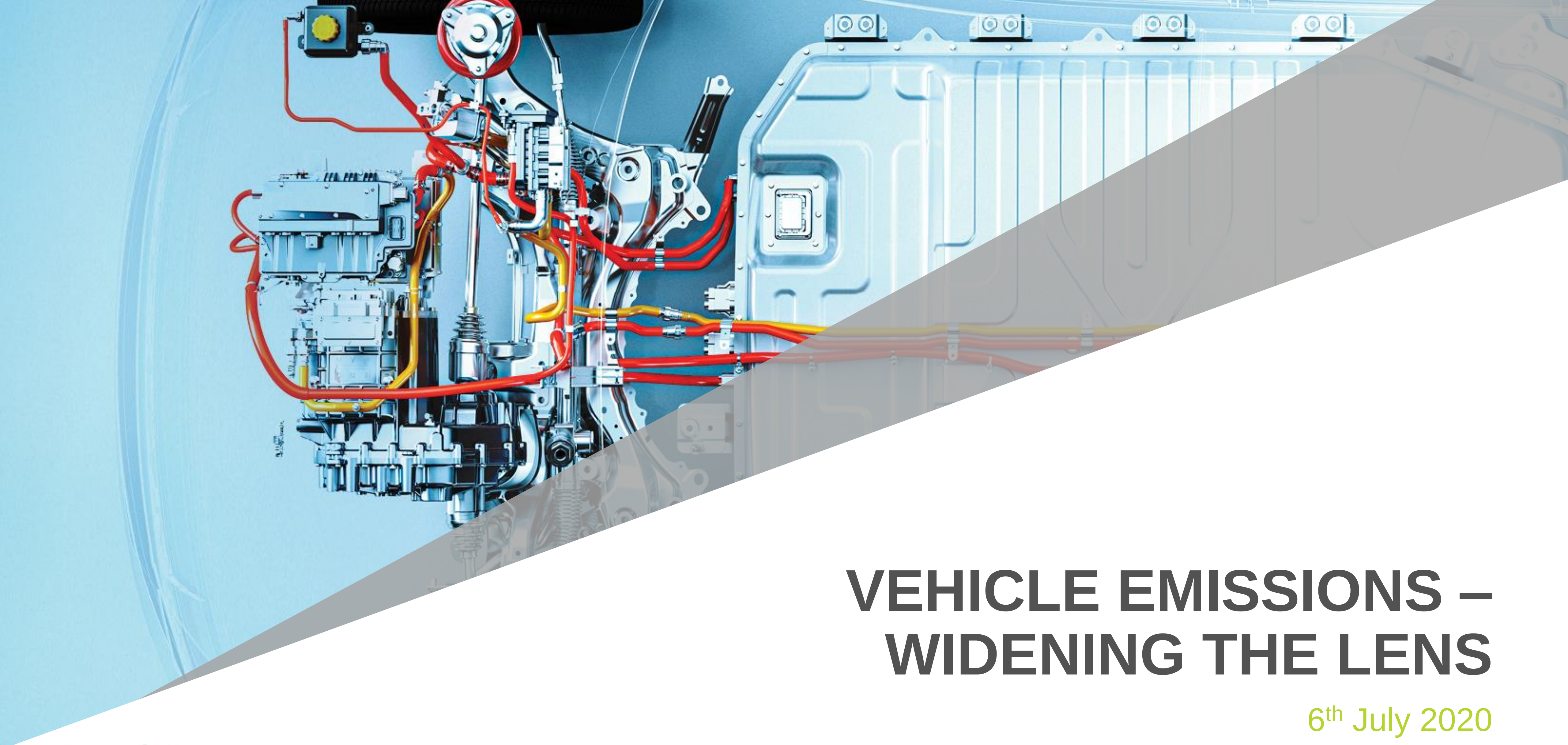

VEHICLE EMISSIONS – WIDENING THE LENS

6th July 2020

LowCVP
Low Carbon Vehicle Partnership

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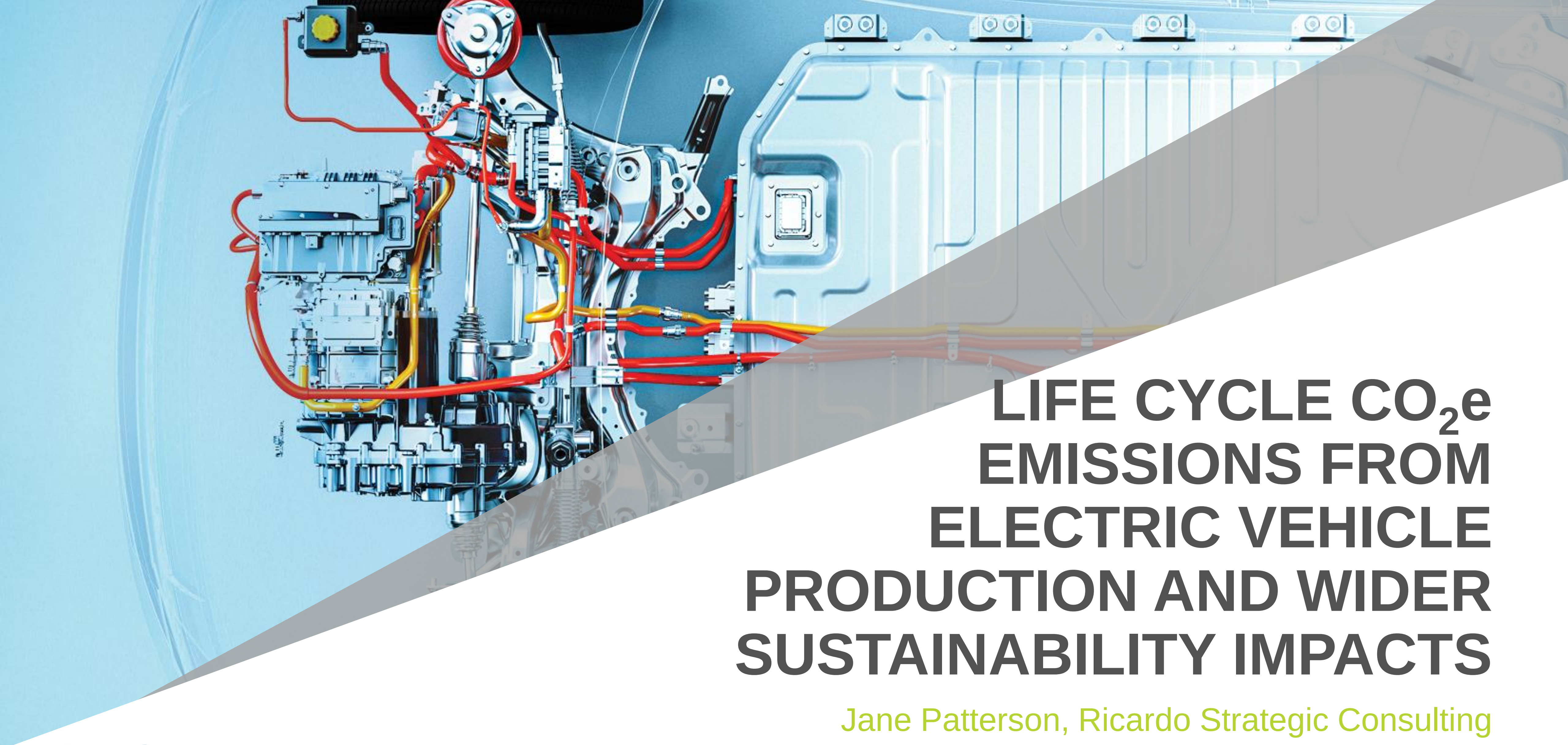


LIFE CYCLE CO_2e EMISSIONS FROM ELECTRIC VEHICLE PRODUCTION AND WIDER SUSTAINABILITY IMPACTS

Jane Patterson, Ricardo Strategic Consulting

Brief overview of Ricardo – over 100 year history of delivering excellence – we work with our clients to create a world fit for the future

We are a global, multi-industry, multi-discipline consultancy and niche manufacturer of high performance products

The objective throughout our history has been to maximise efficiency and eliminate waste in everything we do

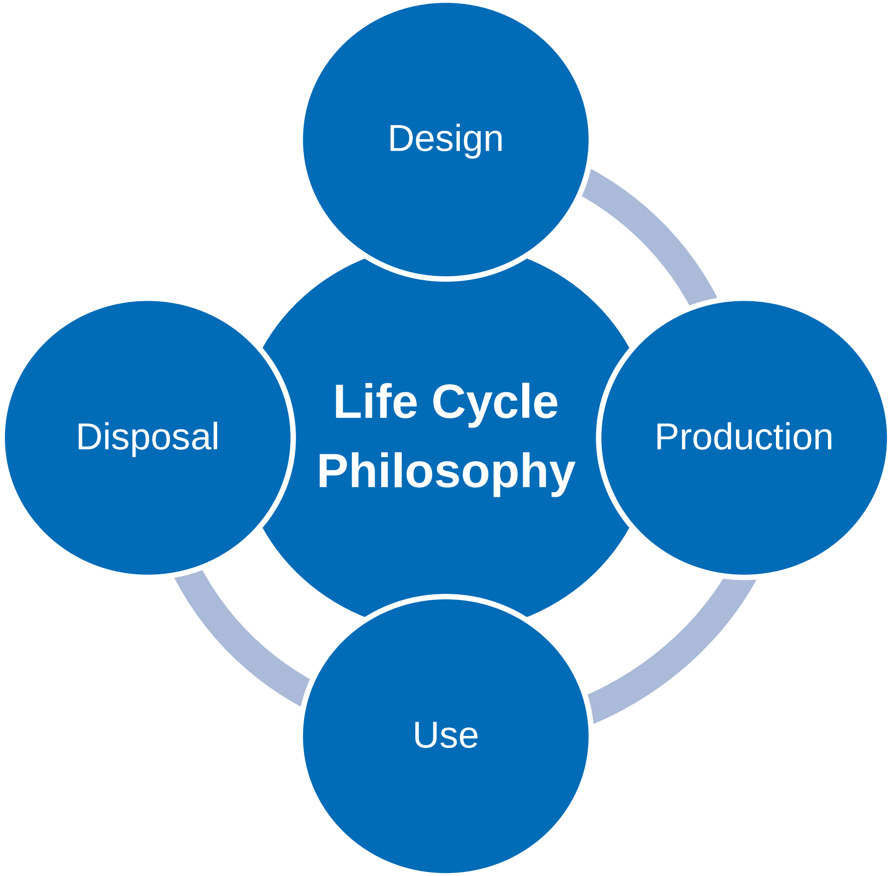
3,000+ staff

88 nationalities

51 sites in **20** countries

This Keynote: An overview into the challenge of sustainability as the focus shifts from ‘in-use’ emissions to those produced throughout the rest of the life cycle

- **What challenge do we need to solve?**
- **Why do we need to take a life cycle approach?**
- **Let’s take a closer look at vehicle production**
- **So, what is the trade-off between production and in-use?**



The transport challenge is a complex interaction between three competing themes: Health, Wealth, and Environment → for a sustainable solution these need balancing

The Transport Challenge

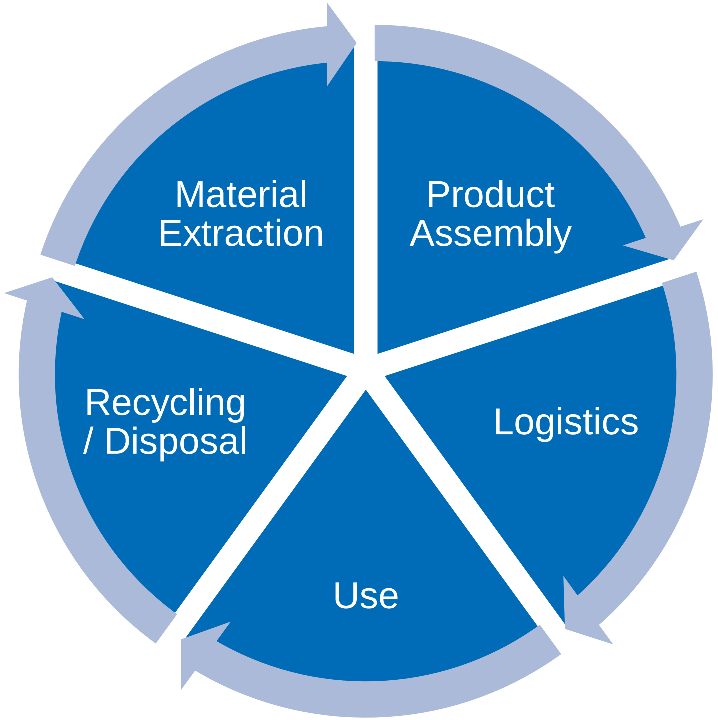
For a sustainable future transport needs to balance:

- Not impacting the environment
- Not adversely affecting peoples health
- Moving people and goods cheaply to maintain healthy economies

Life Cycle Assessment (LCA) is about taking a holistic approach to the analysis of a product’s environmental impact

What is Life Cycle Assessment?

- All things have a **life cycle** of “birth”, “use / service” and “death” in which they impact on their environment
- **Life Cycle Assessment (LCA)** is a technique for quantifying the environmental and human health impacts of a product over its life cycle
  - Other names include “life cycle analysis”, “life cycle approach”, “cradle-to-grave analysis”, “ecobalance” or “environmental footprinting”
- **Life Cycle Thinking** is a way of thinking that includes the economic, environmental and social consequences of a product or process over its entire life cycle



Formal Definition of Life Cycle Assessment

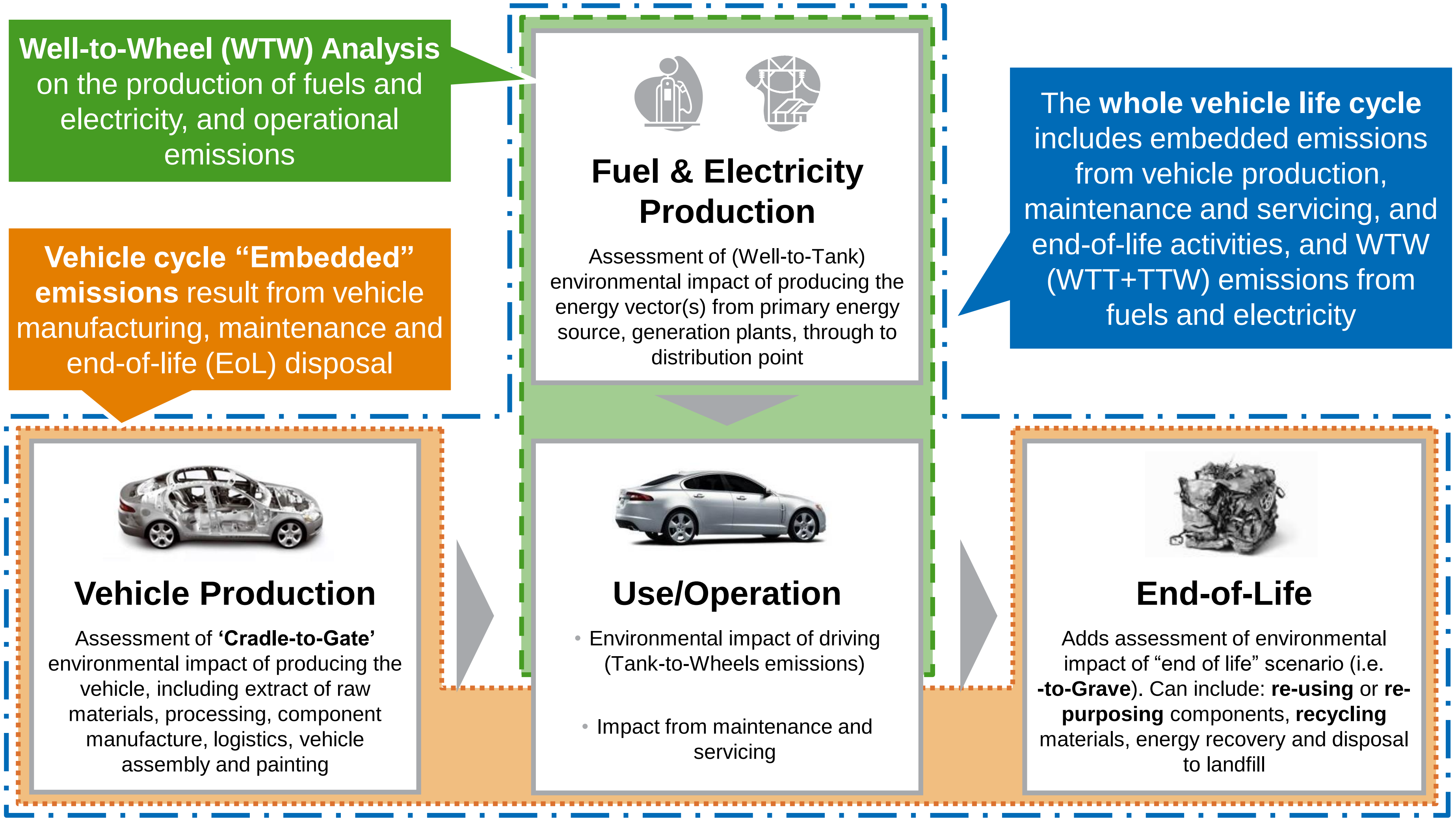
“It is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment. The assessment includes the entire life cycle of product, process or activity, encompassing extracting and processing raw materials, manufacturing, transport and distribution; use, re-use, maintenance; recycling, and final disposal”

SETAC, 1991

Source: See “Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies”, Ricardo report for LowCVP, August 2018, for further explanation of LCA

A vehicle's life cycle consists of four stages – vehicle production, fuel production, use and end of life

Vehicle Life Cycle



Well-to-Wheel (WTW) Analysis on the production of fuels and electricity, and operational emissions

Vehicle cycle "Embedded" emissions result from vehicle manufacturing, maintenance and end-of-life (EoL) disposal

Fuel & Electricity Production

Assessment of (Well-to-Tank) environmental impact of producing the energy vector(s) from primary energy source, generation plants, through to distribution point

The **whole vehicle life cycle** includes embedded emissions from vehicle production, maintenance and servicing, and end-of-life activities, and WTW (WTT+TTW) emissions from fuels and electricity

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 (Tank-to-Wheels emissions)
- Impact from maintenance and servicing

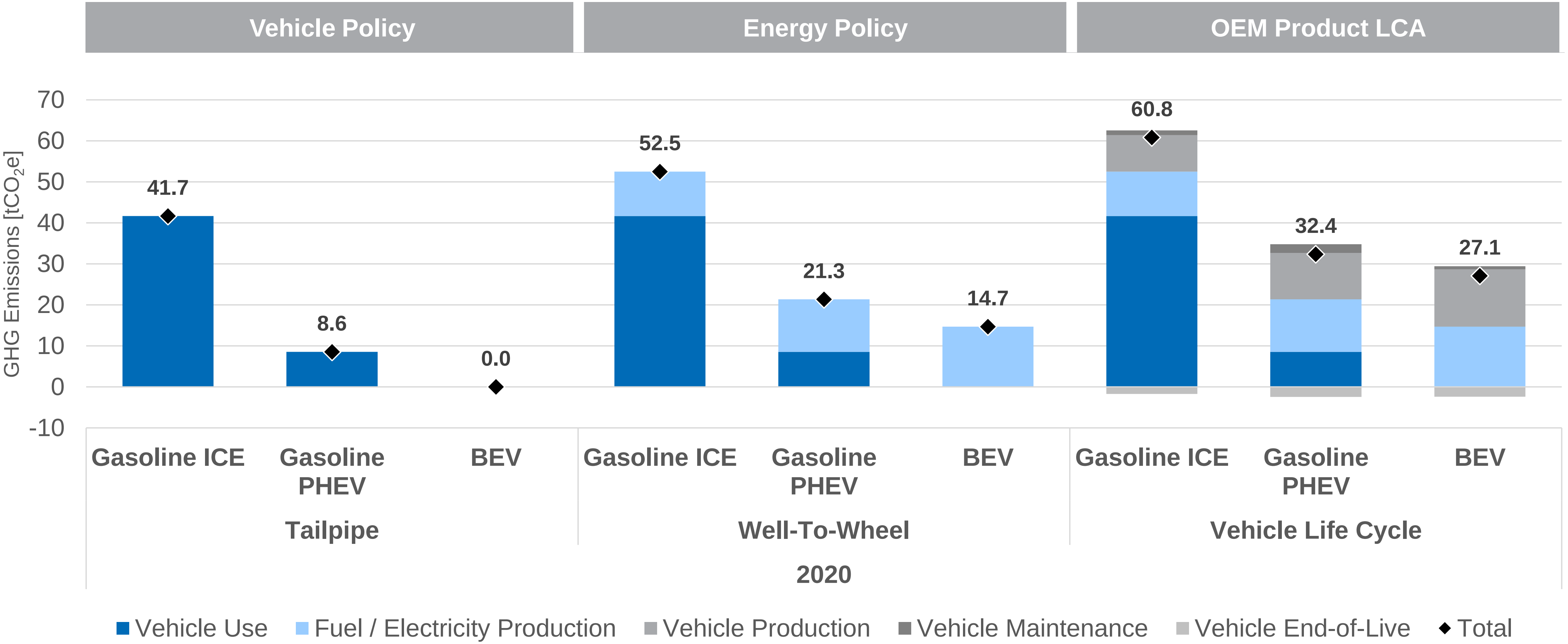
End-of-Life

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

Life Cycle Assessment provides us with deeper understanding of the environmental impacts of our technology decisions

ILLUSTRATIVE

Estimation of GHG Emissions for European Medium Passenger Car

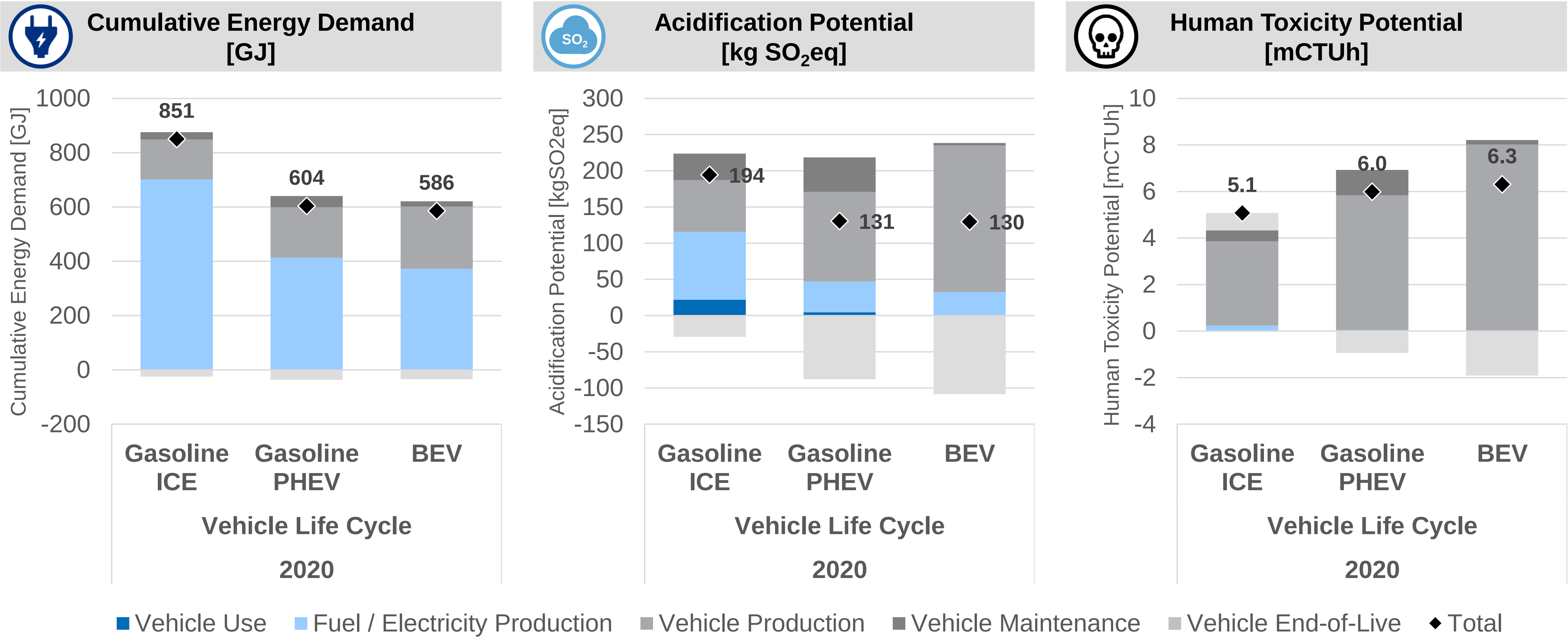


Source: Ricardo Vehicle LCA analysis (June 2020) for average EU lower-medium passenger car (C-segment): Assumes lifetime 225,000 km, real-world fuel consumption based on average EU28 use profile. GHG from fuel/electricity consumption is based on the average fuel/grid electricity factor over the life of the vehicle (Baseline scenario); Calculated 89.0 kgCO_2e/kWh battery in 2020, Includes EoL recycling credits; Analysis assumed PHEV has 11 kWh Li-ion battery pack, and BEV has 57 kWh Li-ion battery pack

And it's not just about Global Warming and GHG Emissions – other impacts need to be considered too

ILLUSTRATIVE

Estimation of other LCA Environmental Impacts for European Medium Passenger Car



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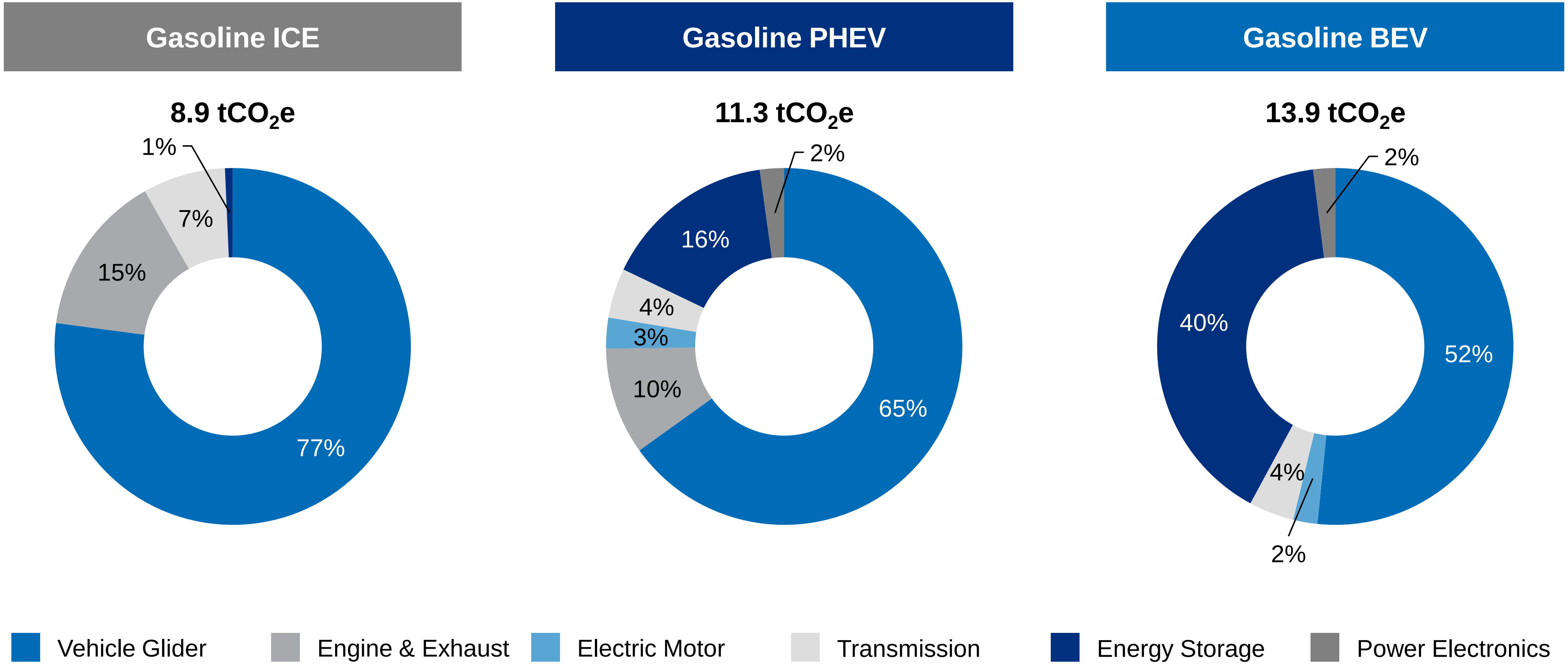
Considering vehicle production: the technology evolution to plug-in vehicles has lead to higher embedded CO_2e emissions due to the addition of new components

ILLUSTRATIVE

Estimation of GHG Emissions for European Medium Passenger Car – Vehicle Production



Source: Ricardo Vehicle LCA analysis (June 2020) for average EU lower-medium passenger car (C-segment): Assumes lifetime 225,000 km, real-world fuel consumption based on average EU28 use profile. GHG from fuel/electricity consumption is based on the average fuel/grid electricity factor over the life of the vehicle (Baseline scenario); Calculated 89.0 $kgCO_2e/kWh$ battery in 2020, Includes EoL recycling credits; Analysis assumed PHEV has 11 kWh Li-ion battery pack, and BEV has 57 kWh Li-ion battery pack

Ricardo is also adopting a life cycle philosophy in our Performance Products division – initial results have been surprising

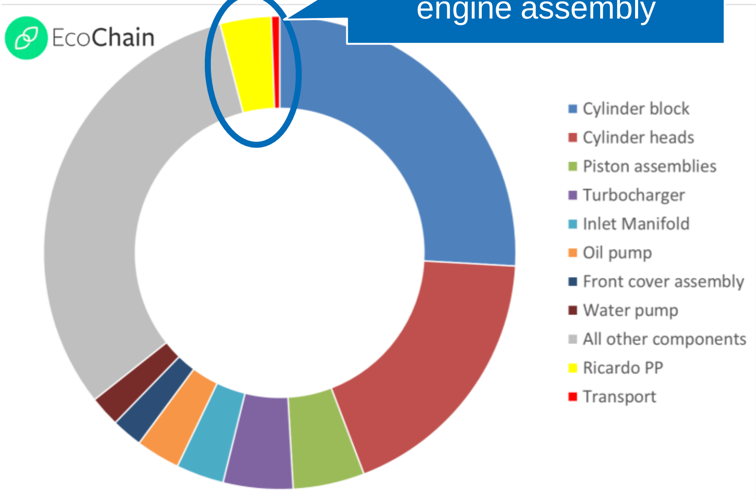
RICARDO
CASE EXAMPLE

Ricardo – Cradle-to-Gate LCA Study of High Performance Engines

- Ricardo Performance Products assemble high performance engines at our Shoreham Technical Centre
- In 2017, we performed a cradle-to-gate life cycle assessment of a high performance engine, using primary data collected directly from our assembly facility, and EcoChain's online LCA modelling tool
- For such a complex product, the calculations were surprisingly simple
- The results were intriguing – only 3.5% of total embedded carbon footprint for one engine arises from Ricardo's assembly

Rather than focusing on further significant improvements in our own energy efficiency, Ricardo PP are engaging with our supply chain to help them reduce their impacts

Embedded CO$_2$e contribution from Ricardo engine assembly

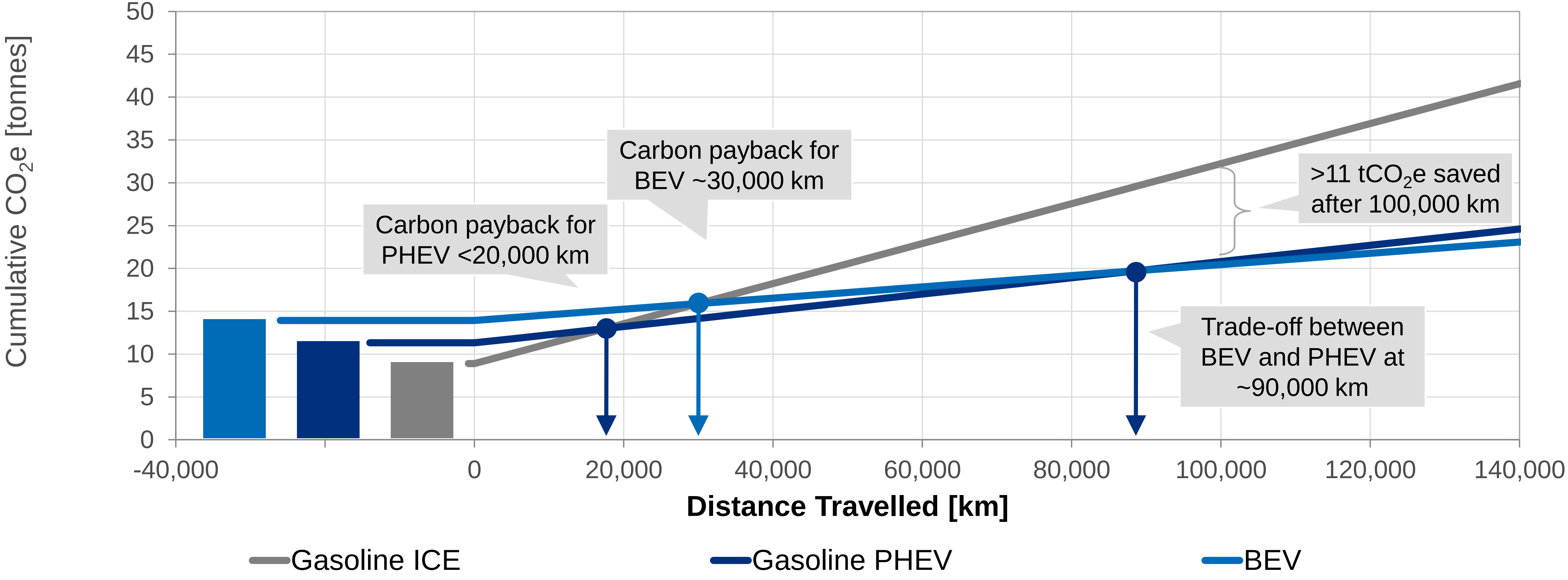


Source: Ricardo "cradle-to-gate" LCA analysis of high performance engine using EcoChain

So, if GHG emissions for producing a BEV or PHEV are higher than for gasoline ICE, how far to you have to travel to payback the GHG emissions?

ILLUSTRATIVE

Estimation of GHG Emissions for European Medium Passenger Car – Vehicle Production



Carbon payback for BEV ~30,000 km

Carbon payback for PHEV <20,000 km

>11 tCO_2e saved after 100,000 km

Trade-off between BEV and PHEV at ~90,000 km

Source: Ricardo Vehicle LCA analysis (June 2020) for average EU lower-medium passenger car (C-segment): Assumes lifetime 225,000 km, real-world fuel consumption based on average EU28 use profile. GHG from fuel/electricity consumption is based on the average fuel/grid electricity factor over the life of the vehicle (Baseline scenario); Calculated 89.0 $kgCO_2e/kWh$ battery in 2020, Includes EoL recycling credits; Analysis assumed PHEV has 11 kWh Li-ion battery pack, and BEV has 57 kWh Li-ion battery pack

To conclude, we need to adopting a life cycle philosophy to meet the challenges of sustainable transport

Conclusions

- A truly sustainable solution for future transport needs to balance three competing themes: Health, Wealth, and Environment
- A life cycle approach enables holistic analysis of the health, wealth and environmental impacts of powertrain technology and fuels
- OEMs and their supply chains will need to work together
- This changes the mobility discussion – making sure environmental burdens are not shifted to other parts of the vehicle life cycle

We need to adopt a life cycle philosophy to successfully engineer net zero transport

Thank-you for listening

Acknowledgements

“Pilot study on determining the environmental impacts of conventional and alternatively fuelled vehicles through Life Cycle Assessment”

A project led by Ricardo Energy & Environment, with its partners ifeu and E4Tech

The study covers road transport vehicles of different types / powertrains, and fuel and electricity production chains looking out to 2050. The work includes a review the literature, development and implementation of a methodology generate results to inform understanding for the Commission in a policy context. A range of stakeholder consultation and data gathering activities have been completed, including a survey (and workshop) with LCA experts/stakeholders. Results were presented in a Final Workshop in January 2020.

For further information, please contact us via the project email address:
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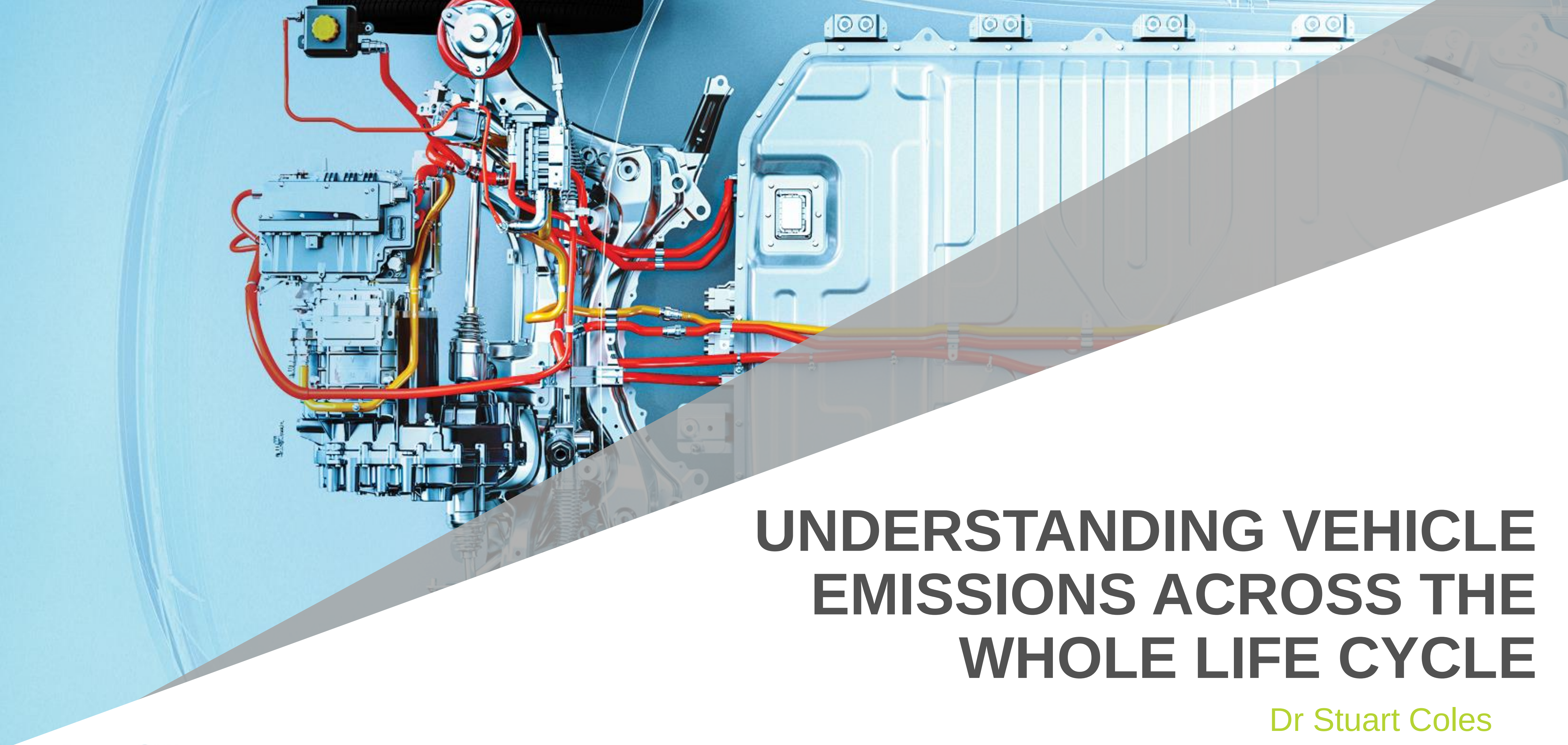


UNDERSTANDING VEHICLE EMISSIONS ACROSS THE WHOLE LIFE CYCLE

Dr Stuart Coles

LowCVP Low Carbon Vehicle Partnership

ADVANCED PROPULSION CENTRE UK

WMG THE UNIVERSITY OF WARWICK

Phases

Manufacturing

cc-by-sa/2.0 - Electric vehicle being charged by Bill Kasman - geograph.org.uk/p/5875286

Usage

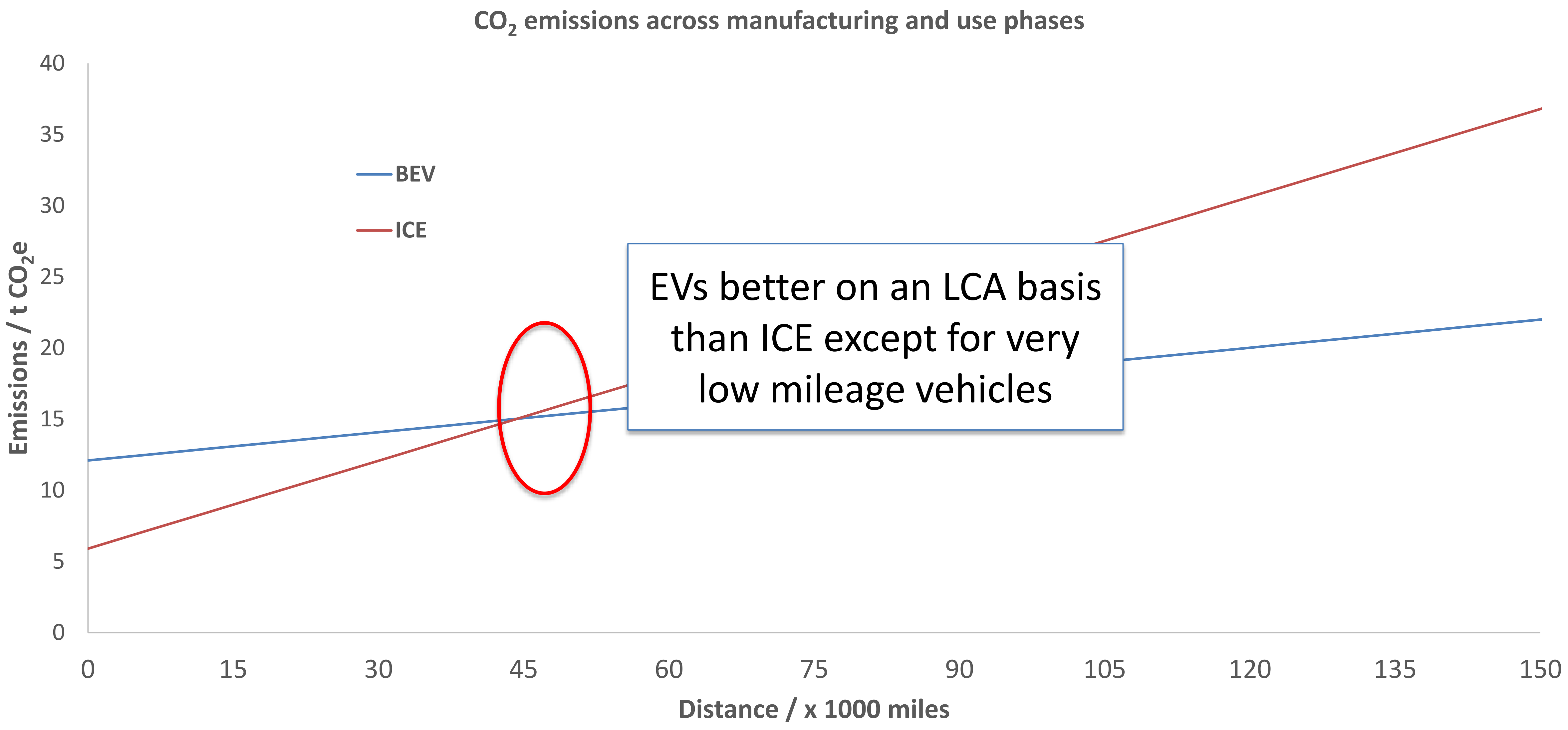
Recycling

Manufacturing

- Manufacturing a battery has more CO_2 emissions associated with it than a comparable ICE
- When considering the whole vehicle, literature reports increases of around 33% - 100%
- Absolute values will change depending on model, location etc. – but trend is clear

Usage

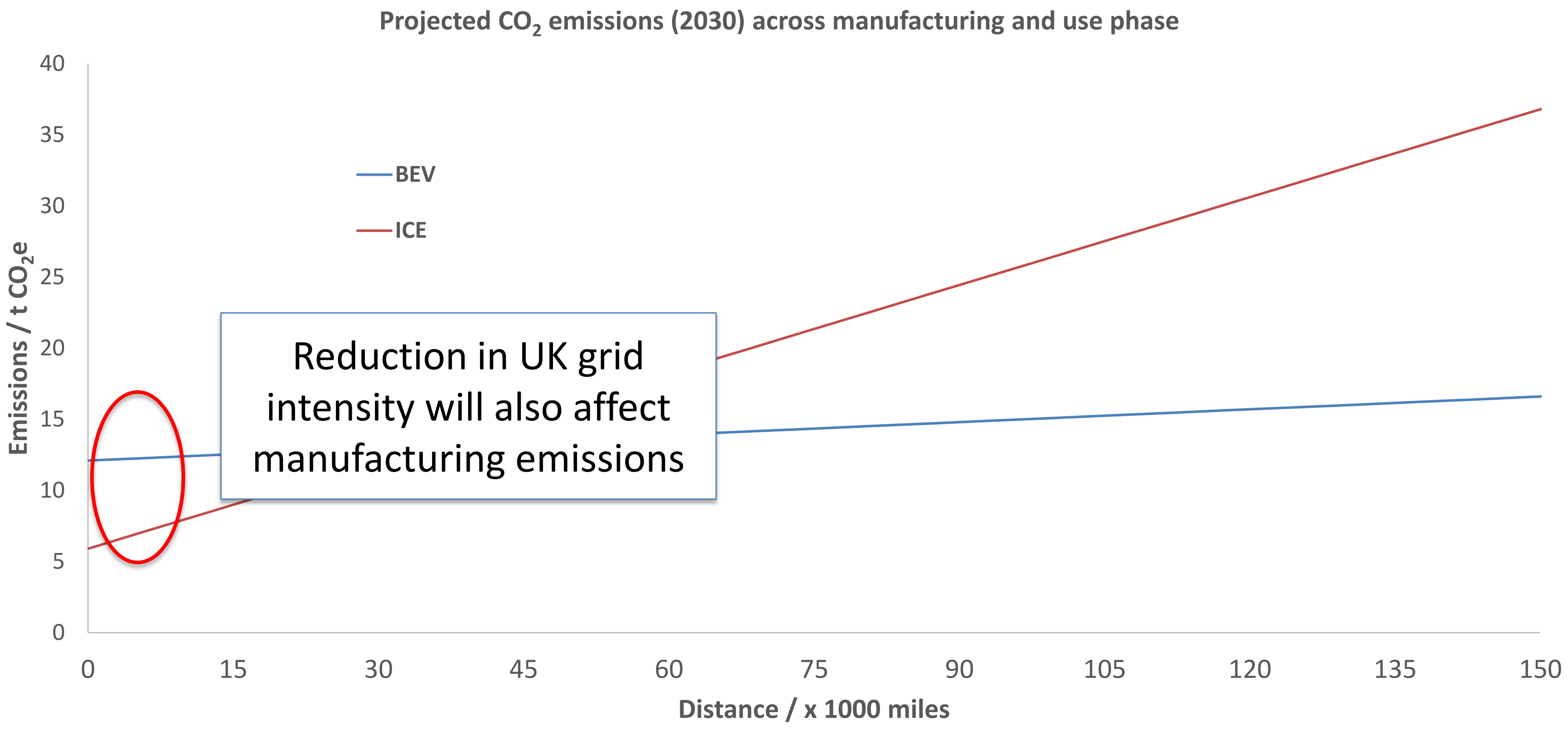
- Zero emission at point of use
  - Driven by legislation to reduce exhaust emissions
- Electricity generation has related carbon emissions
- Comparison with ICE using UK grid mix is favourable



CO_2 emissions across manufacturing and use phases

EVs better on an LCA basis than ICE except for very low mileage vehicles

Mid-range passenger car, manufacturing values calculated using GREET 2019 and Warwick data.
Emissions based on 2019 UK grid average (BEV) and 120 g CO_2e / km (ICV)


Projected CO_2 emissions (2030) across manufacturing and use phase

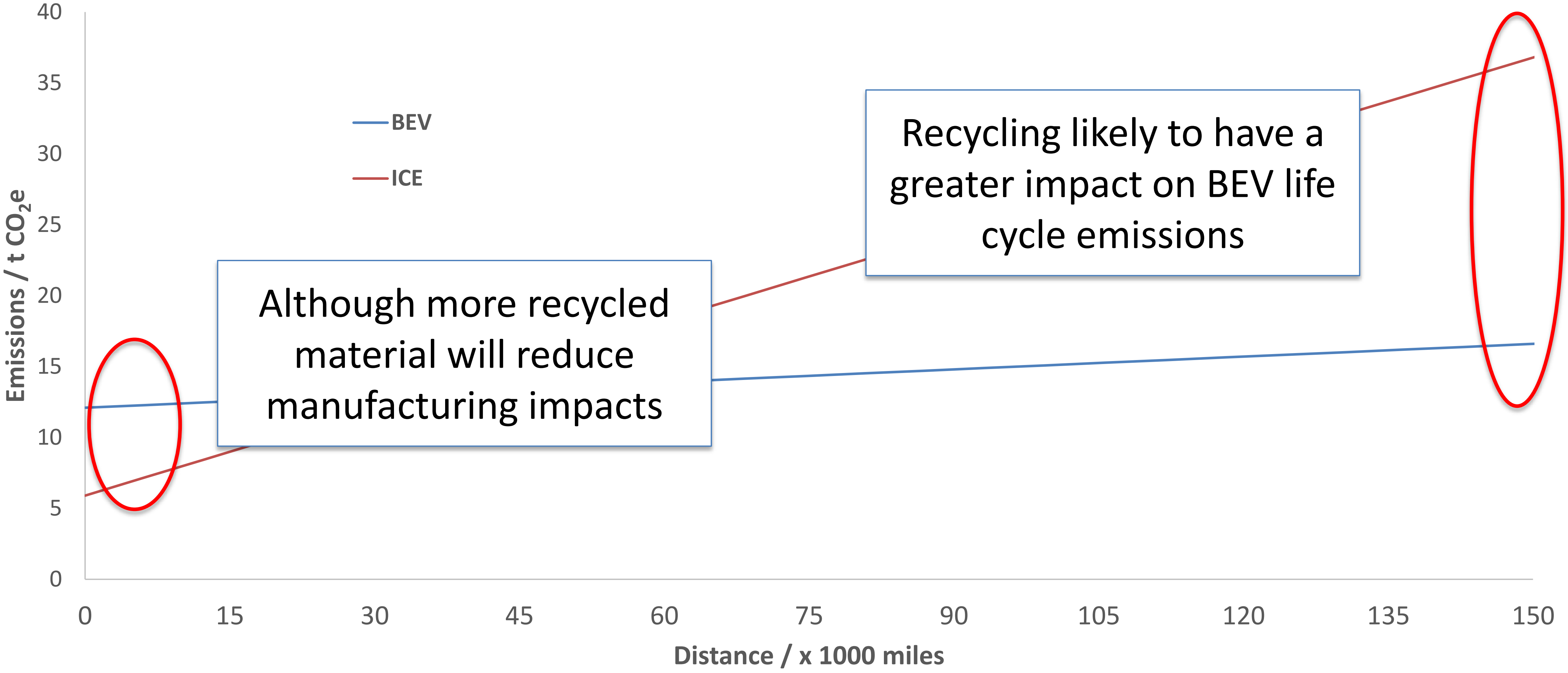
Reduction in UK grid intensity will also affect manufacturing emissions

Mid-range passenger car, manufacturing values calculated using GREET 2019 and Warwick data.
Emissions based on projected 2030 UK grid average (BEV) and 120 g CO_2e / km (ICV)

End of life

- Batteries are difficult to disassemble
  - Energy, emission & cost inefficient
- Lack of industrially-relevant data

Projected CO_2 emissions (2030) across manufacturing and use phase



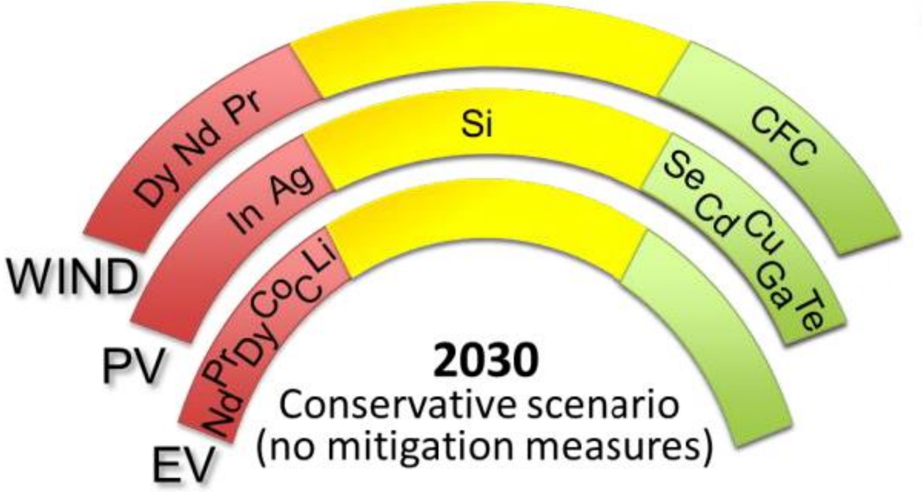
Although more recycled material will reduce manufacturing impacts

Recycling likely to have a greater impact on BEV life cycle emissions

Mid-range passenger car, manufacturing values calculated using GREET 2019 and Warwick data.
Emissions based on projected 2030 UK grid average (BEV) and 120 g CO_2e / km (ICV)

Materials

- Bigger long-term consideration is materials supply
  - Particularly cobalt, neodymium and other critical raw materials
- Needs legislation to drive
  - Current target of 50% recycling by mass doesn't include any specific materials



Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU, EU JRC, **2016**

Summary

- Larger proportion of environmental impact is associated with manufacturing of EV battery (vs. ICE)
  - Improves with increasing energy density and charging infrastructure
- EV is better than ICE for anything other than a very low mileage vehicle
  - Reductions in grid carbon intensity strengthens this case from both manufacturing and usage phase perspectives
- Need to consider the materials impact
  - Particularly cobalt and neodymium; recycling important but cost and carbon inefficient
  - Need battery recycling directive to be more challenging than 50% by mass

References

- Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU, EU JRC, **2016**
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  Whole Life Cycle Analyis of Electric Vehicles
  Unpublished Data, **2020**

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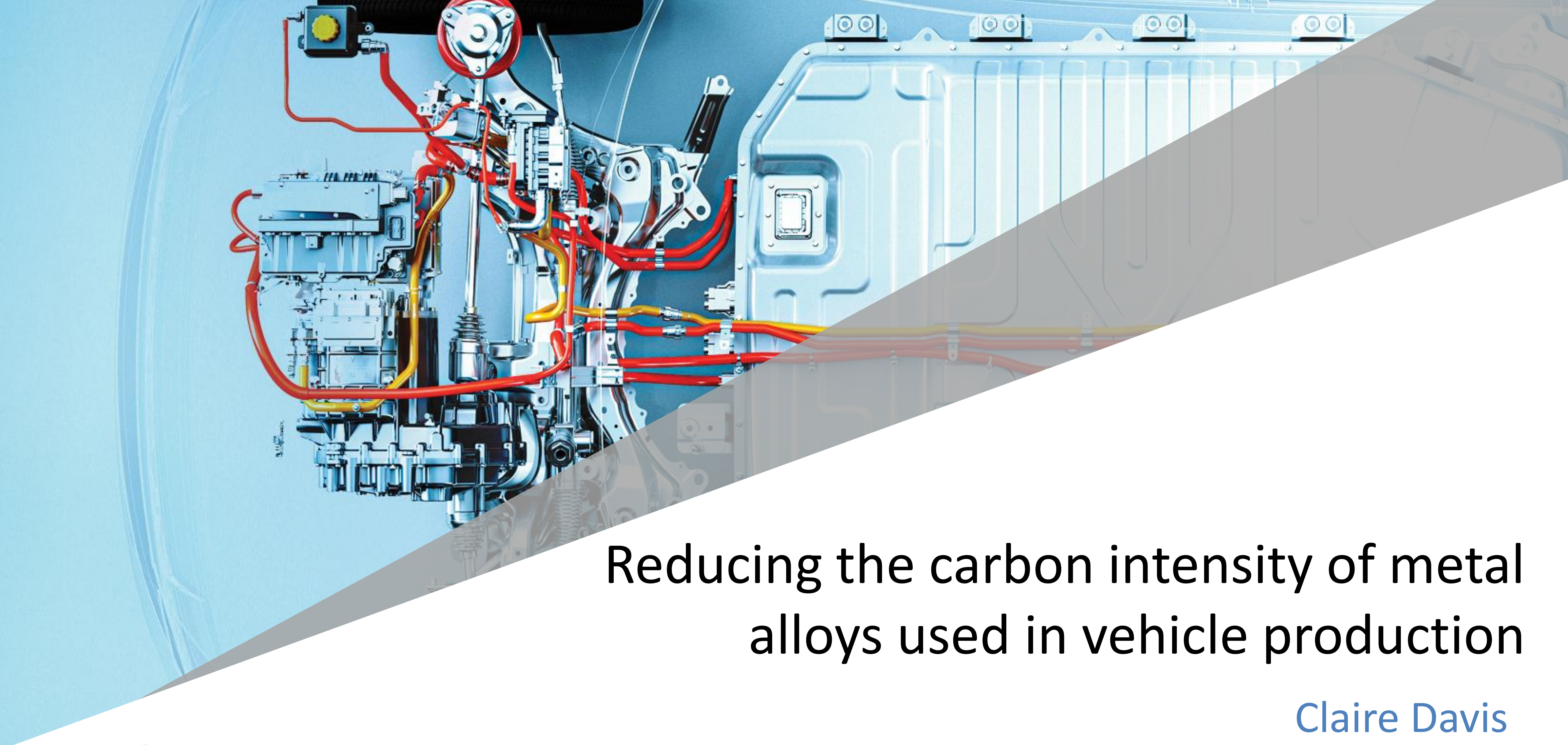

Reducing the carbon intensity of metal alloys used in vehicle production

Claire Davis

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Low Carbon Vehicle Partnership

ADVANCED PROPULSION CENTRE UK

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Issues to be considered

- Energy and carbon costs for steel and aluminium production
- Energy and carbon costs for transportation from producer to fabricator
- Production of improved alloys for light-weighting options
- Recycling
- Design for assembly, disassembly, reuse and remanufacture

Energy and carbon costs for steel and aluminium production

Steel and aluminium are the most commonly used materials for modern vehicles. Primary production of aluminium and steel is very energy intensive but efficient.

In the UK the integrated blast furnace-based process route is the main method used (required for car body steels) and produces about 1.8 t of CO_2 for each tonne of steel with an energy consumption of 24 GJ/tonne. The electric arc furnace scrap melting based route requires only half to two thirds of this energy with a correspondingly lower CO_2 footprint (650 kg CO_2 per tonne of steel).

Primary production of aluminium produces between approx. 5 – 40 t of CO_2 per tonne of aluminium (depending on processing route) whilst the US Department of Energy reports that secondary aluminium production requires 90% less energy than primary production.

Environmental Carbon Footprints Industrial Case Studies 2018, Pages 197-228

https://www.eia.gov/todayinenergy/detail.php?id=16211

Energy and carbon costs for steel and aluminium production

New technologies are being considered to reduce energy and carbon costs for production. Examples include:

- New steel production processes – HYBRIT which uses hydrogen rather than coke and could reduce emissions to 25 kg CO_2 per tonne of steel. Pilot plant facility being built in Sweden (https://www.hybritdevelopment.com/).

- Net shape production: belt casting technology that can reduce energy costs by up to 50%. Alcoa Micromill started production for aluminium alloys in 2016. For steel twin roll casting is used and limited belt casting (Salzgitter Steel)

Alcoa Micromill™
Innovating High Tech Metal
The fastest, most productive aluminum casting and rolling system in the world.

Energy and carbon costs for transportation from producer to fabricator

Transportation of steel or aluminium during production and from producer to consumer also incurs carbon cost.

Example case study (for plate steels):
Carbon cost for transport of overseas produced slab to UK rolling facility is 0.54 t CO_2 per tonne steel compared to 0.20 t CO_2 per tonne steel for UK production of slab transported internally to rolling facility. Ref. CarbonTrust report to WMG 2020

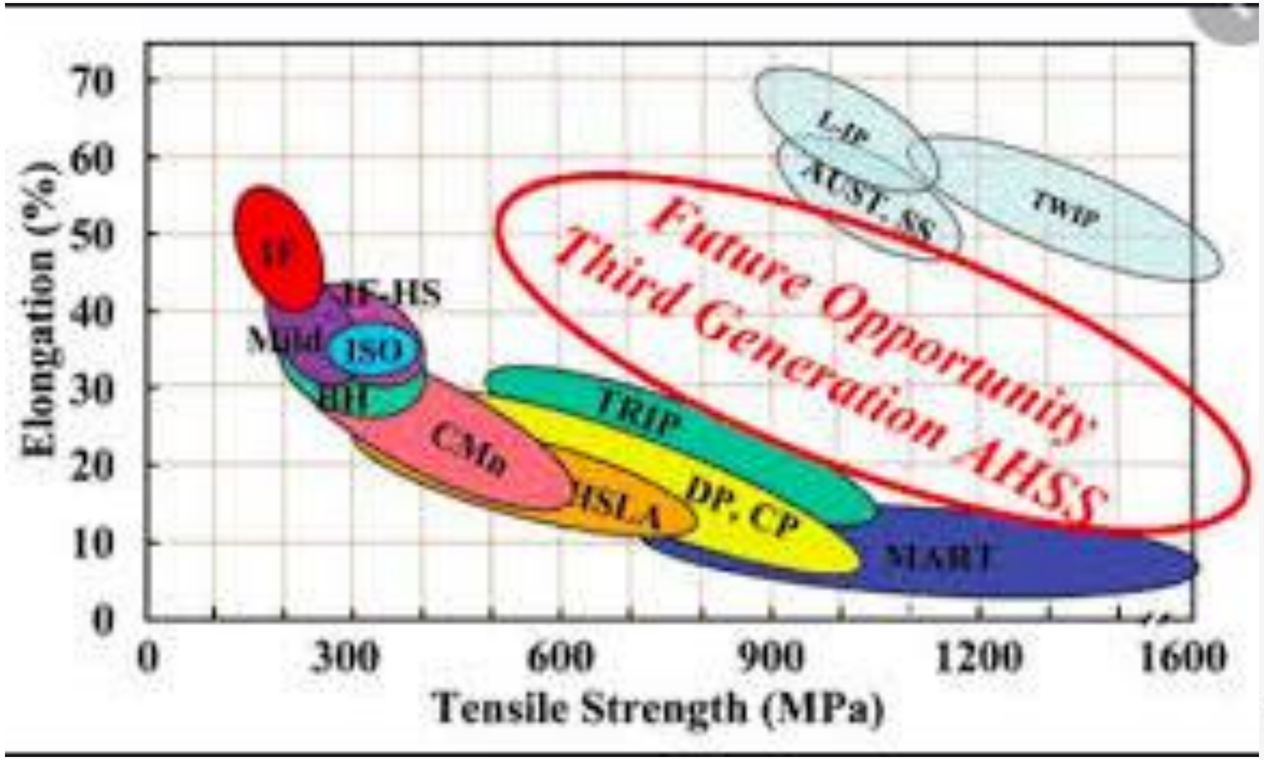
Currently no UK production of primary aluminium. Not all automotive grades of steel are produced in the UK, therefore transportation CO_2 costs are inevitable.

Full energy and CO_2 considerations need to consider local compared to global production and transportation costs.

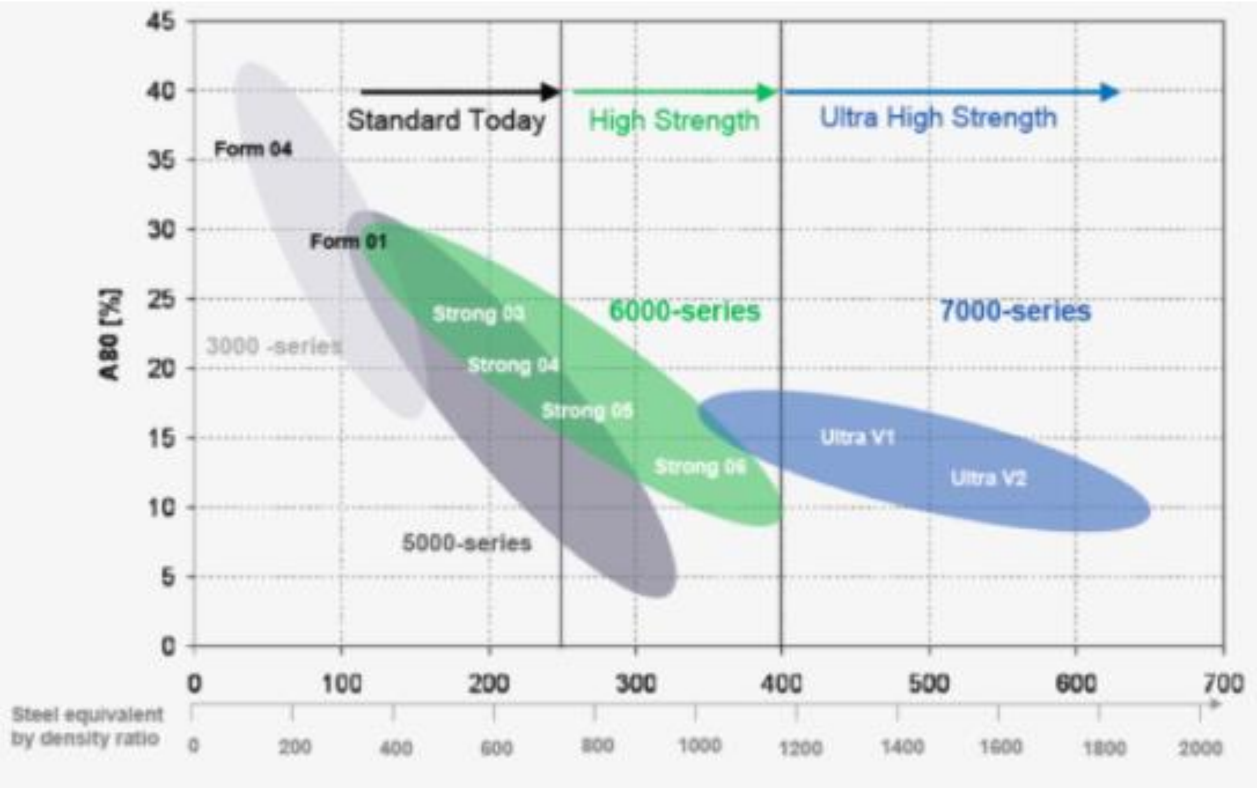
Production of improved alloys for light-weighting options

Aluminium industry and steel industry are continuing to develop improved alloys with higher strength / elongation values to allow light weighting of structures.

New development of Advanced High Strength Steels (AHSS)

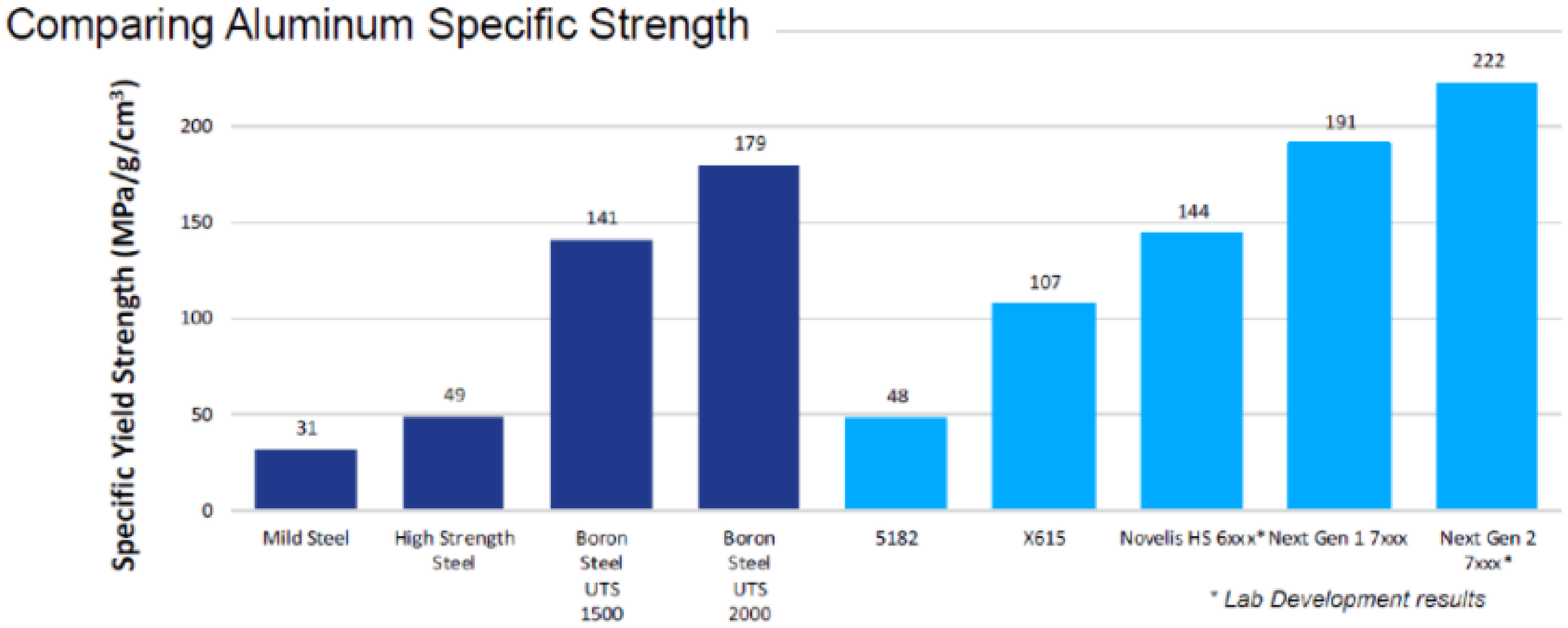


New development of Al alloy sheet for body structures



Production of improved alloys for light-weighting options

Specific properties allow choice between material types.

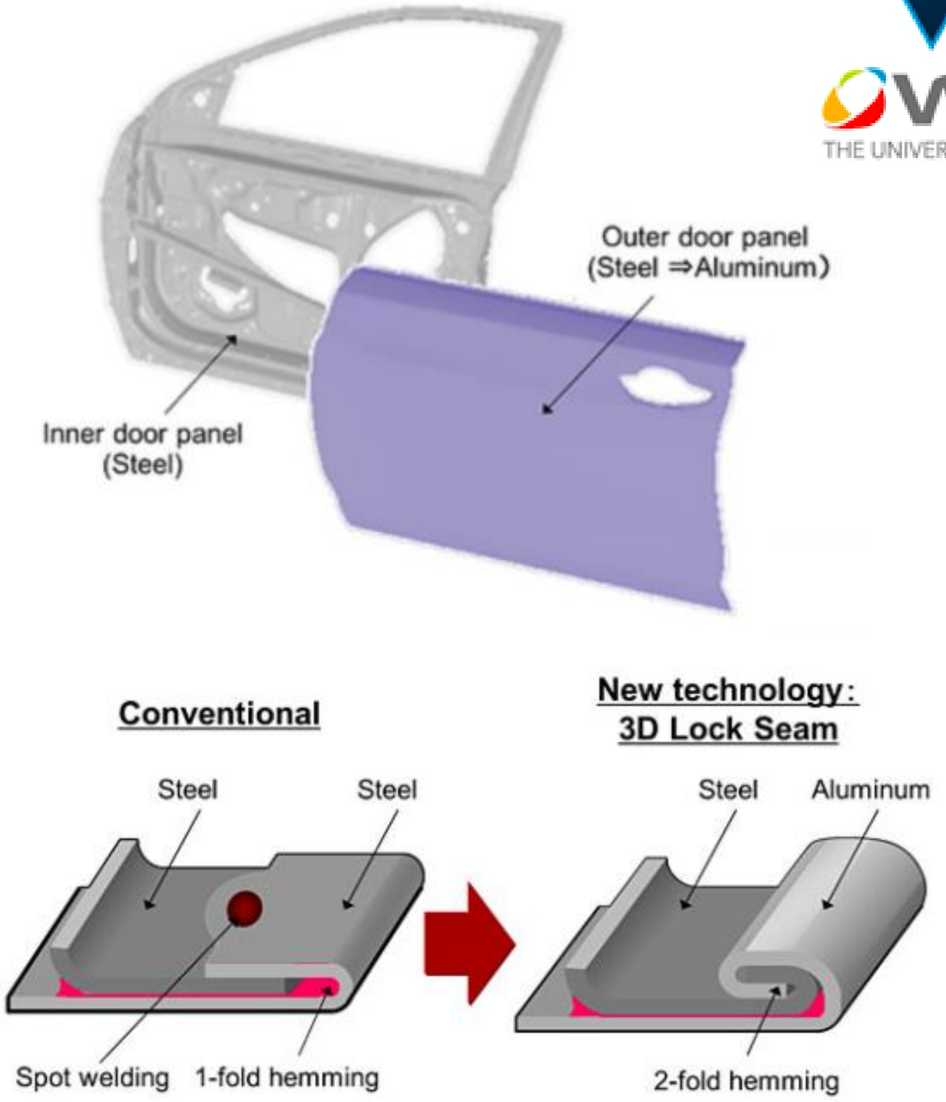


from https://aluminiuminsider.com/aluminium-alloys-automotive-industry-handy-guide/ 2020

Production of improved alloys for light-weighting options

Dissimilar joining is often required when selecting ‘right’ material for a different parts in overall vehicle. This allows better design for light-weighting and hence efficiencies.

New / modified joining approaches are often required:



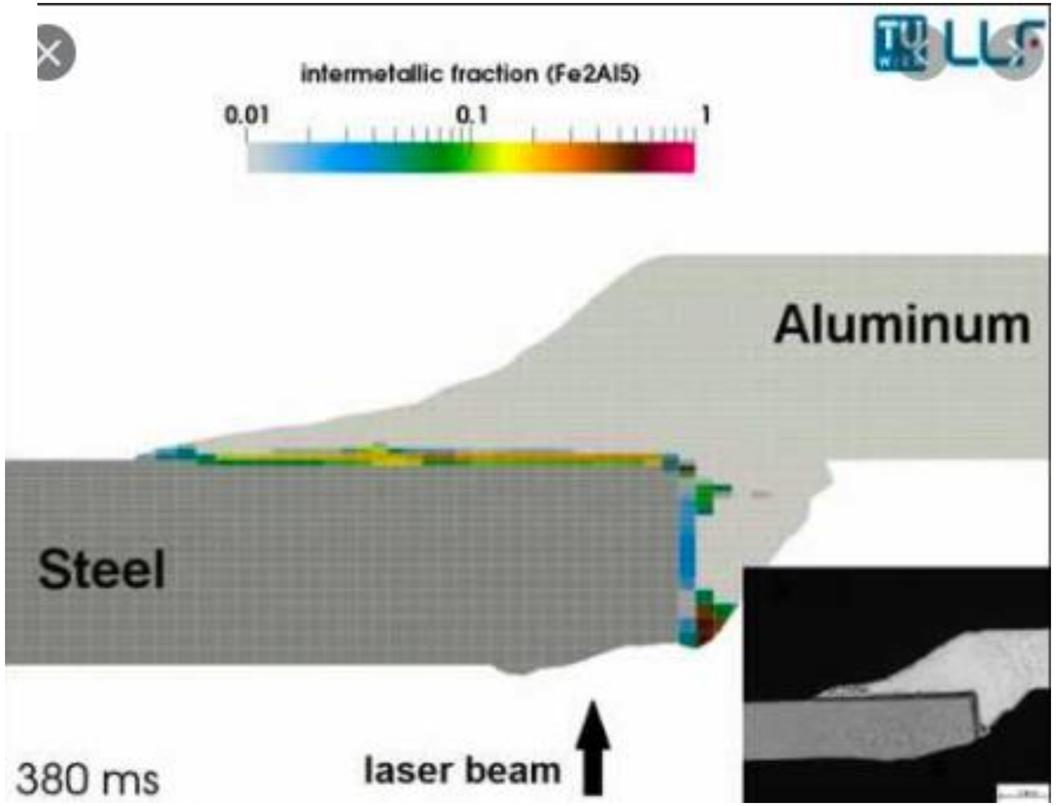
https://www.carbodydesign.com/2013/02/honda-develops-new-technology-to-join-steel-and-aluminum/

Production of improved alloys for light-weighting options

Dissimilar joining is often required when selecting ‘right’ material for a different parts in overall vehicle. This allows better design for light-weighting and hence efficiencies.

New / modified joining approaches are often required.

Care is required to avoid issues, such as intermetallics causing joint failure when laser welding steel to aluminium.



Recycling

To take advantage of the lower energy and CO2 of secondary metal processing it is important to consider the current and future needs for recycling.

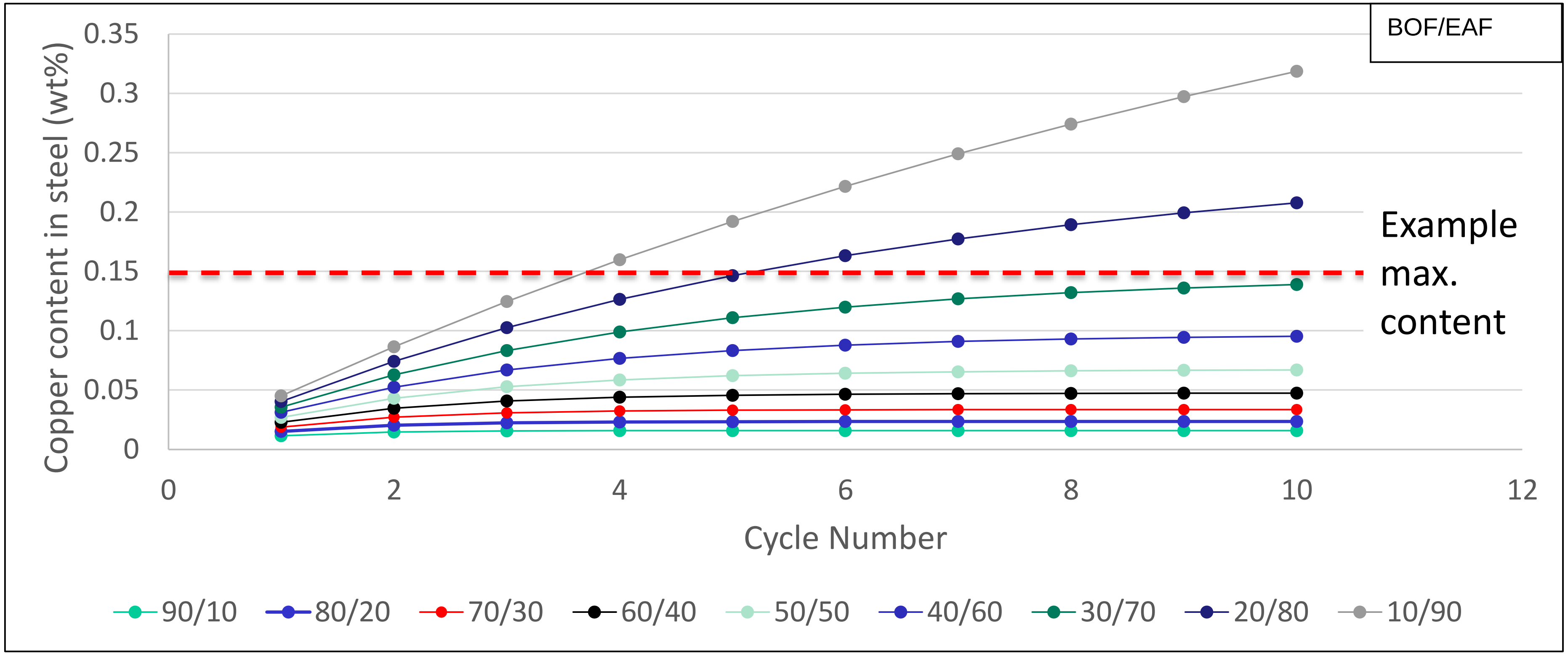
The UK is a net exporter of ferrous scrap, with over 9.3 Mt of ferrous scrap being exported in 2017. Annual scrap consumption in the UK currently stands at around 1 Mt of internally UK generated scrap and 1.4 Mt of imported scrap. End of use vehicles comprise 20% of scrap arising.

Challenges in the UK for more scrap use is related to current plant infrastructure and investment, energy costs, policy and market demand.

An additional challenge for greater scrap use is on the build up of deleterious residual elements (e.g. Cu, Sn) affecting the quality of steel that can be produced. This requires improved sorting of scrap material and more closed loop recycling.

Recycling

Current recycling technology and limits on residual content defines opportunities for increasing scrap use:



Cyclical aggregation of copper due to a theoretical consideration of closed border scrap recycling for BOF and EAF steel production utilising a weighted average of high residual scrap in the BOF at 20% scrap loading and a weighted average of low residual scrap in the EAF at 100% scrap loading.

(ref: S. Spooner, C. Davis and Z. Li, "*Modelling the Cumulative Effect of Scrap Usage within A circular UK Steel Industry – Residual Element Aggregation*"

Recycling

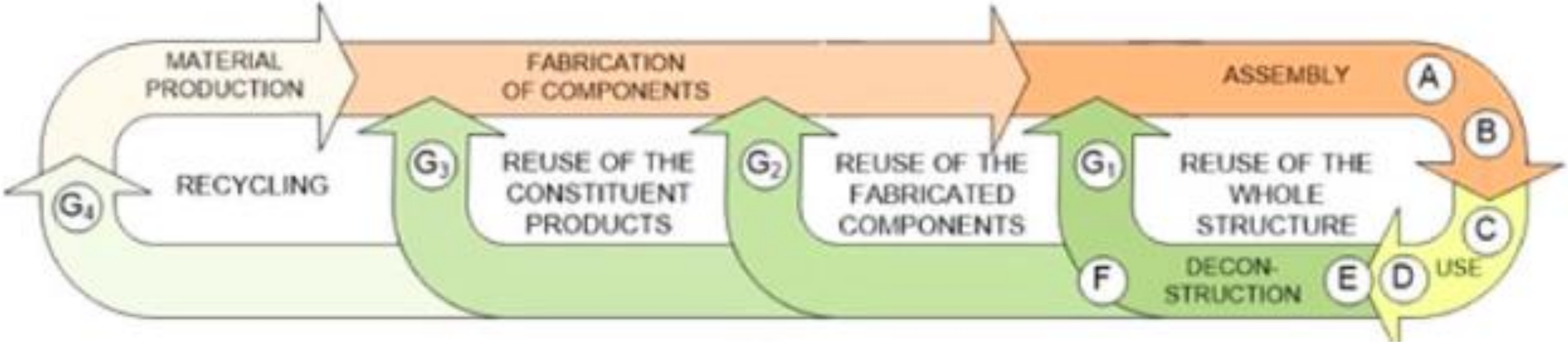
Aluminium in the automotive industry typically falls into two categories (cast and wrought) that use different alloying elements. Important to sort between categories to improve recycling. New technologies, such as laser induced breakdown spectroscopy (LIBS), is being used for compositional analysis for sorting. Closed loop recycling from fabricators is an important element for improved quality control:

For example "Novelis has recently started supplying Jaguar Land Rover with RC5754. This alloy has increased allowances for iron, copper and silicon, allowing the company to make it from 50% production scrap returned from pressing plants. Aleris, for example, incorporates 71 % recycled content in its transportation 3004 alloy, mostly used in truck trailer sheet, horse trailers and irrigation pipes."

from https://aluminiuminsider.com/aluminium-alloys-automotive-industry-handy-guide/ 2020

Design for assembly, disassembly, reuse and remanufacture

Considerations of disassembly and reuse of materials in products in increasing allowing use of lower energy / CO_2 embodied materials. Full LCA required to consider benefits for a given scenario.



Taken from Sirje Vares, Petr Hradil, Michael Sansom & Viorel Ungureanu (2019): Economic potential and environmental impacts of reused steel structures, Structure and Infrastructure Engineering

Design for assembly, disassembly, reuse and remanufacture

Case studies are being developed in different sectors for economic and technical opportunities for disassembly, reuse and remanufacture. Vehicle design should therefore take into account assembly, disassembly, reuse and remanufacture.

Taken from “Dismantling, remanufacturing and recovering heavy vehicles in a circular economy—Technico-economic and organisational lessons learnt from an industrial pilot study” by Michael Saidani, Bernard Yannou, Yann Leroy, François Cluzel in *Resources, Conservation & Recycling 156 (2020) 104684*

Issues considered

- Energy and carbon costs for steel and aluminium production
- Energy and carbon costs for transportation from producer to fabricator
- Production of improved alloys for light-weighting options
- Recycling
- Design for assembly, disassembly, reuse and remanufacture

In summary: there are opportunities for lower energy / CO_2 contribution to full life vehicle assessment from the materials (steel and aluminium) used.

Examples include closed loop recycling, light-weighting via improved materials and design for reuse / remanufacture.