ADVANCED PROPULSION CENTRE UK

Lifecycle CO2e Measures

Collaborate Applicant Guidance

Oct 2025

Why change to lifecycle CO2e?

We want to help you…

- …put together the strongest application
- and identify the most appropriate information to include?
- …capture as many benefits from your project as possible in the simplest way
  - The previous system works for technology that encourages fleet shifts
  - It's clunky for others *E.g. supply chain improvements, production and manufacturing focus, re-use and re-manufacture opportunities.*
  - CO2e enables non carbon greenhouse gas emissions to be tracked and reduced

This new process enables you to capture lifecycle CO2e benefits <u>if applicable to your project.</u>

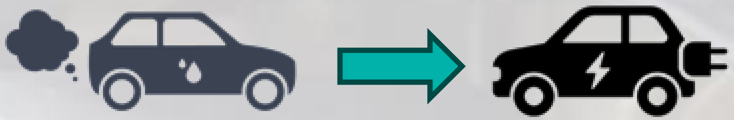
Change is necessary to keep as greenhouse gas reductions a part of APC Competitions.
This widens the benefit capture to include lifecycle impacts, including non-carbon dioxide greenhouse gases (CO2e).

In-use CO2: APC 1-26 (previous method)

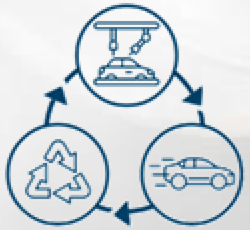
- Applicants required to provide:
  - A comparator vehicle(s) or benchmark
  - A new vehicle with funded technology
  - % impact of this technology from the project (assumption based)
- This calculates a CO2 tailpipe reduction based on the fleet size / volume assumption
- Workarounds have been possible for significant lifecycle impacts (e.g. recycled material, aluminium production, etc)
- *This becomes more challenging:*
  - *ZEV mandate will reduce tailpipe emissions from new light- and heavy-duty vehicles*
  - *It's difficult to articulate the improvement for a 2nd generation ZEV.*

Lifecycle CO2e - DRIVE35 options:

- Provide "best in class"* comparator vehicles to deliver fleet CO2 Tailpipe savings.



- Simplify the process by providing lookup data for lifecycle CO2e* reduction potential from roadmap data.
  - *Key assumptions:*
    - *UK manufactured vehicle with UK energy mix and time-averaged emissions*
    - *Battery material sourced from Asia, manufactured in UK*



- Supply own lifecycle carbon data where available

APC and DBT have designed a process to be as simple as possible to provide lifecycle emissions for the purpose of project appraisal and monitoring.

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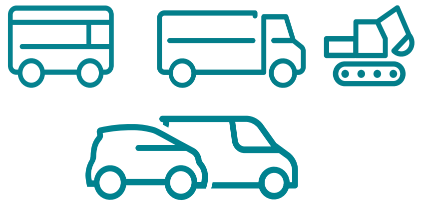
Sections 1,2,5,6

Identify vehicle type and powertrain

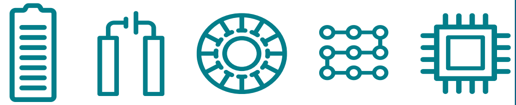
- Customise vehicle by mass, usage, and battery size to scale potential savings.
- Provide comparator vehicles if technology results in tailpipe CO_2e savings from a fleet switch.



Section 3

Select lifecycle stage and technology

- This looks up a potential technology CO_2e reduction from work commissioned with Ricardo in 2025.
- Indicate % of the 2040 potential CO_2e savings

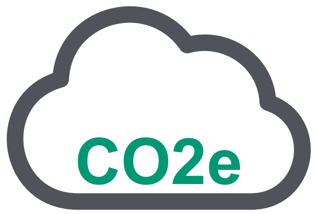


and/or

Section 4

Provide own lifecycle CO2e calculations

- If available (with justification)
- Specifically for material sourcing switches, reuse, increased recycled content, or for other cases not covered by the lookup tables.



Demonstrating significant CO2e impact from your project
How much CO2e is needed to make it worth-while reporting?

Collaborate projects need to meet a minimum return on investment for tax-payer pounds spent. CO2e can form part of this.

- Demonstrating value in the right way adds impact to your project, APC has constructed some guidance to help inform your decision:

- The amount of CO2e savings per vehicle that have an impact on your project's economic ROI will vary based on the number of vehicles planned;
  - 10kg of lifetime CO2e savings per vehicle may make a significant difference across 1 million vehicles…
  - …but with 100,000 planned vehicles, more than 100kg CO2e per vehicle may be required.

    - *Talk to the APC team for further guidance on this.*
    - info@apcuk.co.uk

Things to consider before starting to fill in the form

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The aim of this process is to enable you to capture additional CO2 project benefit to strengthen your application without requiring you to become LCA experts.

Please consider:

- **What technology is being developed, and how it might impact the lifecycle emissions.**
  - E.g. increased cell energy density or lightweighting may have an impact on manufacturing and in-use lifecycle stages.

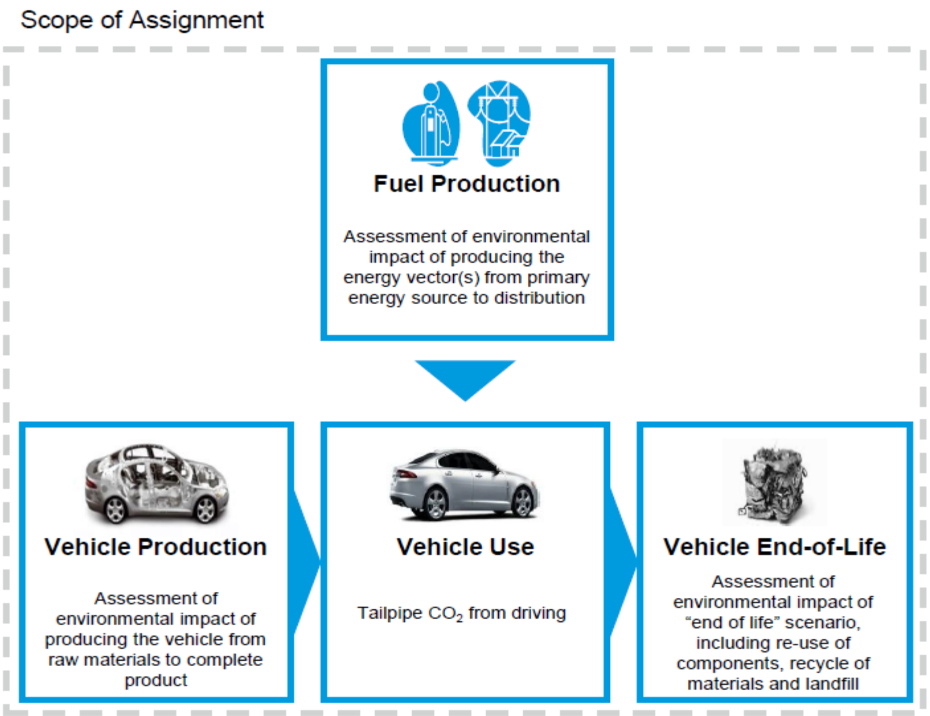
- **Which vehicles and how many will be produced is this technology being applied to**
  - What is your target application vehicle or vehicles? This helps to demonstrate a route to market for your technology.

- **Which lifecycle stages are being impacted**
  - What LCA data have you already considered or gathered data on? You can access APC estimates or provide your own calculations.

- **Consider lifecycle benefits from across your consortium and supply chain**
  - In the past, the project lead would have filled in this form in isolation, are there benefits that could be gained from other parts of the consortium?

Key Assumptions behind estimate lifecycle impacts (section 3)

- Ricardo have delivered a Life Cycle Analysis (LCA) study to review the innovation opportunities to reduce life cycle carbon emissions from vehicles and to quantify the amount of carbon that could be saved through the vehicle life cycle across different use cases, built from improvements detailed in the Automotive Council technology roadmaps.



Assumptions

- All vehicles and materials are manufactured in the UK where possible and Europe for the remainder (except for battery pack production, where global data is used)
- For a specified vehicle segment (e.g. medium passenger car), assume vehicle glider is common across all powertrain types, with CO2 emissions scaled by mass
- Well-to-Wheel (WTW) emission factors of fuels change during vehicle lifetime and is accounted for by time averaged Well-to-Tank (WTT) and Tank-to-Wheel (TTW) factors
    - *This creates accurate results for the vehicle lifetime, but the results cannot be split into the individual years of the vehicle life*
- Carbon intensity of electricity changes during vehicle lifetime and is also accounted for by time averaged emission factors
- Vehicle fuel / electricity consumption does not change with time
- Vehicle fuel / electricity consumption is based on available public domain information, and are not based on vehicle simulations
- No major parts are replaced during the lifetime of vehicle; therefore, carbon impact of maintenance is assumed negligible and is not included
- Vehicle End of Life (EoL) has not been modelled in detail, instead, a factor has been applied to estimate the emissions for vehicle EoL based on embedded emission from vehicle production
- Battery capacities (kWh) which are used for 2025 are not changed for the study in 2030 or 2040
    - *This allows for an increases in energy density and volumetric density to be used as a carbon reduction technology rather than an opportunity for an increased range from increased number of cells*
    - *Assumed emission factor [kgCO2e/kg] constant and overall lifetime emissions changes in 2030 and 2040 with increases in energy density*
- FCEV and H2 ICE vehicles are assumed to produce zero tailpipe emissions during their lifetime

Limitations of the new approach

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- **Section 2: Vehicle**
  - If vehicle specs change over the life of the vehicle, averages may have to be used or variants added for vehicles 2, 3, and 4.
- **Section 3: Lookup CO2e values**
  - This section only allows for **incremental changes to the current vehicle lifecycle**. Significant changes to supply chains, production locations, or technology shifts are not calculated here and data will need to be added to section 4.
- **Section 4: Input own CO2e values**
  - Use this where **evidence/calculations are available** to support values (e.g. Environmental Product Declaration, ISO Life Cycle Impact study).
  - Avoid going too granular in this section. Lifetime CO2e savings over 10kg per vehicle are likely to have an impact on the economic calculations for high volume vehicles, low volume vehicle might need significantly more.
- **Section 5: Comparator vehicles**
  - Only use this section if there is a **strong link from your technology to a fleet change**. This will likely be discounted if other market policies (e.g. ZEV Mandate, clean air zones, etc) force a fleet shift.
  - If comparator emissions change over the vehicle's life, please calculate an average and describe this.

New Form

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Innovation Economic Monitoring Form

Version: Drive35Collab_1.1 26 Sep 2025

Project Title	
Project Number (IFS)	
Lead Partner	
Contact email	
Project starting year	2024/25
Project ending year	2026/27

Please report on a financial year basis, April - March

Key
Select from drop down list
Data entry

Jobs

For each year, report the number of jobs that will be created/safeguarded because of this project, and that persist in that year *(insert additional lines in the middle of the table if needed)*.

Jobs guidance link

Jobs created/safeguarded during the pro *These are typically jobs related to R&D Activity (e.g. if production jobs are supporting protoype builds, please classify them as "R&D")*

Organisation	Job Description	Postcode	Salary	Created/ Safeguarded	Type (R&D/ Manufactu	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30

Description of Jobs created/safeguarded during the project

Jobs created/safeguarded after the proj *These are typically jobs related to industrialising and manufacturing the product developed during the project. Input jobs for up to 10 years post project and describe how you've estimated these jobs*

Organisation	Job Description	Postcode	Salary	Created/ Safeguarded	Type (R&D/ Manufactu	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34	2034/35	2035/36	2036/37	2037/38

Description of Post-project jobs

Spend

Additional spend guidance link

UK Government funding requested for this project

Grant requested	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34
R&D Expediture - Grant										
Capital Equipment - Grant										
Skills & Training - Grant										
Total	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -

UK funding for this project from industrial partners (match)

Match funding	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34
R&D Expediture - Match Funding										
Capital Equipment - Match Funding										
Skills & Training - Match Funding										
Total	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -

Additional UK spend (100% company funded) on related projects because of this project (including any follow-on activity to this project which will not apply for further government funding)

Post Project	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34
R&D Expediture - Post Project										
Capital Equipment - Post Project										
Skills & Training - Post Project										
Total	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -

Description of Additional Spend

TRL / MRL

Please provide a description of the project TRL/MRL level *(insert additional lines in the middle of the table if needed)*

TRL & MRL guidance link

System, sub-system, or technology element	TRL/MRL	Start readiness revel	Please explain why you have assigned this starting level.	Target end readines	Please explain why you have assigned this planned level.	Current readiness level

Technology Segments

Please provide an approximate breakdown of what proportion of the funding will be used for each technology segment

	% Funding
Energy storage and energy management	
Fuel Cells	
Electric Machines and Power Electronics	
Thermal Propulsion Systems	
Lightweight Vehicle & Powertrain Structure	
Electronic and electrical architecture inc. supporting	
Intelligent Mobility	
Other	
Total	0%

This must equal 100%

"Other" description

Innovation CO2e Monitoring Form

Guidance	Use this tab if your project results in a CO2e saving throughout the lifecycle of the vehicle. Follow the numbered steps down throgh Column A and only enter values if relevant to your project/technology

Guidance-CO2e

1: **Define vehicle**
Note: not all powertrain and vehicle types will have estimated lifecycle impacts in section 3.

Vehicle 1

Application Vehicle Type	Pass-car
Powertrain	BEV
Make / Model / Type	

Key
Select from drop down list
Data entry

2: **Adjust default figures** for your specific application (as required), and provide justification.

		Alternative Value	Justification
Lifetime use unit	*km*		
Lifetime use	200,000		
Vehicle Mass - kerb/unladen (kg)	1,500		
Battery Pack Size (kWh)	50		

3: **Lookup estimated lifecycle CO2e impacts.**
If your technology is not listed here, please input your estimates in section 4.
Column H: compare your development plans to the Autocouncil Roadmaps, as a rule of thumb;
60% ~= 2030 technology development
100% ~= 2040 technology development
>100% plan to exceed 2040 technology.
Note: CO2e includes carbon dioxide and other greenhouse gases, expressed in terms of the equivalent amount of cardbon dioxide.

Estimated roadmap CO2e impacts

	Lifecycle stage(s) impacted	Technology developed *If your technology is not listed here, please input your estimates in section 4.*	% Estimated lifecycle CO2e saving realised	CO2e impact per vehicle (kg)	Description of CO2e reduction, please explain reasoning behind % in column H.
1			100%	0	
2			60%	0	
3			60%	0	
4			100%	0	
5			100%	0	
Total CO2e impact per vehicle				0	

<- Unhide for additional rows

Other lifecycle impacts

4: **Enter your own values** (with evidence) if you have you own calculations available.

Enter Lifetime CO2e figures as negative to indicate a reduction of greenhouse gases.

	Lifecycle stage(s) impacted	Technology developed	Lifetime CO2e impact per vehicle (kg)	Description of CO2e reduction, please support with evidence.	Will UK
1					
2					
3					
4					
5					
Total CO2e impact per vehicle			0		

<- Unhide for additional rows

5: **Fleet Change CO2**

If your technology enables a fleet to change to a lower carbon powertrain, enter a representative current vehicle here (instead of in-use lifecycle impacts above).

Describe why this project enables a fleet transition.

		Describe how this project enables a fleet to transition to a lower carbon powertrain and justification for % contribution)
Comparator vehicle type		*Enter justification here*
Comparator Powertrain		
Comparator Make / Model / Type		
Comparator emissions unit	gCO2/km	
Comparator emissions amount		
New vehicle emissions amount		
Project contribution to fleet switch (%)	10%	

6: Enter **number of vehicles** produced/retrofitted per year. Note: carbon savings are lifetime values.

CO2e calculations	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34	2034
Annual production of vehicles					5,000	10,000	10,000	10,000	10,000	10,000	1
% UK Sales					10%	10%	10%	10%	10%	10%	
Fleet change CO2 savings UK (tonne) *Section 5*	-	-	-	-	-	-	-	-	-	-	
Fleet change CO2 savings Global (tonne) *Section 5*	-	-	-	-	-	-	-	-	-	-	
Lifecycle carbon savings UK (tonne) *Sections 3 & 4*	-	-	-	-	-	-	-	-	-	-	
Lifecycle carbon savings Global (tonne) *Sections 3 & 4*	-	-	-	-	-	-	-	-	-	-	

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Lifecycle CO2e Measures

REFERENCE MATERIAL

Oct 2025

Lifecycle reduction detail

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This section explains the meaning of technologies listed in the drop-down boxes in Section 3 of the CO2e tab in the economic monitoring form.

Index:

Battery material sourcing impact

This table can help quantify the CO_2 savings available.
To use, estimate the mass of your pack and multiply by the component.

- The inventory is modelled based on data from Dai et al. (2017; 2018), in which a battery pack of 158 kg, with gross pack energy of 23.53 kWh made of 140 3.6 V- 46Ah prismatic cells is presented. Cells are made of nickel-manganese-cobalt (NMC811) cathode and a silicon coated graphite-based anode, liquid electrolyte and a porous plastic separator. Infrastructure burdens are included. The modelled battery breakdown is provided below:

Battery Pack Component		Breakdown per kg of battery (kg)
Wrought aluminium alloy		0.14
Battery management system		0.024
Battery module packaging		0.06
Copper anode		0.001
Electronic component (passive)		0.004
Ethylene glycol		0.02
Glass fibre reinforced plastic		0.0003
Polyethylene (high density)		0.004
Reinforced steel		0.01
NMC 811 battery cell	Aluminium collector foil	0.02
	Wrought aluminium alloy	0.02
	Battery separator	0.01
	Copper collector foil	0.09
	Copper anode	0.02
	Electrolyte	0.12
	Polyethylene terephthalate	0.002
	Polypropylene	0.001
	Anode, silicon coated graphite	0.16
	NMC811 Cathode	0.27

Vehicle glider/chassis lightweighting

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Technology choices	Description	Reference material
Steel Blend	2040 reduction assumes that the glider is built using 60% renewable energy produced steel (Direct Reduced Iron DRI / Electric Arc Furnace EAF), and 35% recycled content. Assumptions taken from the World Autosteel Report. If your project results in reducing steel used, assume 1.5 kg CO_2 savings for every 1 kg steel reduced.	Lightweight vehicle and powertrain structures Narrative p.20,24
Aluminium Blend	2040 reduction assumes that the glider is built using 60% renewable energy produced aluminium, and 32% recycled content. Reducing aluminium used in the vehicle by 1 kg on average will reduce CO_2eq emissions by ~15 kg, but this is dependent on Aluminium source.	Lightweight vehicle and powertrain structures Narrative p.20,24
Polymer composite structures	Carbon fibre reinforced polymer has been assumed to have no recycled content due to its use in the model to create pressured tanks. BIW applications (e.g. chassis).	Lightweight vehicle and powertrain structures Narrative p.18, 21
Niche additive manufactured parts for lightweighting	For some small parts in mass-volume manufacturing. It is expected that cost barriers can be overcome to realise high-volume additive manufacturing applications. For example, hollow structures, which can be metallic lattice structures produced by laser-sintered additive manufacturing, can offer mass savings on a vehicle component.	Lightweight vehicle and powertrain structures Narrative p.23
High-volume additive manufacturing	It is expected that cost barriers can be overcome to realise high-volume additive manufacturing applications. For example, hollow structures produced by laser-sintered additive manufacturing, can offer mass savings on a vehicle component.	Lightweight vehicle and powertrain structures Narrative p.23
Seat-system lightweighting	Higher focus on sustainability in interior design rather than lightweighting to move away from leather and increase recycled content.	Lightweight vehicle and powertrain structures Narrative p.22
Infotainment lightweighting	Electronics miniaturisation to reduce weight	Lightweight vehicle and powertrain structures Narrative p.22
Cockpit lightweighting	Material and design choices to reduce weight	Lightweight vehicle and powertrain structures Narrative p.22
Seat and cockpit integrated into vehicle structures	A trend to reduce parts count, improve manufacturability, especially in ultra-light vehicles.	Lightweight vehicle and powertrain structures Narrative p.22

BEV powertrain and energy storage

Technology choices	Description	Reference material
Cell Energy Density Improvements	NMC(A) Lithium-Ion Batteries Specific energy: 200–300 Wh/kg (2025) → 300–500 Wh/kg (2040). Energy density: 500–750 Wh/l (2025) → 800–1,300 Wh/l (2040). High-nickel cathodes and silicon-dominant anodes (e.g., NMC(A)/Si) are expected to drive these gains, particularly for luxury and high-performance vehicles. LF(M)P: Specific energy rises from 100–160 Wh/kg (2025) to 150–250 Wh/kg (2040). Energy density increases from 300–400 Wh/l to 400–650 Wh/l in the same period.	EES roadmap narrative
Semi-solid state	Advances in manufacturing (e.g., dry processes, AI-driven material discovery) and electrolyte innovations (e.g., hybrid solid-state systems) will enable the above improvements	EES roadmap narrative
Compact lightweight architectures	Manufacturers are increasingly using lighter materials, such as aluminium and innovative winding designs, to reduce motor weight. Integration of motors into vehicle structures is emphasised to save space and enable flexible designs.	Lightweight vehicle and powertrain structures Narrative
Embedded Sensors	These sensors are integrated into motors to monitor critical parameters such as temperature, vibration, and torque in real time. By enabling predictive maintenance and optimising motor control, embedded sensors contribute to improved lifetime and reduced downtime	EM roadmap narrative
NVH Optimised storage	Active damping techniques involve using electronic control systems to counteract vibrations generated by the motor. In hybrid engines, these systems can adjust motor parameters in real-time to mitigate vibrations, leading to a smoother and more comfortable ride	EM roadmap narrative page 25
Cell-to-chassis batteries	Innovative method of packing battery cells within the structural chassis of the vehicle	EES roadmap narrative page 32
Wireless BMS	Wireless BMS provides a battery management system without a need for wire harnesses and enables simpler battery system architecture	EES roadmap narrative page 29
Improved joint techniques	BIW application. Joining techniques for composites and multi-material parts include adhesive bonding, mechanical fastening and welding. The use of adhesive helps reduce weight on a body structure and aids the disassembly process.	Lightweight vehicle and powertrain structures Narrative p.20
Reduced REE Content	Neodymium-based permanent magnet technology remains dominant, but alternatives like iron ferrite and magnet-free motors are being explored to reduce reliance on rare earth elements.	EM roadmap narrative
Reduced component count		
Material supply impact	If your project considers a resourcing of battery pack manufacturing or supply information, the model will not automatically calculate this. See next slide for a table to help your own calculations.	See next slide

In-use BEV

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Technology choices	Description	Reference material
Cell Energy Density Improvements	Innovative battery materials to improve overall energy density of automotive battery cells	EES roadmap narrative page 19-24
Semi-solid state	Semi-solid state batteries are cells that have electrolyte in either solid or hybrid state	EES roadmap narrative page 21
Compact lightweight architectures	New motor designs are to be developed using advanced simulation tools that allow for the precise modelling of electromagnetic fields and thermal behaviours, enabling better optimisation of motor designs before physical prototyping	EM roadmap narrative page 17 (not sure if it means advanced architecture??)
Reduced wastage of rotor/stator stacking	There is a focus on reducing waste material in multiple parts, including stator and rotor, through design and improved manufacturing techniques	EM roadmap narrative page 24
NVH optimised designs	Active damping techniques involve using electronic control systems to counteract vibrations generated by the motor. In hybrid engines, these systems can adjust motor parameters in real-time to mitigate vibrations, leading to a smoother and more comfortable ride	EM roadmap narrative page 25
Improvement in energy recovery	Improvements to brake blending and energy recovery will improve vehicle efficiency. As regenerative braking improves, this enables the deletion of physical brakes, which are considered a source of particulate emissions	EM roadmap narrative page 27
Submerged cooling for high performance	Innovative cooling techniques to cool the high temperature/performance batteries to maintain optimal efficiency	EES roadmap narrative page 29
Cell-Chassis Batteries	Innovative method of packing battery cells within the structural chassis of the vehicle	EES roadmap narrative page 32
Wireless BMS	Wireless BMS provides a battery management system without a need for wire harnesses and enables simpler battery system architecture	EES roadmap narrative page 29
Vehicle weight reduction materials	Aluminium and polymer composites for battery enclosure and BIW.	Lightweight vehicle and powertrain structures Narrative page 20
Advanced cooling concepts	Advanced Cooling Concepts – Direct Liquid Cooling: Utilising direct liquid cooling methods for winding, stator, and rotor components significantly enhances heat dissipation	EM roadmap narrative page 19
Aero and tyre efficiency improvements	While not relating to lightweighting, this is important with regard to air-particulate regulations, especially HDV applications.	Lightweight vehicle and powertrain structures Narrative page 18

In-use ICE (Diesel and Gasoline)

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Technology choices	Description	Reference material
Biofuel blend	Biofuel blends are an interim solution to lower carbon fuels, that include a mixture of a biofuel, such as bioethanol or biodiesel with conventional fuels like petrol or diesel. Differing blend levels are available, such as 10%, 20%,etc.	Internal Combustion Engines Narrative Report p.28
Widespread cylinder deactivation, VVT and VVL	Flexible valve events can also enable increased efficiency measures such as cylinder deactivation, variable valve timing, and further design optimisations.	Internal Combustion Engines Narrative Report p.19
Advanced turbocharging	The use of waste-heat recovery (WHR) increases the power output and efficiency of the system whilst reducing emissions. Current examples of WHR systems are turbo-compounding and ORC.	Internal Combustion Engines Narrative Report p.20
Reduced heat loss	A common trend in engine development is to reduce this heat loss through a number of options which can include moving to more advanced coatings and materials, such as ceramic and silicone-based. The alternative materials still need to have the same properties, such as high adhesion at high temperatures, durability, corrosion resistance and high-load capacity.	Internal Combustion Engines Narrative Report p.19
Fuel Injection Innovations	As combustion cycles change, new fuels are introduced, high-efficiency gains are targeted, and injection systems will continue to develop. Several examples are listed in the roadmap.	Internal Combustion Engines Narrative Report p.22
Engine downsizing	From now until 2030, the general trend seen in engine design is 'right-sizing'. Simply just down-sizing may not be the right path for all. This applies to both streams and is paired with increasing hybridisation and efficiency in the ICE engine design	Internal Combustion Engines Narrative Report p.21
Vehicle weight reduction materials	Aluminium and polymer composites for BIW.	Lightweight vehicle and powertrain structures Narrative report p.20
Friction reducing technologies	In wet compression, water is injected at an inlet providing continuous cooling due to the evaporation of water droplets in the air compression process, offering a high efficiency and lower pollutant emissions.	Internal Combustion Engines Narrative Report p.19
Improved aftertreatment systems	Some examples of diesel after-treatments include diesel particulate filters (DPFs), lean NOx trap and diesel oxidation catalysts. For gasoline-fuelled engines, potential after-treatments could include active catalytic coating, three-way catalysts (TWCs) and electrically heated catalysts. Hydrogen also benefits from after-treatment systems to tackle NOx.	Internal Combustion Engines Narrative Report p.23
Automated transmission technology, engine down speeding and gear ratios	Transmissions enable optimum engine operations, particularly when moving towards 10+ gear smarter automatic transmissions replacing existing manual transmissions. These new transmissions should operate more closely with the smarter onboard systems, for example, using V2X and powertrain control to manage gear selection	Internal Combustion Engines Narrative Report p.26
Aero and tyre efficiency improvements	While not relating to lightweighting, this is important with regard to air-particulate regulations, especially HDV applications.	Lightweight vehicle and powertrain structures Narrative report p.18

In-use H_2 ICE

Technology choices	Description	Reference material
Advanced turbocharging	The use of waste-heat recovery (WHR) increases the power output and efficiency of the system whilst reducing emissions. Current examples of WHR systems are turbo-compounding and ORC.	Internal Combustion Engines Narrative Report p.20
Reduced heat loss	A common trend in engine development is to reduce this heat loss through a number of options which can include moving to more advanced coatings and materials, such as ceramic and silicone-based. The alternative materials still need to have the same properties, such as high adhesion at high temperatures, durability, corrosion resistance and high-load capacity.	Internal Combustion Engines Narrative Report p.19
Fuel Injection Innovations	As combustion cycles change, new fuels are introduced, high-efficiency gains are targeted, and injection systems will continue to develop. Several examples are listed in the roadmap.	Internal Combustion Engines Narrative Report p.22
Widespread VVT	Flexible valve events can also enable increased efficiency measures such as cylinder deactivation, variable valve timing, and further design optimisations.	Internal Combustion Engines Narrative Report p.19
Vehicle weight reduction materials	CFRPs are key materials used in the production of hydrogen tanks due to their exceptional strength-to-weight ratio, durability and resistance to high pressures. Hydrogen tanks are critical components in fuel cell vehicles and CFRPs offer significant advantages over traditional materials like steel or aluminium. Type III and IV tanks use CFRPs (refer to the Hydrogen Fuel Cell System and Hydrogen Storage Technology Roadmap).	Lightweight vehicle and powertrain structures Narrative ' Narrative report p.21
Friction reducing technologies	In wet compression, water is injected at an inlet providing continuous cooling due to the evaporation of water droplets in the air compression process, offering a high efficiency and lower pollutant emissions.	Internal Combustion Engines Narrative Report p.19
Automated transmission technology	Transmissions enable optimum engine operations, particularly when moving towards 10+ gear smarter automatic transmissions replacing existing manual transmissions. These new transmissions should operate more closely with the smarter onboard systems, for example, using V2X and powertrain control to manage gear selection	Internal Combustion Engines Narrative Report p.26
Aero and tyre efficiency improvements	While not relating to lightweighting, this is important with regard to air-particulate regulations, especially HDV applications.	Lightweight vehicle and powertrain structures Narrative report p.18

In-use fuel cell

Technology choices	Description	Reference material
Reduced parasitic losses	The fuel cell requires numerous ancillary components and systems for monitoring and operation, such as blowers, compressors, filtration systems, water management, etc. These consume power continuously for safety and management of the entire system. A focus is to reduce these losses to improve system efficiency.	Hydrogen Fuel Cell and Hydrogen Storage Narrative reportp.22
Built in cell diagnostics	There is a requirement for high-detail cell management within the fuel cell to inform design decisions to increase cell health as well as built-in cell management paired with software-controlled systems. This would allow prolonged cell life by managing the fuel cell components on a micro-scale, with a view to having wider stack voltage management to manage systems on a less focused scale.	Hydrogen Fuel Cell and Hydrogen Storage Narrative reportp.20
Non-woven carbon fibre gas diffusion layers	The GDLs, as part of the membrane electrode assembly (MEA), are a porous material, typically composed of a dense array of carbon fibres, providing an electrically conductive pathway for current collection. They also perform the function of reactant transport, heat / water removal, mechanical support and corrosion protection.	Hydrogen Fuel Cell and Hydrogen Storage Narrative reportp.19
Improved membranes and ionomers	The operating temperatures for PEMFCs, usually run at around 60-80°C, which limits the energy conversion rate and directly affects the performance and efficiency of the fuel cell stack. At levels of above 120°C, these fluoropolymer membranes face limitations with proton conductivity, thermal stability and water management.	Hydrogen Fuel Cell and Hydrogen Storage Narrative reportp.18
High performance resins	Thermoset resins are used in compressed-gas storage, primarily for the barrier properties, safety and durability capability offered. The current barrier to mass adoption is high material requirement costs, and bringing these down will greatly increase the amount of high-volume manufacturing.	Hydrogen Fuel Cell and Hydrogen Storage Narrative reportp.26
Highly optimised for high temp operation	Ensuring the fuel cell remains at the optimal temperature for efficiency is crucial, and this is achieved through various thermal management components within the balance-of-plant, including heat exchangers and fan systems to dissipate heat. The optimal temperature currently for a PEMFC is around 80°C. A higher temperature than this can affect performance and could potentially cause irreversible damage to fuel cell components, such as the membrane.	Hydrogen Fuel Cell and Hydrogen Storage Narrative report p.21
Vehicle weight reduction materials	Type 5 tanks are similar to Type 4; however they do not have a liner, and instead rely on an all-composite shell which acts as the liner. This allows a greater reduction of material costs, manufacturing complexity and the introduction of lightweight design, but at the cost of a lower usable hydrogen capacity.	Hydrogen Fuel Cell and Hydrogen Storage Narrative report p.26
Aero and tyre efficiency improvements	While not relating to lightweighting, this is important with regard to air-particulate regulations, especially HDV applications.	Lightweight vehicle and powertrain structures Narrative report p.18

End of life

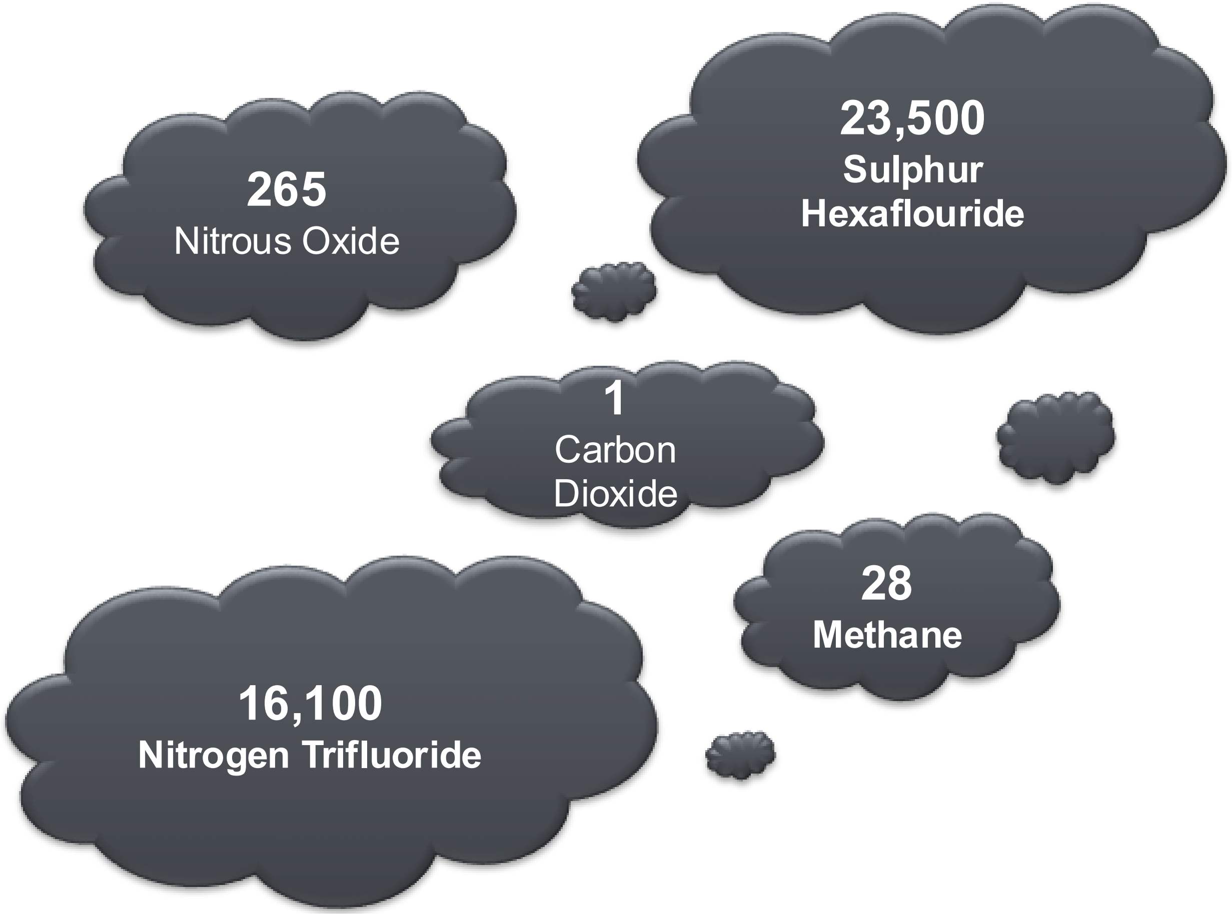
Technology choices	Description	Reference material
Design for disassembly	- To increase the amount of recycled material available, there is a need to design for disassembly. With some designs that have a high level of integration with other vehicle components, it could be challenging - To enable a vehicle to be taken apart at the end of its life cycle is crucial for efficient recycling, repair, and maintenance. Designing for easy disassembly from the start of the process facilitates the separation and recycling of materials, reducing waste and the need for virgin materials.	EM roadmap narrative page 29 Lightweight vehicle and powertrain structures Narrative page 4
New methods of material segregation	New methods for material segregation are being developed, not only to segregate magnet material, but also to ensure high-grade copper can be segregated for reuse alongside segregating the steel and aluminium	EM roadmap narrative page 30
Techniques for material recovery	To improve circularity, production waste will be reduced and more recycled content will be integrated into the production phase	EM roadmap narrative page 29
Cell-to-chassis batteries	Innovative method of packing battery cells within the structural chassis of the vehicle	EES roadmap narrative page 32
Hybrid disassembly	Human robot co-operation, for example via telerobotics, can improve disassembly times and mitigate safety hazards	EES roadmap narrative page 34
Demagnetisation techniques	New techniques and technologies are needed to disassemble used magnets in an easier way	EM roadmap narrative page 30

ADVANCED PROPULSION CENTRE UK

CO2e – it's not just carbon dioxide

Different green house gases have different Global Warming Potential (GWP)

Project reporting is moving to Carbon Dioxide equivalents (CO2e), which enables the effects of the main greenhouse gases to be measured and compared.



Data: GWP given for 100yr time horizon, IPCC 2021, expressed as multiples of CO2's GWP.
E.g. 1 kg of methane with have 28 times the effect on global warming as 1kg of CO2.