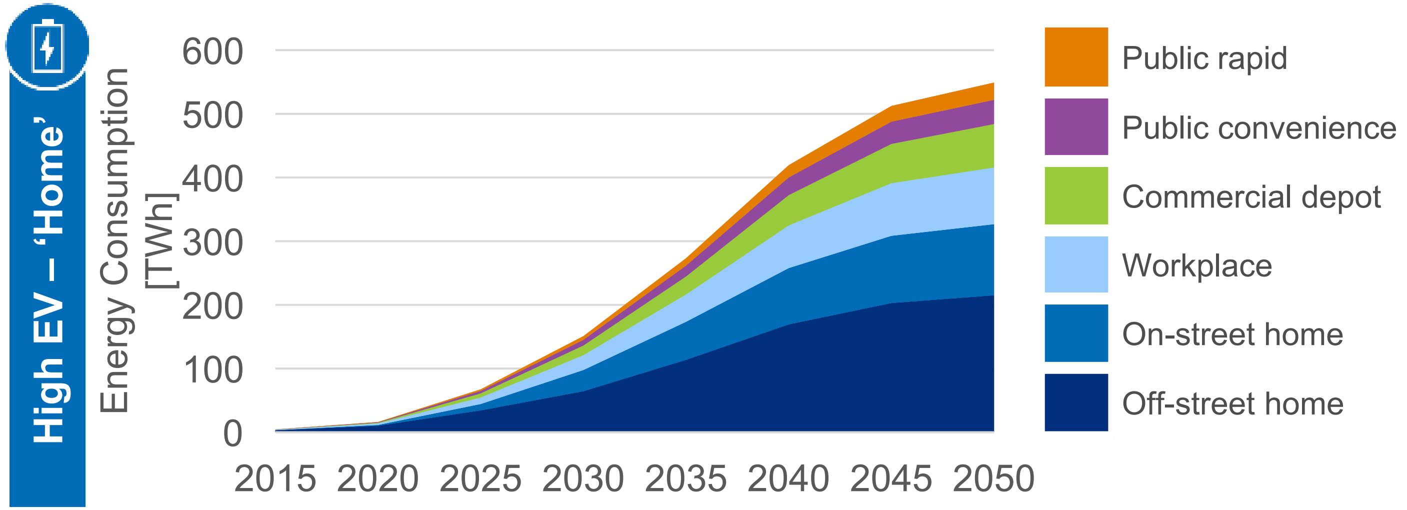
→ Sensitivities on low carbon fuel availability show similar magnitude of variations

Source: Ricardo Energy & Environment SULTAN modelling and analysis

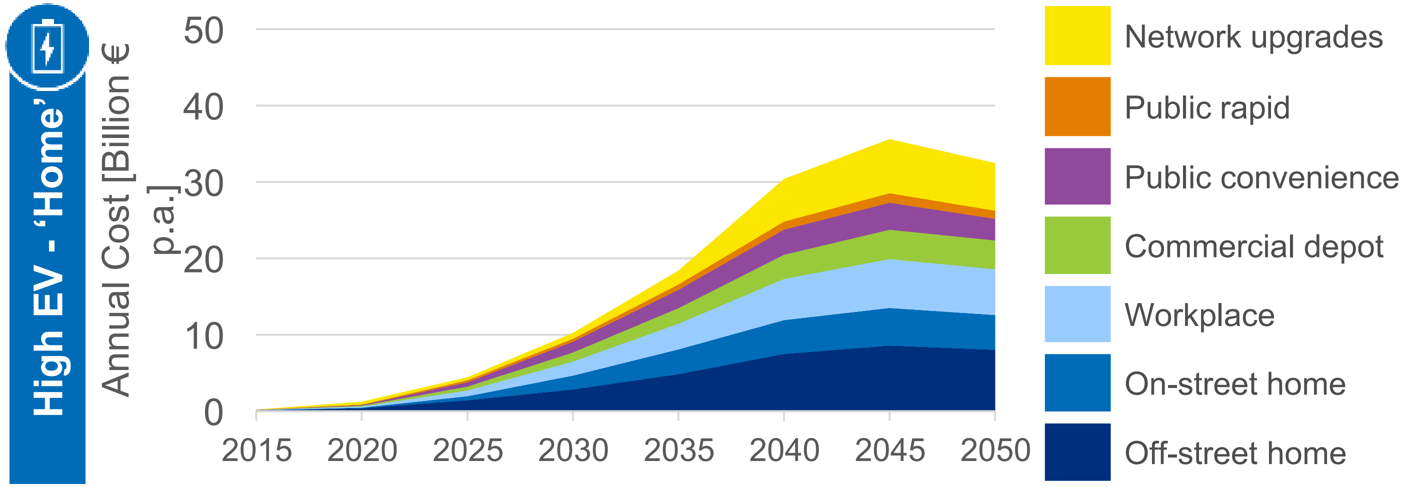
Charging scenarios considered “Home” and “Grazing” variants as well as “Managed” and “Unmanaged” charging, including network upgrade costs

RICARDO

Electricity consumption from recharging by location



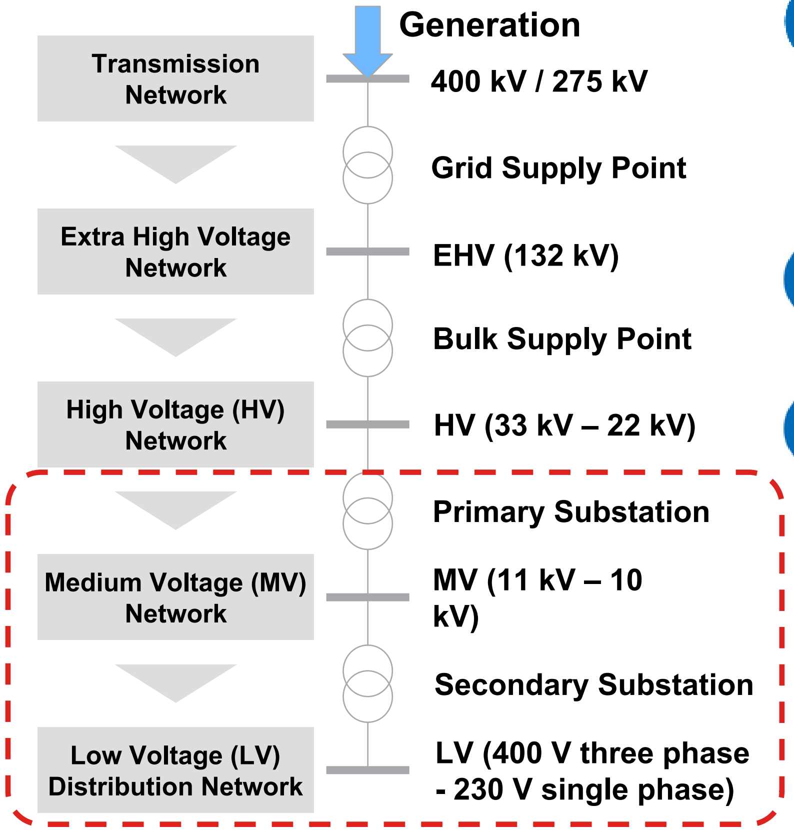
Annualised capital costs from charging infrastructure (Managed)



Source: Ricardo Energy & Environment SULTAN modelling and analysis

- In the default ‘Home’ scenario, most energy (~60%) is expected to come from charging overnight in residential areas
- The alternative ‘Grazing’ scenario assumes more frequent top-ups at mainly public convenience and rapid chargers
- Infrastructure costs also include electricity network upgrades
- Unmanaged charging requires significantly more upgrades: ~double the network upgrade cost and peak power requirements by 2050

Network reinforcement required beyond 15-20% EV penetration to deliver adequate EV re-charge power will be significant*



Significant Re-enforcement Required

Electricity for EV charging increases to ~550 TWh in 2050, ~**17.5% EU 2015 electricity generation**

- Capital costs for re-enforcing EU EV charging infrastructure & charge facilities for High EV scenario

€630 billion assuming primarily "Home" charging (€326 billion for Low Carbon Fuels)

€830 billion assuming "Grazing" frequent top-up

- Based on "Smart" network with charge periods selected to minimise local network loads

Only a small part of total road transport costs including vehicles and energy, but who pays for this?

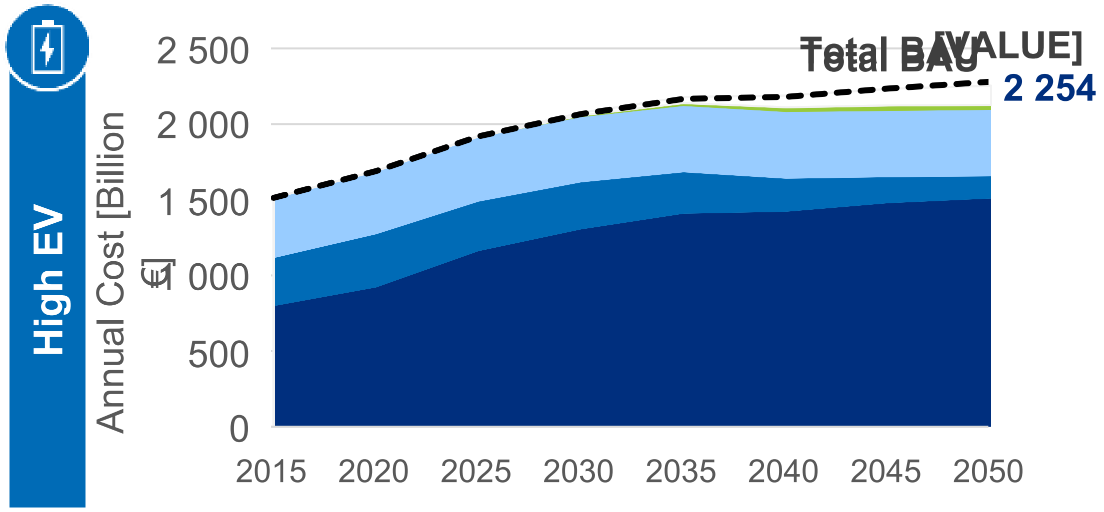
Unmanaged charging would require significantly more upgrades to Low Voltage (LV) networks *to support off-street and on-street charging (and therefore much higher cost – more than double the cost cumulatively to 2050)*

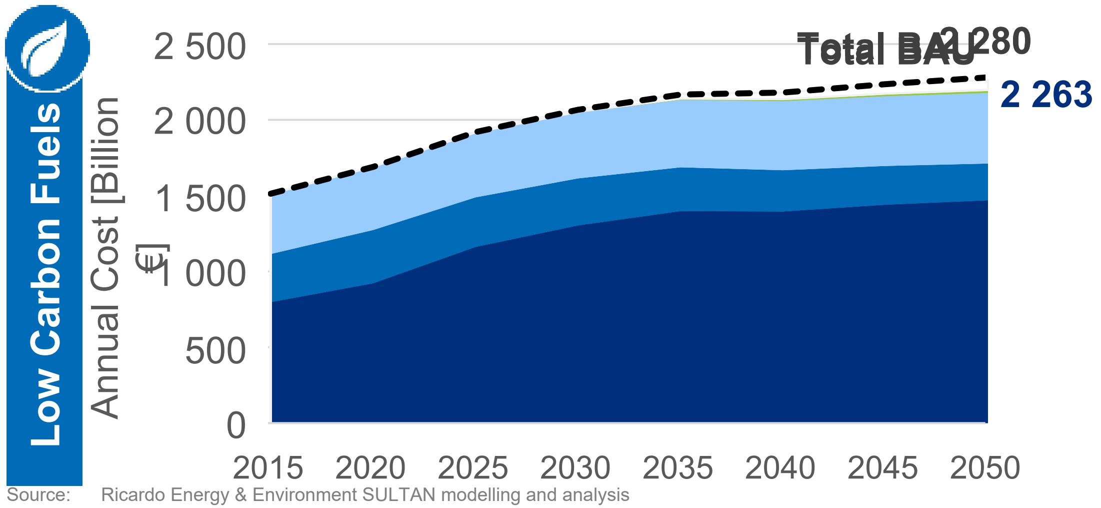
Source: The Energy Technologies Institute & *Household Electricity Survey - A study of domestic electrical product usage Intertek Report R66141; Impact Analysis of Mass EV Adoption – Ricardo; Defossilizing the transportation sector - FVV

The annual parc total costs to the end user are similar for the High EV and Low Carbon Fuels scenarios if lost fuel tax revenue is considered

Taxes are applied for all energy carriers at their current and projected (BAU) levels

Total Parc Annual Costs to End-user for All Light Duty Vehicles





- **Total annual parc cost to the end user is similar for both scenarios in 2050**, when adjusting to maintain Net Fiscal Revenue

Cumulative cost savings to the end end-user between ~€1,100 & €1,600bn (1.3% - 1.8%) vs EC BAU reference to 2050

- Cost of electricity infrastructure upgrades
- Operation and maintenance costs
- Fuel / energy costs
- Capital (vehicle)

Net Fiscal Revenue (NFR) loss: Reduction in fuel tax receipts to governments

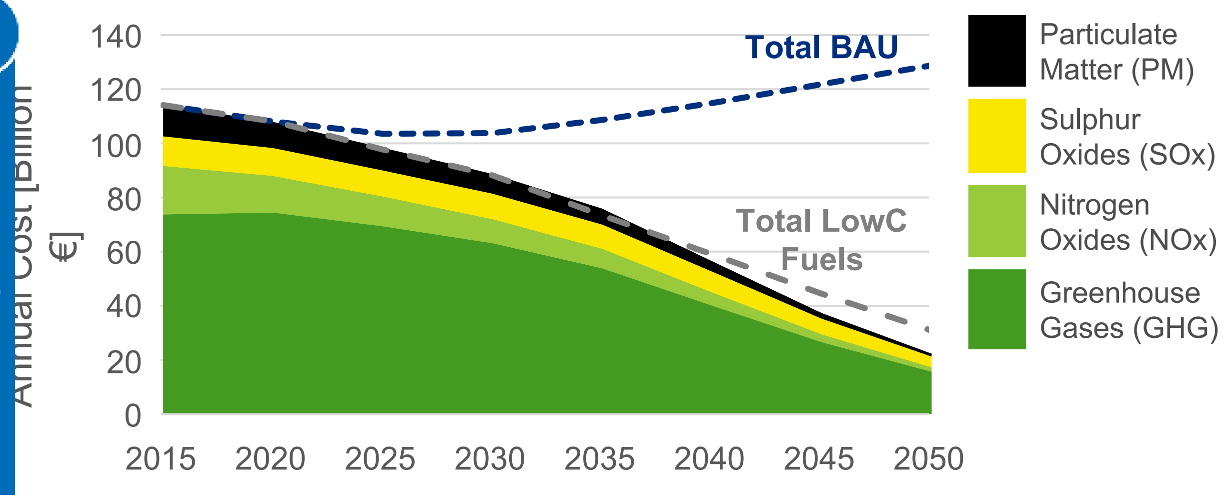
Source: Ricardo Energy & Environment SULTAN modelling and analysis

Note: *Including infrastructure costs but excluding adjustment for Net Fiscal Revenue **BAU scenario as used by European Commission as a baseline for quantifying the impact of future policy changes

Externalities from emissions of GHG and air quality pollutants decrease significantly in both scenarios, but more under High EV

Externalities for WTW emissions of GHG, and also WTW emissions of NOx, PM and SOx

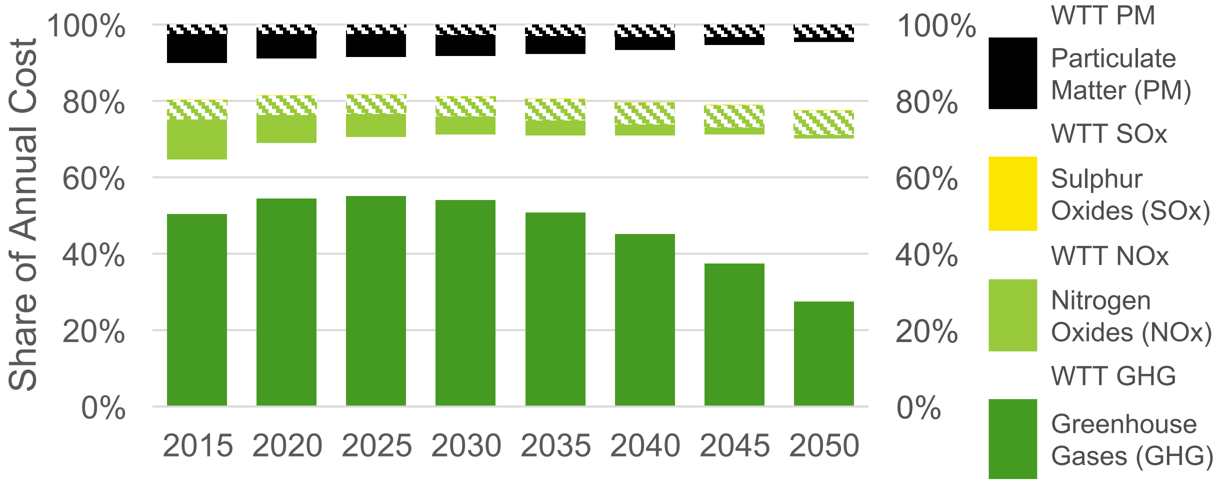
High EV



- External costs (or ‘externalities’) are monetary values attached impacts due to indirect effects, for example on public health and other elements
- Commonly used in cost-benefit analysis (CBA), e.g. for policy impact assessments, to assess wider net impacts of policies on total societal costs

Relative share of WTT and TTW annual costs for emissions of GHG, NOx, PM and SOx (High EV)

Share of Externalities



- Externalities associated with GHG dominate in later periods:
  - Reduced to the greatest degree in the High EV scenario by 2050

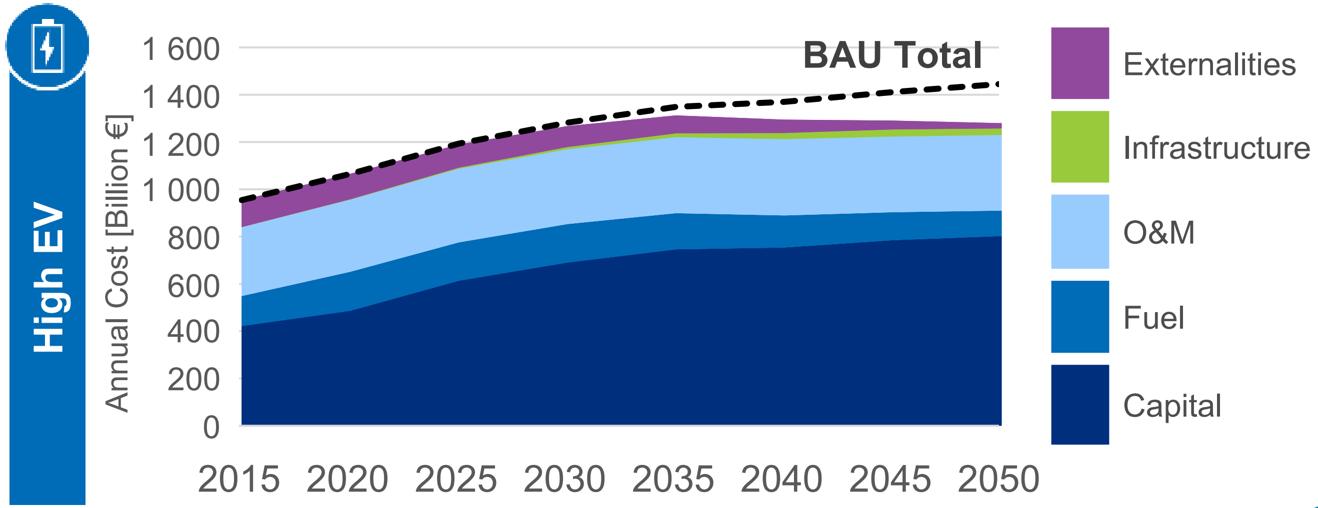
Note: Technologies will continue to develop to deliver “zero impact” on air quality from tailpipe: this was only partially considered in this analysis

Source: Ricardo Energy & Environment SULTAN modelling and analysis; External costs for PM, NOx, SOx, GHG are extrapolated from 2010 base values through to 2050 using EU GDP projections. 2010 base values are from “Update of the Handbook on External Costs of Transport”: https://ec.europa.eu/transport/sites/transport/files/handbook_on_external_costs_of_transport_2014_0.pdf

The net societal cumulative costs are lower for High EV scenario only in later periods

External costs (or ‘externalities’) are the monetary value attached to GHG and Air Quality emissions

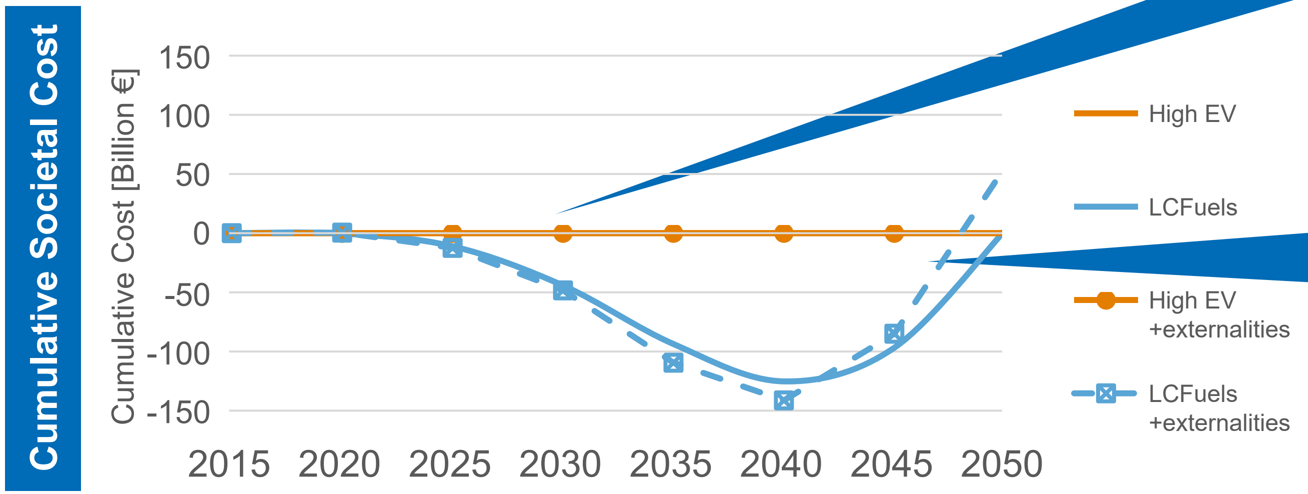
Total Parc Annual Societal Costs (excl. tax), including Externalities



Emission externalities contribute to significantly lower social costs for both scenarios

Note: Societal costs exclude all taxes

Cumulative Net Societal Costs (relative to High EV)



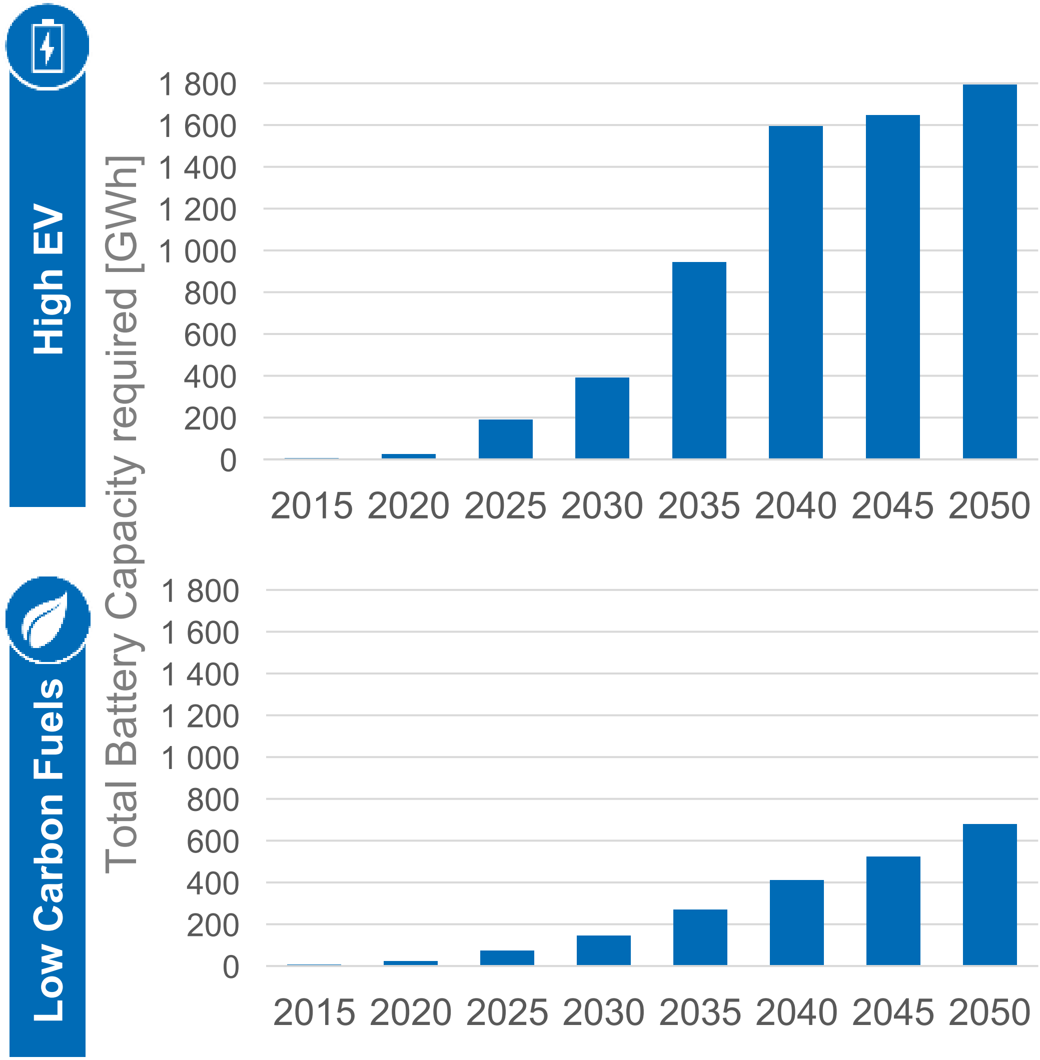
Cumulative net societal costs are significantly higher for the High EV scenario in earlier periods

Overall cumulative cost-effectiveness is best for the other scenarios up to 2045-2050

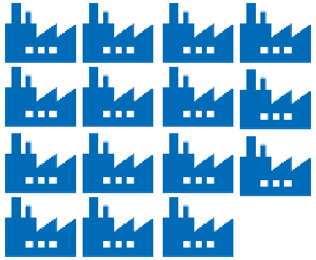
Source: Ricardo Energy & Environment SULTAN modelling and analysis;

Under the High EV scenario, ~15 Gigafactories would be needed to supply batteries to the European EV market by 2050

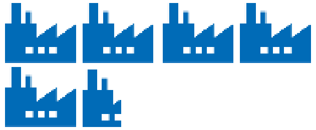
Resources & Materials – Annual Battery Capacity [GWh]



Estimated number of battery Giga-factories required for Europe



- The High EV scenario requires almost **three times the total battery capacity** compared to the Low Carbon Fuels scenario

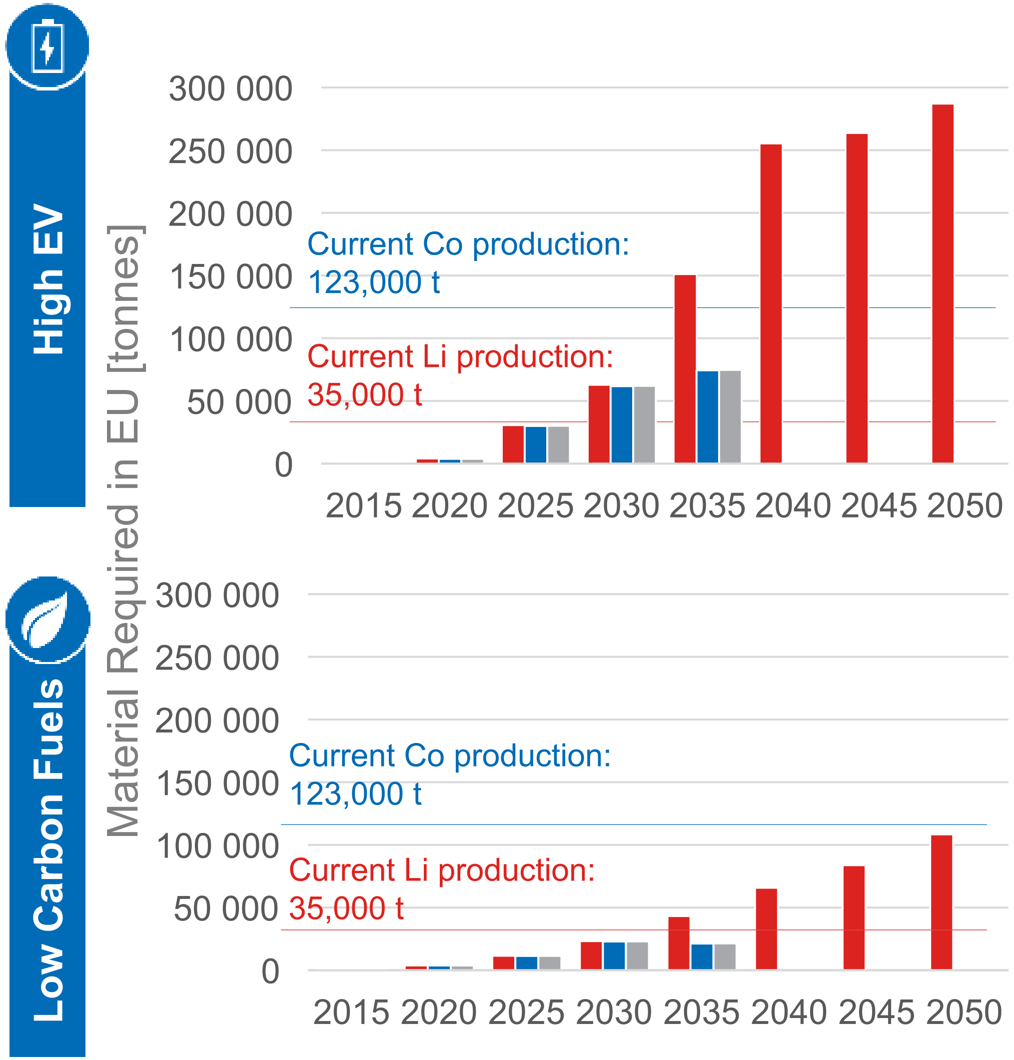


Note: Tesla Giga Factory estimates factor in anticipated battery energy density improvements per unit from 2025-2050 This output should be expected to scale with increased battery kg/Wh*

Source: Ricardo Energy & Environment SULTAN modelling and analysis; * Tesla (https://www.tesla.com/en_CA/gigafactory)

The Lithium resource requirements for the Low Carbon Fuels scenario are less than half of those for the High EV scenario

Resources & Materials – Key Battery Materials [tonnes], annual demand



- Assuming current chemistry mixes the resource requirements for Lithium, Cobalt and Nickel would increase very substantially over the period to 2050, which would pose a potential availability risk
- Current global total production p.a.:
  - Li : 35 kt
  - Co : 123 kt

The use of Cobalt and Nickel in battery chemistries is expected to be phased out between 2030 and 2040: the share after this is uncertain

Source: U.S Geological Survey (Mineral Commodity Summaries 2017); Ricardo Energy & Environment Sultan Modelling And Analysis

Both scenarios have significant challenges. A broad range of solutions, including liquid low carbon fuels, would minimise the risks in achieving our future targets

	Positives	Uncertainties
High EV	• Most efficient use renewable electricity • Free up low carbon fuel supplies for other transport applications	• Battery costs and improvements in energy density • Investment in charging infrastructure and electricity distribution network • Availability of resources for batteries (e.g. Lithium & Cobalt)
Low Carbon Fuels	• No behaviour change in refuelling • Allows greater use of our existing manufacturing skills and assets	• Low carbon fuel supply chain and processes scale up • Development to deliver zero impact on air quality from tailpipe

- A broad range of solutions should be considered, **including electrification and liquid or gaseous fuels,** to minimise the risks associated with a single scenario
- The efficiency and emissions of ICEVs will need to continue to develop, and to **accept future low carbon fuels**

Thank you

Nikolas Hill
Ricardo Energy & Environment
The Gemini Building
Fermi Avenue
Harwell, Didcot
OX11 0QR
United Kingdom

T: +44 (0)1235 75 3522
E: nikolas.hill@ricardo.com
E: VehicleLCA@ricardo.com

Dr Nick Powell
Ricardo Strategic Consulting
Shoreham Technical Centre
Old Shoreham Rd
Shoreham-by-Sea
BN43 5FG
United Kingdom

T: +44 (0)1273 794524
E: nick.powell@ricardo.com