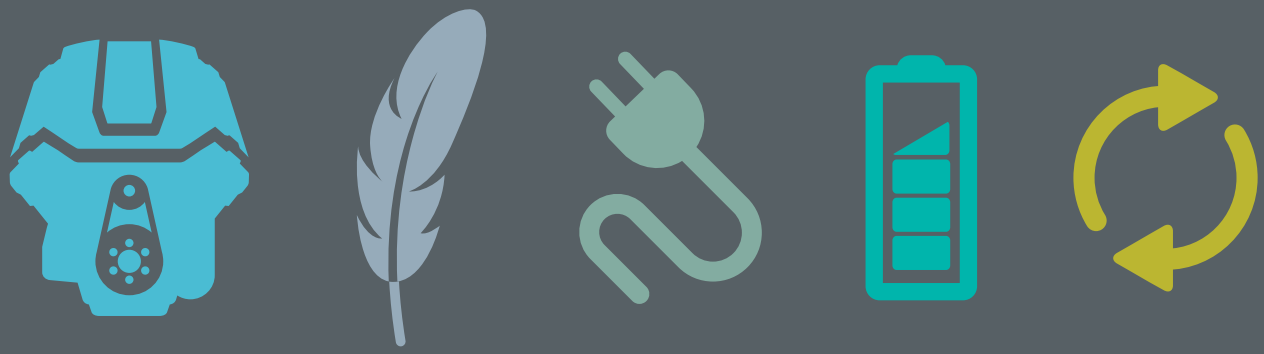
Department for Business, Energy & Industrial Strategy

automotive council UK

Low Carbon Automotive Propulsion Technologies

The UK's capability to capitalise upon future technology-led research-to-manufacture supply chain opportunities



ADVANCED PROPULSION CENTRE UK

RICARDO

E4tech
Strategic thinking in sustainable energy

Produced by the Advanced Propulsion Centre UK in collaboration with Ricardo and E4tech on behalf of the Automotive Council UK

Low Carbon Automotive Propulsion Technologies

The UK's capability to capitalise upon future technology-led research-to-manufacture supply chain opportunities

Further information

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Foreword

Dr. Graham Hoare
Chair, Automotive Council Technology Group

This study successfully builds upon the foundations of the Automotive Council's consensus roadmaps and definition of the key strategic technologies for the UK automotive industry to identify tangible low carbon propulsion-related opportunities for the UK research-to-manufacture supply chain. The report helps us to celebrate the numerous capabilities of the UK automotive sector, including our world-leading research, world renowned aptitude for innovation and world-class manufacturing productivity. However, it also shines a light on the challenges faced by the UK automotive industry as it competes in a highly competitive global market place. Since its inception in 2009, the Automotive Council and its members have worked tirelessly to position the UK automotive industry for a prosperous future through its Technology, Supply Chain and Business Environment and Skills working groups. For example, in 2016 the Automotive Council is forming Challenge Networks to improve alignment of academic research with future industry challenges. The Automotive Council looks forward to continuing working with UK Government, academia and industry to ensure that the opportunities highlighted in this report can be capitalised upon to provide sustainable benefit to the UK.

The report helps us to celebrate the numerous capabilities of the UK automotive sector, including our world-leading research, world renowned aptitude for innovation and world-class manufacturing productivity

DR. GRAHAM HOARE

automotive council UK

Ian Constance

Chief Executive, Advanced Propulsion Centre

This study has highlighted how the need to drastically reduce carbon and pollutant emissions to meet legal commitments and address societal challenges is generating new opportunities as it drives rapid technological change in vehicle propulsion systems. Organisations operating in the UK can build upon world-class research, development and manufacturing capabilities to capitalise upon these technology-led disruptions to incumbent supply chain positions. However, the international competition for these opportunities is fierce and the incumbent supply chain is very strong so the UK needs to act quickly and use collaboration to mount a credible challenge, else these opportunities could become threats. Collaboration underpins the Advanced Propulsion Centre programme. The Advanced Propulsion Centre co-invests in collaborative research and development projects, building upon UK Government investments made via EPSRC and Innovate UK to accelerate the development of low carbon and low emissions technologies. In addition the Advanced Propulsion Centre is facilitating broader collaboration through the Spoke network, which draws together communities with common technical interest from academia, industry and other supporting organisations. The Advanced Propulsion Centre team is looking forward to working with the Spoke communities and other agencies to identify and execute the actions that will enable the UK to capitalise upon the opportunities identified by this study.

> The need to drastically reduce carbon and pollutant emissions to meet legal commitments and address societal challenges is generating new opportunities as it drives rapid technological change in vehicle propulsion systems

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How to interpret this study

This study aims to represent the capabilities of and opportunities for the whole of the UK automotive industry, which encompasses a broad range of market sectors and organisation types. Therefore it is important to define how this study is intended to be interpreted.

This study does:

- Build upon the 2010 *Automotive Technologies: The UK's current capability* report published by the Technology Strategy Board (now Innovate UK) and endorsed by the Automotive Council Technology Group.
- Focus on low carbon propulsion technologies with application in on and off-road automotive market sectors, including: motorcycles, passenger cars, buses, coaches and on and off-highway commercial vehicles.
- Combine quantitative and qualitative insights gathered from a range of academic and industry stakeholders representing 152 different organisations with insights developed by a consulting team to identify key areas of capability and opportunity.
- Aim to frame dialogue between UK Government, academia and industry regarding future opportunities relating to low carbon propulsion technologies.
- Provide a basis for stakeholder feedback to feed into future Automotive Council road-mapping and capability studies.
- Represent a snapshot in time and requires update on a periodic basis to reflect the changing technological landscape and evolving capability of the UK automotive industry.

The study does not:

- Aim to pick specific technology winners, it prioritises technology options based upon their attractiveness as global market opportunities and the UK's ability to develop and/or supply them.
- Include the development of fuels/energy vectors and their supply infrastructure.
- Consider automotive technologies not directly related to lowering the carbon emissions of vehicle propulsion; specifically intelligent transport system technologies which will be addressed in appropriate detail by other studies.
- Provide any indication of the future investment strategy of the Advanced Propulsion Centre or any other organisation.
- Act as a guide for any individual organisation's strategy; the opportunities identified may or may not be suitable for any individual organisation and further due diligence would be required to ascertain this.

This study aims to represent the capabilities of and opportunities for the whole of the UK automotive industry

Executive summary

The Advanced Propulsion Centre exists to position the UK as a centre of excellence for low carbon propulsion development and production. The low carbon and air quality agendas are driving rapid technological change in transport propulsion systems, creating the potential for new opportunities whilst simultaneously threatening incumbent supply chain positions.

The Advanced Propulsion Centre has conducted this study on behalf of the Automotive Council in order to identify technology-led disruptions to established automotive supply chains that could provide opportunity to grow and sustain low carbon propulsion-related strategic capabilities in the UK.

How we conducted the study

The study focussed on propulsion technologies applicable to motorcycles, passenger cars, buses, coaches and on and off-highway commercial vehicles. It analysed the supply chain positioning of hundreds of companies, the investment of public funds in 427 projects, the registration of thousands of patents, the submission of 125 surveys and the insight of 76 influential industry stakeholders in order to determine notable aspects of UK capability, define likely future industry needs and identify potential opportunities for the UK related to low carbon propulsion technologies. 152 different organisations contributed to the study, varying in size from micro to large and varying in supply chain position from academic research through to vehicle manufacturer.

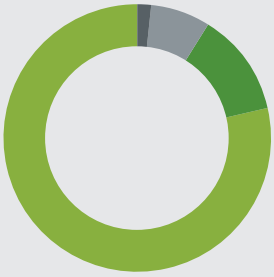
A balanced view of the UK's capabilities was ensured by securing contributions from organisations headquartered inside and outside the UK and respondents inside and outside the UK. It is important to focus on priorities in order to unite industry, government and academia regarding the technology-led opportunities that are most likely to be of importance in the future, and upon which the UK can deliver. Therefore the opportunities have been prioritised into 3 categories based upon how attractive the market appears to be and how well positioned the UK is to capitalise upon it: Focus; Invest to Improve; Opportunistic. The analysis was tested and refined with the help of 59 experts through consensus-building workshops leading to the summary presented in this report.

The study focussed on propulsion technologies applicable to motorcycles, passenger cars, buses, coaches and on and off-highway commercial vehicles

152 organisations contributed to the study

125 online surveys completed

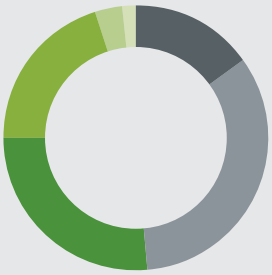
76 stakeholders interviewed

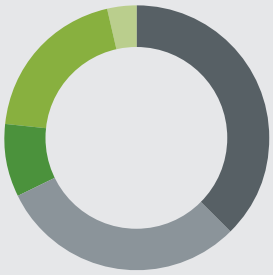


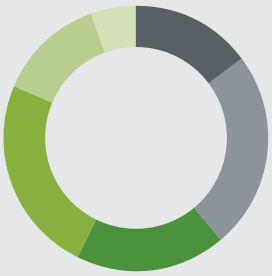
59 workshop participants

Representing organisations of greatly differing size:

Micro Small Medium Large







And a variety of different supply chain positions:

Vehicle Manufacturer Supplier Technology Developer

Engineering Service Provider Research Other

The key potential opportunities for the five technology themes can be found on page 14

The UK's low carbon propulsion technology capabilities and strategic growth opportunities

The drive to dramatically reduce emissions and the resultant trend towards electrification of the vehicle powertrain is disrupting incumbent supply chains and providing opportunity for organisations willing to embrace change. This study has identified a number of opportunity areas that align with strong capability and latent potential in organisations operating in the UK. These provide the potential for the UK to build a strong future supply chain position given suitable investment. The identified UK capabilities, needs and opportunities are organised into 5 technology themes:

Engines

The combustion engine has been the dominant automotive propulsion technology for over 100 years, with production controlled by the vehicle manufacturers and key technologies delivered in partnership with global Tier 1 suppliers. Its dominance is threatened by the electric motor, but the combustion engine still has an important role to play for many years to come. Combustion engines provide an affordable pathway to long-range zero emissions capable vehicles through plug-in hybrid and range-extended powertrains. Furthermore most heavy duty vehicles will rely on efficient combustion engines to haul their heavy payloads over demanding duty cycles until there is a major breakthrough in electrical energy storage technology. There is a clear imperative to minimise the pollutant emissions of engines, whether they combust fossil or alternative fuels, providing good opportunity for organisations working in these areas. The UK has a world-class engine research-to-manufacture capability and produces over 2.4 million engines per year, most of which are exported. This foundation, combined with a strong innovator community, positions the UK to capitalise upon incremental improvement opportunities (such as emissions control, adaptation for electrification, electrified boosting, and waste heat recovery) as well as more radical concepts (such as zero tailpipe emission expansion engines). However, UK organisations are operating in a highly competitive global market and are challenged by a manufacturing cost base that has resulted in a lot of Tier 2 component supply moving off-shore.

Transmissions, driveline and kinetic energy recovery systems

The transmission and driveline market is mature, using relatively stable technology produced by both vehicle manufacturers and Tier 1 suppliers. However, new hybrid and electric powertrains are creating opportunity for disruptive transmission and kinetic energy recovery system (KERS) concepts.

High volume vehicle manufacturers will continue to source simplified transmissions for electrified powertrains either in-house or from established Tier 1 suppliers, but those suppliers may be driveline rather than transmission specialists. Low volume vehicle manufacturers will need to source electrified powertrains from Tier 1 suppliers that can provide tailored solutions. High volume transmission manufacturing is somewhat limited in the UK, but the UK is home to world-class transmission design and motorsport transmission production capabilities. This positions the UK strongly to provide engineering services and license IP for new transmission concepts, in addition to Tier 1 supply at low volumes if existing motorsport-derived supply chains can be scaled to provide cost effective solutions at higher than existing niche production volumes.

The kinetic energy recovery system market is embryonic, but with good potential for improving the efficiency of bus and off-highway applications that do not require zero emission running. The UK is a global leader in flywheel KERS technology and could be well placed to meet bus and off-highway manufacturers' needs if current niche volume manufacturing capability can be scaled to be cost effective for thousands to tens of thousands of units.

Traction electric machines and power electronics

Irrespective of whether fuel cell, plug-in-hybrid or battery electric vehicles dominate in the future, electric machines and power electronics will be required to convert their stored energy into motion. Vehicle manufacturers' supply chain strategies are still emergent, but this study has identified a trend for high volume manufacturers to migrate toward in-house manufacture, whilst lower volume manufacturers migrate toward Tier 1 solutions. There will potentially be strong future demand from UK manufacturers of buses and low volume luxury / high performance passenger cars for Tier 1 solutions and UK manufacturers of high volume passenger cars for Tier 2 components. This will present opportunities for Tier 2 and Tier 1 suppliers alike, in addition to engineering service providers and research organisations. The UK can leverage its strong research and development capability, a wealth of innovative SMEs, world-class engineering service providers and experience in manufacturing lower power electric machines and power electronics to capitalise upon these demands. However, capability investment and process innovation will be required to ensure large machines can be cost effectively manufactured in high volumes in the UK.

Traction batteries and fuel cells

Whether the liquid fossil fuel tank becomes an electrochemical battery in an electric vehicle or a hydrogen tank in a fuel cell vehicle, the migration to zero tailpipe emissions vehicles provides opportunities for the energy storage supply chain to capture increased value.

Whilst the supply chain for traction battery packs is nascent, the study has identified a trend for high volume vehicle manufacturers to migrate toward in-house traction battery system assembly, using either bought-in cells or cells manufactured in-house (most likely through joint venture with a specialist cell supplier). Conversely the trend is for lower volume manufacturers migrate toward turnkey Tier 1 battery system supply. This potentially presents opportunities for Tier 1 and Tier 2 suppliers, in addition to engineering service providers and research organisations. The UK is well positioned to meet emerging domestic low volume Tier 1 demand through its renowned systems integration skills and experience producing battery systems in niche volumes. The UK could also capitalise on high volume Tier 2 material and component supply opportunities as it has a strong track record of attracting high volume vehicle manufacturing, which will need close-to-plant final assembly of battery systems to minimise logistics costs. However, beyond Nissan the UK lags behind on the high volume experience curve and needs to invest to capitalise on this opportunity.

Opportunities related to fuel cells are less clear as the immaturity of the technology is such that the major vehicle manufacturers are still in the early stages of market exploration. The UK already capitalises upon Tier 2 supply opportunities to the major vehicle manufacturers, specialising in high intellectual property components. The UK is also positioned to capitalise on any potential low volume Tier 1 supply opportunities as it is home to a number of world-leading businesses developing complete fuel cell systems.

Lightweight technologies

Lighter vehicles are more efficient, whether they be an electric powered car, a hybrid powered bus or a combustion engine powered earth moving machine. The imperative to reduce vehicle weight is very strong, particularly as electrified powertrains are tending to increase mass.

The design and construction of the body structure, which often grabs the headlines through large mass reductions, tends to be controlled by the vehicle manufacturer but every single component from each different supplier contributes to the overall vehicle mass and needs to be optimised. The study has highlighted the strong UK domestic demand for lightweighting in premium and high performance passenger cars. The study has also identified a risk that manufacturers of lower volume vehicles will be disadvantaged as the majority of lightweighting R&D activity is focussed on the requirements of high volume passenger cars, which differ significantly from those of specialist vehicles. This potentially presents opportunities for engineering service providers and component suppliers that can help low-to-mid volume and specialist vehicle manufacturers harness advanced materials and design and process techniques to lightweight their products.

The UK is globally recognised as a leader in lightweight technologies, with a reputation forged in the aerospace, defence and motorsport industries. This reputation, combined with strong R&D capability, positions the UK to capitalise upon lightweighting opportunities, including supply to domestic manufacturers and engineering services to global manufacturers. Longer-term, an evolving sustainability agenda is likely to drive demand for lightweight materials with lower embedded carbon and improved recyclability, presenting opportunities to the UK's capable materials research community.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Potential opportunities for the UK

The drive to dramatically reduce emissions and the resultant electrification of the vehicle powertrain is disrupting incumbent supply chains and providing opportunity for organisations willing to embrace change. This study has identified a number of opportunity areas that align with strong capability and good potential in organisations operating in the UK. These provide the potential for the UK to assert a strong future supply chain position given suitable investment.

The identified opportunities are intended to provide a foundation for further due diligence and dialogue between UK Government, academia, industry and investors.

Focus:

UK could provide focused support to build upon existing advantages in these attractive opportunity areas

Theme	Opportunity	Commercialisation Timeframe
	Provision of vehicle system integration services to high and low volume vehicle manufacturers and Tier 1 suppliers	Short timeframe (by 2020)
	Research, development and manufacture of advanced internal combustion engines with improved efficiency and reduced emissions that are adapted to hybridisation for low and high volume applications	
	Development of improved exhaust aftertreatment and Tier 2 supply of high value aftertreatment sub-systems (including catalysts) to Tier 1 exhaust system suppliers	
	Development and supply of alternative fuel engine solutions for medium and heavy duty commercial vehicles for both original equipment and retrofit applications	
	Application and systems engineering services for next generation traction electric machine and associated power electronics technology focussing on low volume and specialist applications, in addition to in-house activity conducted by high volume vehicle manufacturers' R&D centres in the UK	
	Development and supply of lower cost, shorter cycle time lightweight components, focussing at least initially on the low to mid volume requirements of domestic UK vehicle manufacturers	
	Provision of research and development services to lower volume and specialist vehicle manufacturers, leveraging advanced design and process techniques to deliver affordable lightweighting solutions	
	High volume manufacturing of traction battery packs (and/or cells) by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of materials and components	Medium timeframe (by 2025)
	Research, development and low volume manufacturing leading to licensing of next and next + 1 generation battery cell chemistry	Long timeframe (after 2025)

= System integration

Invest-to-Improve:

UK could invest to improve positioning since these opportunities appear to be attractive

Theme	Opportunity	Commercialisation Timeframe
	Development and Tier 1 supply of transmissions that cost effectively meet the specific requirements of low volume hybrid and electric vehicles Development and Tier 1 supply of electric machines and associated power electronics for low volume / high performance traction applications Development and Tier 1 supply of modular traction battery packs for low volume vehicle applications	Short timeframe (by 2020)
	High volume manufacturing of electric traction machines by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of components and/or sub-assemblies	Medium timeframe (by 2025)
	Development of new sustainable lightweight materials that are low cost, low embedded energy and recyclable, with commercialisation via licensing to established material producers	Long timeframe (after 2025)

Opportunistic:

UK has good positioning for these opportunities, though their relative attractiveness is lower – UK could take advantage of its position as opportunities emerge

Theme	Opportunity	Commercialisation Timeframe
	Development of advanced boosting solutions, with commercialisation via in-house development by Tier 1 suppliers with a UK footprint and/or intellectual property licensing to Tier 1 suppliers without a UK footprint Development and low volume production of cost effective kinetic energy recovery systems, primarily for bus and off-highway applications	Short timeframe (by 2020)
	Development of advanced waste heat recovery solutions, with commercialisation most likely via intellectual property licensing to established Tier 1 suppliers of exhaust and/or thermal systems Development and Tier 1 supply of novel propulsion and auxiliary power engines to niche and specialist vehicle manufacturers to comply with emissions regulations and sustainability commitments Development and licensing of innovative solutions to established transmission manufacturers (vehicle manufacturers and Tier 1 suppliers) for integrating the traction electric motor, transmission and driveline in electrified powertrains	Medium timeframe (by 2025)
	Development and Tier 1 supply of integrated fuel cell systems to low volume vehicle manufacturers R&D, co-development and Tier 2 supply of high value components to fuel cell manufacturers	Long timeframe (after 2025)

The implications for key stakeholders

The evidence base and definition of the UK's current capability and future opportunities were used to identify a series of implications and recommendations for government, academia, industry and investors. These include:

- Engines will remain an important focus for UK research-to-manufacture activities for some time, but the role of the internal combustion engine will decline and the UK must evolve with this new reality.
- The prioritisation of propulsion technologies is intertwined with and needs to be developed in conjunction with future global energy systems.
- Lightweight technologies, traction batteries, traction electric motors and power electronics all present good opportunities as they are compatible with megatrends, are resilient to foreseeable scenarios, have cross-sector potential and are aligned with UK capability strengths.
- Technology-led disruptions to incumbent supply chains and the resurgence in the UK's domestic vehicle manufacturers is creating a window of opportunity for the UK supply chain, but the competition is fierce and the UK supply chain needs to act quickly.
- The UK can capitalise on a reputation for world-class research, being open for international business and having very well aligned research and development support through jointly funded schemes (via EPSRC, Innovate UK and the Advanced Propulsion Centre) and tax relief (via R&D tax credits and Patent Box).
- Attractive opportunities may not always encompass on-shore manufacturing, however the UK needs to attract inward investment in high volume manufacturing of zero emission capable propulsion technologies to offset declining long-term demand for the 2.4 million internal combustion engines currently manufactured each year in the UK.
- UK organisations need to be widely recognised as leading the world in specific and significant areas of technology to attract further investment and secure more export opportunities.
- The UK lacks many global Tier 1 suppliers so the UK supply chain must collaborate to offer competitive products and services that can challenge the incumbent Tier 1 supply chain positions.
- The UK needs to do more to help technology developers commercialise intellectual property for the benefit of the UK.
- There are further opportunities to strengthen alignment between academia and industry with respect to identifying research, training and educational needs.

Future iterations of this study will assess the emerging opportunities arising from longer term disruptive themes (such as autonomous vehicles and Industry 4.0) that have been largely excluded from the scope of this study to maintain a tight focus on tangible opportunities. Future iterations of the study will also focus on emerging enablers, in particular the digital engineering and testing tools that will become a key source of competitive advantage by transforming our ability to deliver increasingly complex and rapidly evolving technology systems through sophisticated virtual engineering techniques.

How we can work together to capitalise upon opportunities

This report is intended to be a catalyst for further dialogue between UK Government, academia and industry regarding future opportunities relating to low carbon propulsion technologies.

The report's value will only be realised if you engage in the debate and work collaboratively to deliver any identified actions. The Advanced Propulsion Centre will be organising a series of events to provide a forum for this dialogue and formation of plans.

Please contact the Advanced Propulsion Centre if you would like any further information regarding these activities:

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Full report

Contents

Introduction

The Advanced Propulsion Centre has conducted this study on behalf of the Automotive Council in order to identify technology-led opportunities to grow strategic low carbon propulsion capabilities in the UK for on and off-road transport.

The low carbon imperative

The low carbon and air quality agendas are driving rapid change in propulsion systems technology, with the potential to create new opportunities whilst simultaneously threatening incumbent positions. The automotive industry is subject to a series of international, national and local regulations that drive reduction in CO_2 emissions and other pollutants impacting air quality. Examples include the European Union fleet average CO_2 emissions targets and pollutant emissions standards, plus the London Congestion and Ultra Low Emissions zones. Meeting future legislation and regulation requires both significant improvements to the efficiency of internal combustion engines and increasing electrification of the powertrain via hybridisation toward zero tailpipe emission electric vehicles.

Stakeholders in the UK research-to-manufacture supply chain need to be positioned to capitalise upon this change, rather than succumb to it as a threat.

According to the Society of Motor Manufacturer and Traders (SMMT), during 2015 the UK directly employed 158,000 people in manufacturing 2,368,477 internal combustion engines (most of which were exported), 1,587,677 passenger cars (of which 77% were exported) and 94,479 on-road commercial vehicles (of which 50% were exported). This included 76,484 light commercial vehicles, 14,602 heavy commercial vehicles and 3,393 buses. In addition, according to the Motorcycle Industry Association (MCIA) approximately 18,900 motorcycles were produced in the UK during 2014.

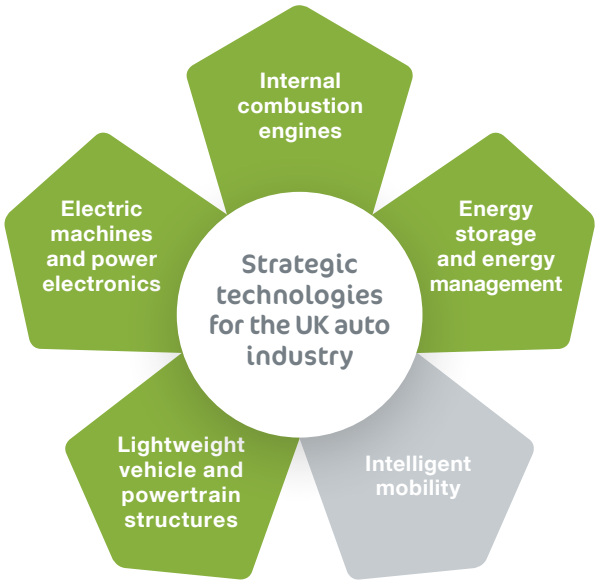
The Automotive Council

The Automotive Council (a joint initiative between the UK automotive industry and UK Government) has been working since it was established in 2009 to ensure the UK capitalises upon technological change. The Automotive Council issued its first propulsion roadmap in 2009, which described a de-carbonisation path for passenger cars through increasing levels of hybridisation of internal combustion engine based powertrains toward a future state comprising electric vehicles with electrochemical battery and/or hydrogen fuel cell energy storage systems. This roadmap was followed in 2010 by the report *Automotive Technologies: The UK's current capability*, which established a consensus view of the UK's ability to deliver key passenger car technologies.

automotive council UK

The strategic technologies for the UK automotive industry

The *Automotive Technologies: The UK's current capability* report authored by Ricardo and published by the Technology Strategy Board engaged with 40 different organisations via surveys and workshops to broaden consensus around the propulsion roadmap, identify specific areas of UK capability and develop an evidence base for relative strategic prioritisation of different automotive technologies. The Automotive Council used this analysis to define the strategic technologies for the UK automotive industry that along with a series of further propulsion roadmaps established a strong foundation for engagement between UK Government, industry and academia.



The Advanced Propulsion Centre

The Advanced Propulsion Centre was formed in 2013 from a commitment made by the UK Government and automotive industry through the Automotive Council to position the UK as a global centre of excellence for low carbon powertrain development and production. In addition to facilitating partnerships between those who have good ideas and those who can bring them to market via a grant funding programme, the Advanced Propulsion Centre maintains the Automotive Council's propulsion roadmaps and capability studies. Accordingly the Advanced Propulsion Centre is establishing an iterative update process to forge stronger links between future capability and roadmap reports in order to identify technology-led opportunities for UK research and development (R&D) and/or manufacturing growth.

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The study

The Advanced Propulsion Centre has built upon the foundations of *Automotive Technologies: The UK's current capability* to identify specific strategic growth opportunities through this new study. Working in collaboration with Ricardo and E4tech and with the support of the UK Government Department for Business, Energy and Industrial Strategy enabled the Advanced Propulsion Centre to research a broader range of market sectors. The Advanced Propulsion Centre surveyed industry experts regarding their low carbon propulsion R&D activities in order to assess the UK's capability to deliver strategic technologies in addition to identifying new technology-led opportunities, assessing their relative attractiveness and determining how barriers to their attainment can be overcome.

This study has identified potential priority opportunities for the UK that are intended to provide a foundation for further due diligence and dialogue between UK Government, academia, industry and investors. Future iterations of this study will assess the emerging opportunities arising from a rapidly changing technological landscape and will in particular give further consideration to potentially disruptive themes (such as autonomous vehicles and Industry 4.0) that have largely been excluded from the scope of this study to maintain a tight focus on tangible low carbon propulsion-related opportunities. Future iterations of the study will also focus on emerging enablers, in particular the digital engineering and testing tools that will become a key source of competitive advantage by transforming our ability to deliver increasingly complex and rapidly evolving technology systems through sophisticated virtual engineering techniques.

How we conducted the study

The study was conducted with the principal aim of identifying low carbon technology-led disruptions to established automotive supply chains that could provide good opportunities for organisations operating within the UK. The study focussed on propulsion technologies applicable to motorcycles, passenger cars, buses, coaches and on and off-highway commercial vehicles. The study identified key areas of UK capability and opportunity by combining data gleaned from a range of primary and secondary sources with quantitative and qualitative insights provided by academic and industry stakeholders.

The study was conducted in four stages:

Stage 1: Collected data and general insight

Market Analysis	Industry Survey	Stakeholder Interviews
Mapped key global research-to-manufacturing supply chain players to identify areas of opportunity Leveraged secondary research and expert insight to identify key market sector pulls and technology drivers	Analysed data provided by 125 different organisations regarding their R&D activities Captured insights relating to UK strengths and opportunities, plus enablers and barriers	Conducted interviews with 76 people in 56 different organisations to explore potential strategic opportunities for the UK
00s companies	125 surveys	76 stakeholders

Capabilities Built	Public Investment	Intellectual Property
Mapped anecdotal evidence of key capabilities built in the UK since 2010	Analysed data relating to 427 EPSRC, Innovate UK, APC and AMSCI projects accounting for £542m of grant funding to map trends in early stage R&D	Analysed thousands of patents to identify global trends in filing activity
5 years	427 projects	000s patents

Stage 2: Formed hypotheses

UK Capabilities	Needs and Opportunities
Combined data regarding focus of investment and technology development with qualitative insights to hypothesise UK capability strengths and weaknesses across 5 technology areas. Used patent filing data and qualitative insights from multi-national organisations to calibrate self-assessment of international competitiveness.	Combined capability assessment with market analysis and qualitative insight to identify addressable industry needs and hypothesise potential opportunities arising from them. Rated opportunities according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation.
5 technology areas	34 needs

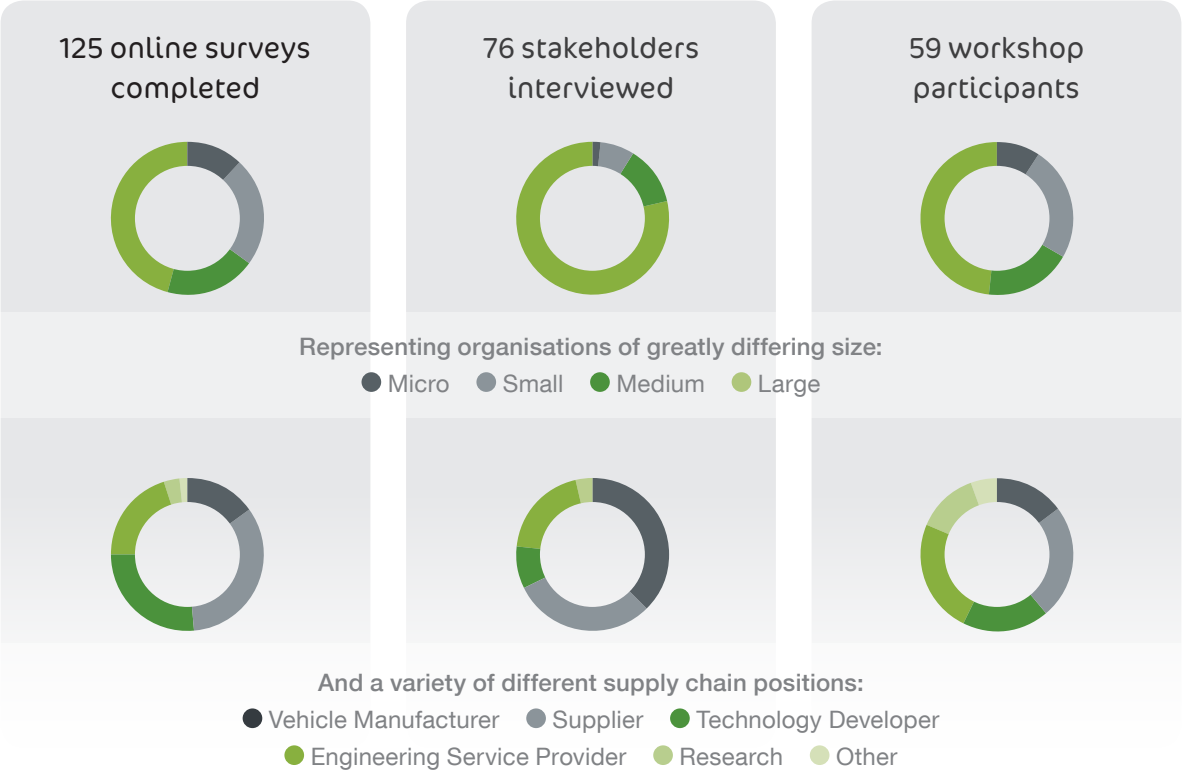
Stage 3: Validated hypotheses

Consensus Building Workshops
Conducted workshops with a broad range of experts representing 54 different organisations to secure feedback on the evidence base collected and the hypotheses developed regarding the UK's current capability and potential future opportunities.
59 participants

Stage 4: Defined conclusions

Implications and Recommendations
Used the expert feedback to refine the definition of the UK's current capability and potential future opportunities. Identified cross-cutting implications and developed recommendations for the four key stakeholder groups: UK government, academia, industry and investors.
21 opportunities

152 organisations contributed to the study



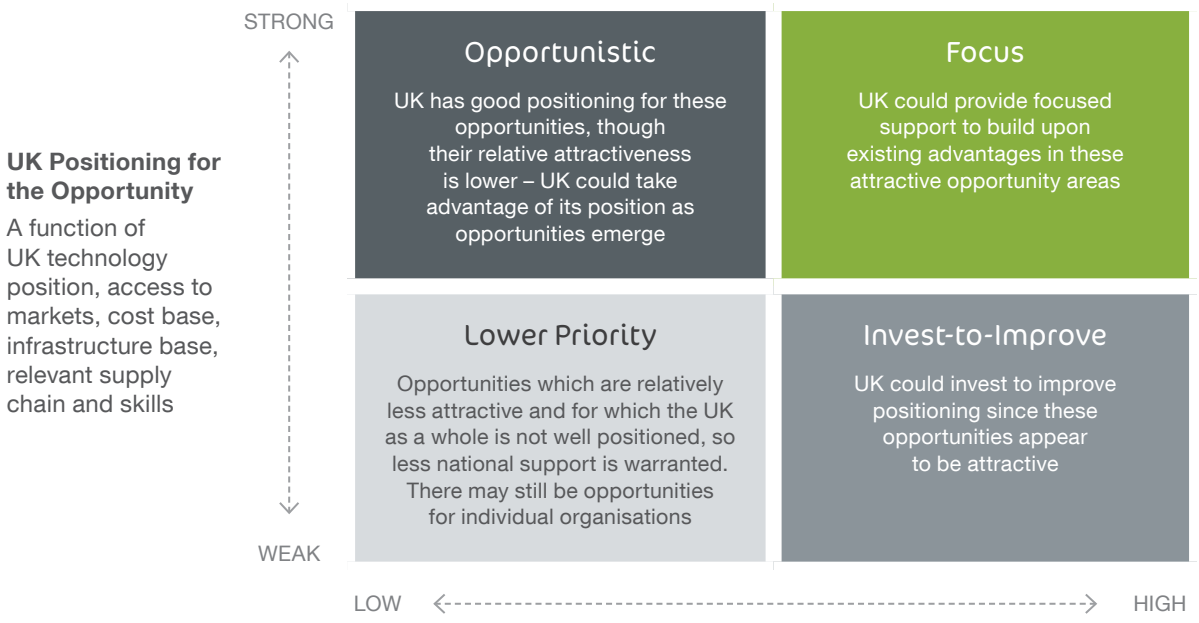
Data collection

The industry survey used to collect data and insight from vehicle manufacturers, suppliers, technology developers and engineering service providers was conducted online. The survey was open to all participants; it was promoted via the Advanced Propulsion Centre's communication channels and via hundreds of targeted invitations sent to businesses with UK operations. Key areas of academic and early stage industrial activity were mapped via data provided by the principal funding agencies (including EPSRC and Innovate UK). In-depth stakeholder interviews were conducted on an invitation basis with organisations both with and without UK operations, who were selected to provide a representative cross-section of the research-to-manufacture supply chain and provide a robust international perspective.

The study employed a detailed technology classification to enable comparison of data originating from multiple sources. The classification built upon the strategic technologies for the UK automotive industry, which are the themes identified by the Automotive Council in 2010 as offering the greatest opportunity for the UK to show leadership through specialisation. However, the classification was i) broadened to encompass any technology potentially applicable to low carbon propulsion systems and emissions control to ensure emerging opportunities were not overlooked; ii) deepened to enable identification of specific capabilities and opportunities. The study excluded the development of fuels/energy vectors and their supply infrastructure, but did include the on-vehicle systems that burn fuels or convert energy vectors (e.g. internal combustion engines; fuel cells). The study did not include the development of facilitating technologies (e.g. engineering and test tools); however any key gaps and/or opportunities in facilitating technology capability critical to delivering future low carbon propulsion technologies were considered. The study also excluded emerging automotive technologies not directly related to lowering the carbon emissions of a vehicle's propulsion system; specifically intelligent transport system related technologies, which comprise a complex cross-industry picture that warrant a dedicated study.

Prioritisation

The UK is not able to prioritise everything, so the study sought to focus on opportunities where the market appears attractive and the UK has a basis to be competitive. A framework was developed to facilitate prioritisation, which assigned weighting and scoring to multiple attributes in order to assign each opportunity to one of four categories:



Consensus

Two workshops were conducted with a broad range of experts during March 2016 in order to secure feedback on the evidence base collected through the study and the hypotheses developed regarding the UK's current capability and potential future opportunities. The workshop participants included representatives of funding bodies, academic institutions and a range of industry organisations (including vehicle manufacturers, suppliers, technology developers and engineering service providers). The participants validated and added to the evidence base, in addition to improving the definition of the UK's current capability and potential future opportunities through a series of structured debates. This valuable expert feedback was integrated into the definition of the UK's current capability and potential future opportunities as outlined in this report.

The following section summarises the analysis of the evidence base and the subsequent definition of the UK's low carbon propulsion technology capabilities and strategic growth opportunities.


TAXI
TX5
TX5

The UK's low carbon propulsion technology capabilities and strategic growth opportunities

The study has analysed the supply chain positioning of hundreds of companies, the investment of public funds in 427 projects, the registration of thousands of patents, the submission of 125 surveys and the insight of 76 influential industry stakeholders in order to determine notable aspects of UK capability, define likely future industry needs and identify potential opportunities for the UK related to low carbon propulsion technologies. This analysis has been refined through consensus-building workshops with 59 industry experts leading to the summary presented in this report. Contributions from organisations headquartered inside and outside the UK, and from respondents located inside and outside the UK provided a balanced view of the UK's perceived and actual capability strengths and weaknesses.

Cross-cutting themes

The analysis has been organised into 5 discrete technology areas, which are used to structure the following sections of this report. However, the study also identified a number of cross-cutting themes.

UK universities and the fundamental academic research conducted by them are world renowned. Increasingly UK universities are also being recognised for the applied research being conducted at higher technology readiness levels in closer collaboration with the automotive industry. There remains a significant gap to the strength of industry collaboration achieved in Germany through the Fraunhofer model, but the gap is being closed by actions such as the Automotive Council's Challenge Networks, the Advanced Propulsion Centre's Spoke Network, the Catapult centres and the Institute for Advanced Manufacturing and Engineering. UK academia is universally praised for its openness to working with organisations headquartered outside the UK, making it a magnet for world-class research and providing great opportunity to engage with the organisations creating technological disruption on a global stage.

Historically the UK has struggled to maximise the commercial benefit of the great ideas formed within its borders, and is perceived to have a weak track record of turning innovation into high volume automotive products. However, the alignment of public investment with industrial research and development is now considered to be amongst the best in the world, with the UK Government providing continuous support to the progression of automotive technologies up the readiness scale through EPSRC, Innovate UK, the Advanced Propulsion Centre and the Catapult centres (amongst others). These actions, along with the tax relief offered by R&D tax credits and Patent Box legislation, are helping to anchor research and development activity in the UK, providing high quality employment and

UK academia is universally praised for its openness to working with organisations headquartered outside the UK

providing a foundation upon which to attract manufacturing of the technologies developed.

The UK is perceived to be a source of innovation and home to world-class problem solving skills, derived from our leadership position in challenging industries such as aerospace, defence and motorsport. This is evidenced by the wealth of SMEs developing innovative automotive technologies in the UK in addition to the number of vehicle manufacturers and their suppliers who come to the UK to conduct system engineering and complex powertrain and vehicle integration activity.

The relatively limited presence of global scale Tier 1 suppliers conducting research-to-manufacture activity in the UK continues to be a structural weakness. The Tier 1 suppliers typically integrate new technologies from their own innovation teams and external sources into a full-service supply offer that vehicle manufactures can source for their products. The lack of proximity to the decision makers in these suppliers and their high volume vehicle manufacturing customers is a continuing challenge for pulling innovation from technology developers through the UK supply base to market. This means that UK organisations must work harder to market their capabilities on a global stage. However, the resurgence in strength of the UK's domestic vehicle manufacturers is increasing global Tier 1 supplier interest in the UK and is providing a stronger potential stepping stone to global markets for UK based suppliers.

The UK continues to be challenged by an engineering skills shortage and relatively high manufacturing labour rates. The Automotive Industrial Partnership is working in close collaboration with government, academia and industry to align education and training with future industry needs to address the skills issue, but the crunch persists in the short-term. UK-based automotive manufacturing facilities are consistently amongst the most productive in Europe (for example, as according to Eurostat gross value added per employee statistics), mitigating the impact of relatively high labour costs. In addition, the factory of the future is anticipated to rely increasingly on automated systems rather than human labour, reducing the significance of labour costs in the decision making process for factory location.

The relatively limited presence of global scale Tier 1 suppliers conducting research-to-manufacture activity in the UK continues to be a structural weakness

Public investment

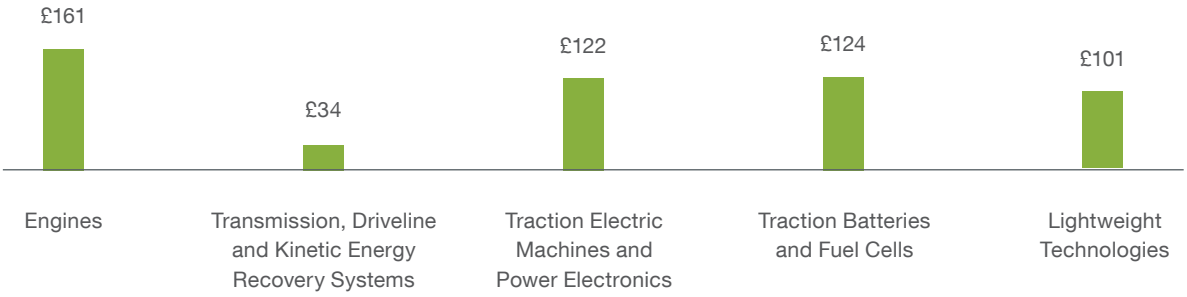
Public funding for the development of low carbon propulsion technologies in the UK has increased significantly since the report *Automotive Technologies: The UK's current capability* was published. The 2010 report identified 111 projects related to equivalent low carbon propulsion technologies for passenger car applications, whereas this study has identified over 427 projects (encompassing applications across motorcycle, bus and on and off-highway commercial vehicles, in addition to passenger cars). This additional investment follows on from the recommendations of the 2009 NAIGT *An Independent Report on the Future of the Automotive Industry in the UK* and 2013 Automotive Council *Driving Success – a strategy for growth and sustainability in the UK automotive* sector reports. The 2013 report led directly to the formation of the Advanced Propulsion Centre, which is designed to ensure that the promising technologies graduating from the Innovate UK platform are commercialised within the UK.

The distribution of grant funding co-invested by the UK Government (via EPSRC, Innovate UK, the Advanced Propulsion Centre and others) through research and development projects for automotive

£542 million granted to 427 low carbon related projects during 2010 to 2015

Technology Maturity	Principal Agency	Number of Projects	Total Grant Value £ millions
Early Stage	EPSRC	134	£174
Demonstrator	Innovate UK	258	£231
Applied	Advanced Propulsion Centre	35	£137

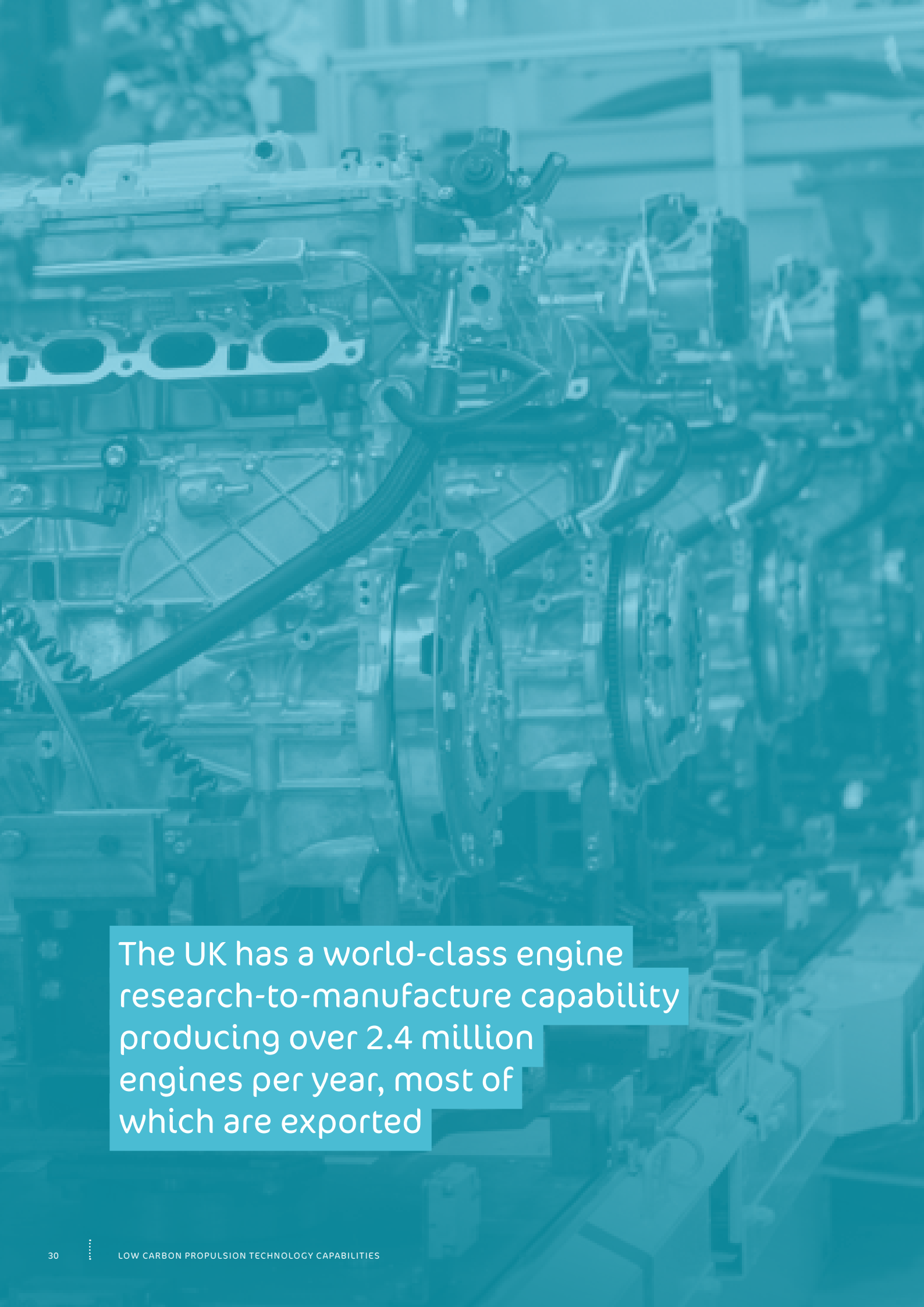
Funding allocation by technology area £ millions



applications during the period 2010 to 2015 demonstrates the impact the Advanced Propulsion Centre has already had since its formation in 2013, with over a quarter of the total funding at higher technology maturity levels. Over this period, internal combustion engine related technologies have attracted the largest amount of public grant funding for the greatest number of projects amongst the 5 technology areas explored in this study. However, electric machines and power electronics, batteries and fuel cells and lightweighting focussed projects follow closely behind demonstrating the increasing importance of these areas and the good balance in the UK research and development portfolio. Transmissions and kinetic energy recovery systems have received a lower level of funding over this period, albeit greater than that allocated to connected and autonomous vehicles. However, the funding allocated to connected and autonomous vehicles (which are outside the scope of this study but potentially have a significant role to play in improving vehicle efficiency and reducing pollutant emissions in the future) is increasing rapidly. In addition to the £10 million invested in trials through the Innovate UK Introducing Driverless Cars to UK Roads competition the UK Government recently announced that £17 million has been co-invested in 8 collaborative R&D projects through the Centre for Connected and Autonomous Vehicles (CCAV) and Innovate UK Connected and Autonomous Vehicles competition, which is drawn from the £100 million intelligent mobility fund established by the UK Government.

Evidence base

The following section summarises the analysis of the evidence base and the subsequent definition of the UK's low carbon propulsion technology capabilities and strategic growth opportunities in each of these 5 technology areas.



The UK has a world-class engine research-to-manufacture capability producing over 2.4 million engines per year, most of which are exported

The key potential opportunities for *engines* can be found on page 41

Engines

Overview

The combustion engine has been the dominant automotive propulsion technology for over 100 years, with production controlled by the vehicle manufacturers and key technologies delivered in partnership with global Tier 1 suppliers. Its dominance is threatened by the electric motor, but the combustion engine still has an important role to play for many years to come.

Combustion engines provide an affordable pathway to long-range zero emissions capable vehicles through plug-in hybrid and range-extended powertrains. Furthermore most heavy duty vehicles will rely on efficient combustion engines to haul their heavy payloads over demanding duty cycles until there is a major breakthrough in electrical energy storage technology. There is a clear imperative to minimise the pollutant emissions of engines, whether they combust fossil or alternative fuels, providing good opportunity for organisations working in these areas. The UK has a world-class engine research-to-manufacture capability and produces over 2.4 million engines per year, most of which are exported. This foundation, combined with a strong innovator community, positions the UK to capitalise upon incremental improvement opportunities (such as emissions control, adaptation for electrification, electrified boosting, and waste heat recovery) as well as more radical concepts (such as zero tailpipe emission expansion engines). However, UK organisations are operating in a highly competitive global market and are challenged by a manufacturing cost base that has resulted in a lot of Tier 2 component supply moving off-shore.

How is the global supply chain structured?

The global supply chain for high volume passenger car internal combustion engines is dominated by the vehicle manufacturers, with some sharing resources or buying engines from each other. Occasionally a high volume vehicle manufacturer will source an engine from a specialist, such as BMW sourcing a small 2 cylinder engine from Taiwanese company Kymco for the i3 electric vehicle's range extender. A number of independent low volume vehicle manufacturers source engines either from the high volume manufacturers or from specialists, for example Ricardo produces engines for McLaren, Toyota for Lotus and Mercedes AMG for Aston Martin (in addition to Aston Martin producing its own engines within Ford owned factories). Low volume manufacturers that are owned by large vehicle manufacturers (such as Bentley by Volkswagen Group and Rolls Royce by BMW) tend to source core engine technology from within the parent group, though some manufacture the engines themselves (such as Bentley producing the W12 engine for Volkswagen Group).

A similar situation prevails in the motorcycle sector with vehicle manufacturers predominantly producing their own engines, with both Triumph and Norton doing so in the UK. Heavy commercial vehicles in Europe typically use engines produced by the vehicle manufacturer, whilst in the United States vehicles are often fitted with other manufacturer's engines. The bus vehicle manufacturers in the UK typically buy-in chassis systems from foreign bus manufacturers (such as MAN, Mercedes-Benz, Scania and Volvo) and the engines either from the same vehicle manufacturers or from an engine supplier, such as Cummins (who have significant R&D and manufacturing operations in the UK). Off-highway manufacturers have varied strategies. John Deere manufacture their own engines from their production sites in the US, Mexico and Argentina whilst Volvo Powertrain manufacture engines in Sweden, the US and India for use in their construction equipment and trucks. JCB and CAT produce engines for their own use, but also make them available for 3rd party applications. Conversely Cummins is primarily an engine supplier that does not produce vehicles; though it has a joint venture with Komatsu to manufacture engines for Komatsu's off-highway machines. Hitachi Construction Equipment also sources its engines from Cummins but have also signed an agreement with German engine company Deutz to provide engines for some of its wheel loaders.

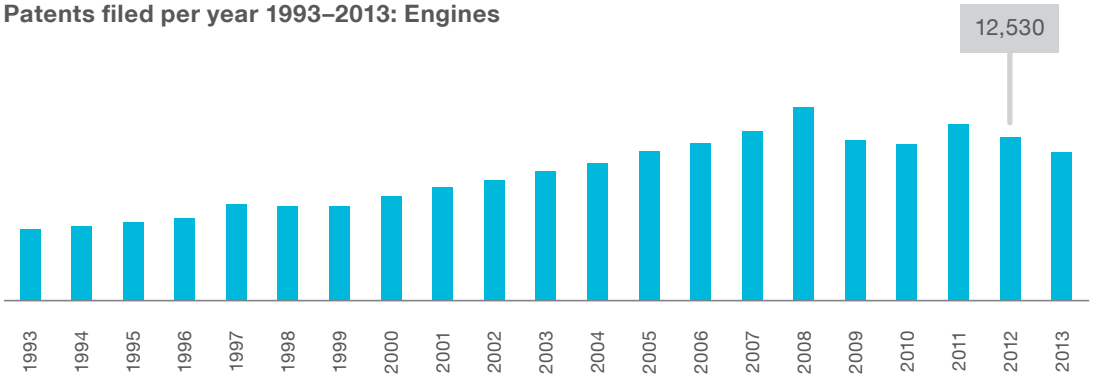
However, across all the sectors Tier 1 suppliers (such as Bosch and BorgWarner) tend to control key elements of engine technologies, such as fuel injection equipment and turbochargers, which are delivered in partnership with the engine manufacturer.

The global supply chain for high volume passenger car internal combustion engines is dominated by the vehicle manufacturers

Across all the sectors Tier 1 suppliers tend to control key elements of engine technologies

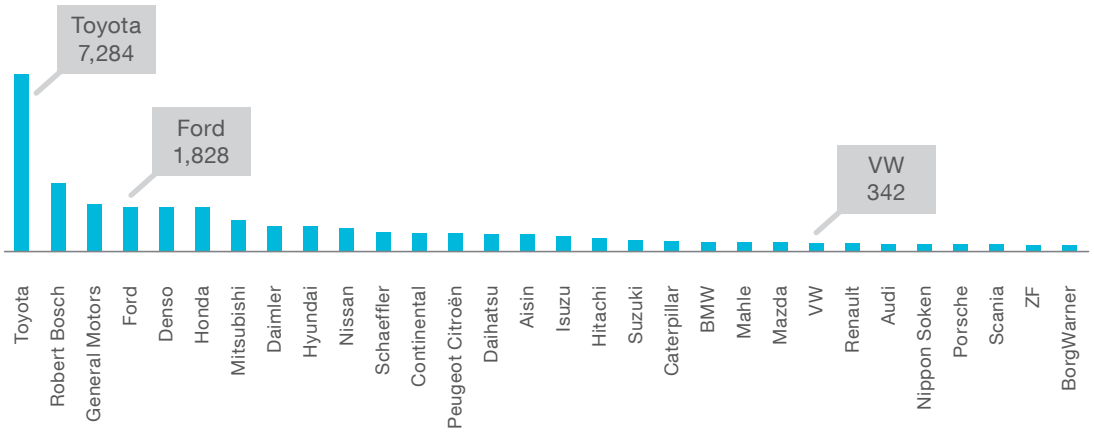
What does global patent filing activity tell us?

Patents filed per year 1993–2013: Engines



Internal combustion engines are the most highly patented of the technology areas considered by this study. However, the level of activity in this mature technology area has been relatively steady since 2010 in contrast to rising levels in less mature automotive technologies such as traction electric motors and batteries. The majority of filing activity since 2010 associated with internal combustion engines for automotive applications is accounted for by the leading vehicle manufacturers and the global Tier 1 suppliers. The relative level of filing activity since 2010 between Toyota (many thousands of patents), Ford (thousands of patents) and Volkswagen (hundreds of patents) reflects the differing patenting cultures between global geographies, with Japanese companies being the most prolific filers and European companies some of the least.

Top patent filers 2010–2016: Engines



(Footnote: The analysis of patents relating to internal combustion engines for automotive applications was conducted in February 2016. The search utilised a combination of International Patent Classifications, Cooperative Patent Classifications and keyword searches; some patents may have been classified differently and therefore will not have been captured by this analysis.)

What activity is taking place in the UK?

The UK has a strong research to manufacture capability for passenger car, motorcycle and commercial vehicle engines, in addition to world-class capability for motorsport engines. According to the Society of Motor Manufacturers and Traders (SMMT) 2.4 million passenger car engines were manufactured in the UK in 2015 by Ford, Nissan, Toyota, BMW, Honda, Jaguar Land Rover, Bentley and McLaren / Ricardo. This capability includes Toyota manufacturing a hybrid engine for the first time outside Japan at its Deeside plant and BMW manufacturing the down-sized engine for its i8 plug-in hybrid at its Hams Hall plant. In addition Cummins, Perkins (CAT), JCB, Norton and Triumph all produce engines in the UK, with Cummins announcing in 2015 that production of its Euro VI four cylinder B series 4.5 litre bus engines would be transferred from its Chinese plant to its Darlington facility. JCB opened its engine facility in 2004 and in 2014 signed a contract with Terex GB to supply engines for dumpers made at Terex's Coventry plant. The UK is also home to a large number of commercial and academic organisations engaged in engine research and development, with the biggest being Ford's Dunton Technical Centre, which employs over 3,500 people. This inventive environment also nurtures a number of start-up businesses developing innovative engine technologies, such as Dearman (which has filed 7 patents since 2010 relating to its liquid nitrogen expansion engine technologies), Libertine (which has filed 13 patents related to its linear piston engine technologies since 2010) and Bladon Jets (which has filed 3 patents related to its micro gas turbine engine technologies since 2010)

An engine sub-system that is witnessing increasing patent activity is boosting (either via super or turbo charging), aligned with the industry trend to downsize and boost engines to improve their efficiency and reduce vehicle CO_2 output that is prevalent in passenger cars and commercial vehicles and is expected to soon extend to motorcycles. The latest innovation in boosting is coupling electric machines to the compressor and/or turbine to enable increased performance and efficiency by decoupling energy recovery and boosting from engine speed. The first market introduction of this technology is via the 2016 Audi SQ7, which features a Valeo supplied 48 volt electric compressor that builds upon technology acquired from UK company Controlled Power Technologies in 2011. UK-based Integral Powertrain has formed a joint venture with global Tier 1 supplier Magna International to commercialise an alternative 12v electro-mechanical boosting concept, whilst Aeristech has worked with MAHLE Powertrain to demonstrate its high performance electric compressor. However patent activity in the electrified boosting area remains limited with Valeo holding tens of patents, whilst UK companies such as Aeristech, Controlled Power Technologies, Bowman Power and Integral Powertrain each hold a handful of patents.

The UK has a strong research to manufacture capability for passenger car, motorcycle and commercial vehicle engines, in addition to world-class capability for motorsport engines


KOMATSU
HB
215
LC
Hybrid

Where is UK public investment being channelled?

Engines have received the highest level of public grant funding support of all the technology areas considered by this study. Approximately £161 million of public grant funding was co-invested by the UK Government (via EPSRC, Innovate UK, the Advanced Propulsion Centre and others) through 122 internal combustion engine and novel engine research and development projects for automotive applications during the period 2010 to 2015. These projects sought to improve performance and efficiency of the engine via combustion improvements, waste heat recovery, and adaptation for hybridisation. In addition a number of projects explored novel engine concepts such as micro gas turbine engines (developed by Bladon Jets and Delta Motorsport) and a liquid nitrogen expansion engine (developed by Dearman). The funding was well distributed across different technology maturity levels, reflecting the strong research-to-manufacture capability present in the UK.

This compares very favourably with the 36 internal combustion engine projects for passenger car applications that were supported during the period 2005-2010 (as reported by Ricardo in the 2010 *Automotive Technologies: The UK's current capability* report).

£161 million granted to 122 engine related projects during 2010 to 2015

Technology Maturity	Principal Agency	Number of Projects	Total Grant Value £ millions
Early Stage	EPSRC	43	£61
Demonstrator	Innovate UK	71	£68
Applied	Advanced Propulsion Centre	8	£32

Approximately £161 million of public grant funding was co-invested by the UK government through 122 projects during 2010 to 2015

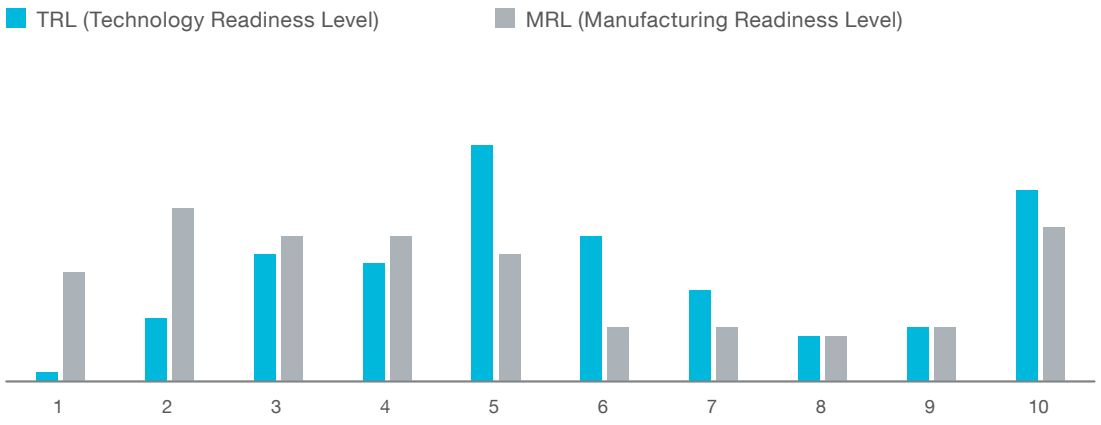
What did we learn from the industry survey and stakeholder interviews?

More than half of the engine research and development projects captured via the industry survey are being conducted without public funding, which evidences the confidence of UK organisations to invest in this mature technology area but also the continuing importance of public funding in maintaining the UK's globally competitive capability. Over 90% of respondents believe their research and development is either in-line with or leading the market, covering a complete range of engine sub-systems including fuel injection and boosting, plus novel thermodynamic cycles. However, whilst the UK undoubtedly produces good quality innovation the quantity lags behind the European leader, Germany. The healthy distribution of the projects across market sectors and technology readiness levels shows there are good route to market opportunities. Despite this relatively strong position, respondents to the industry survey and participants in the consensus-building workshops did express concerns that there are constraints to commercialising these innovations within the UK, including production facilities for novel concepts and equipment and skills from research through to manufacture.

The industry survey, stakeholder interviews and data analysis combine to suggest that the UK remains a globally competitive research-to-manufacturing base, albeit lagging behind in terms of quantity of innovation output (if not quality). The UK has a number of world-class strengths, including simulating combustion and integrating engines into hybridised powertrains. However, most of the Tier 1 research and development work is conducted outside the UK, with some exceptions such as strong turbomachinery activity within the UK. The UK could be doing more to attract this Tier 1 research and development activity, such as joint pre-competitive research (as per the FVV model in Germany). The UK retains a strong internal combustion engine manufacturing footprint in the UK, but this masks a weakness in the supply chain with many Tier 2 components being imported from lower cost countries.

Whilst the UK undoubtedly produces good quality innovation the quantity lags behind the European leader, Germany

Maturity of UK R&D projects reported to the industry survey



What new capabilities have been built in the UK since 2010?

- Bladon Jets' micro gas turbine is used as a range extender for the electric Jaguar C-X75 concept supercar (2010)
- JCB announces a £31 million investment to build more efficient engines in the UK (2011)
- Ricardo opens a new low volume engine production facility in Shoreham (2011)
- The Innovate UK funded RE-EVolution project finishes demonstrating a range extended Infiniti EMERG-E and a plug in hybrid Jaguar XJ_e (2012)
- Norton acquires Donnington Hall in order to expand production of its engines and motorcycles (2013)
- Ford invests £24 million in the Bridgend plant to produce the 1.5L EcoBoost engine, building upon the success of the 1.6L EcoBoost (2013)
- Clean Air Power (now part of Vayon Group) provides 50 of its dual fuel engines to Sainsbury's UK distribution fleet (2014)
- Jaguar Land Rover opens its £500 million Engine Manufacturing Centre in Wolverhampton to build the new Ingenium engine (2014)
- The University of Oxford, UCL and Jaguar Land Rover invest £1 million into two new centres of excellence for engine combustion research (2014)
- BMW starts building the engine for the i8 high performance hybrid car at its Hams Hall plant (2014)
- Mercedes AMG develops the winning power unit for the Mercedes Formula 1 team in Brixworth (2014)
- Cosworth's £22 million engine manufacturing centre opens with a unique plasma ion coating capability (2015)
- Dearman begins testing its liquid nitrogen expansion engine in a delivery truck and opens its new R&D centre (2015)
- Aeristech and MAHLE showcase a heavily downsized engine with an electrically assisted supercharger at the 2015 Low Carbon Vehicle event (2015)
- Toyota invests £7 million into its engine plant in Wales to produce a new hybrid engine (2016)

Continued investment in engines sustains the UK's strong global position

The continued investment in engine development from both government and industry has maintained the UK's strength in research to manufacture. University led research funded by EPSRC into advanced combustion, split-cycle engines and dual-fuel engines remains strong whilst Innovate UK has funded some innovative prototype designs. Furthermore novel concepts such as micro gas turbine engines (Bladon Jets; Delta Motorsport), rotary engines (AIE) and expansion engines (Dearman) have also been supported through the public funding network and are starting to reach commercialisation as a result of consistent funding.

Jaguar Land Rover investment generates supply chain opportunities

A number of jobs and opportunities have been created across the supply chain and academia as a result of Jaguar Land Rover's investment in the Ingenium engine plant. For example BorgWarner, who were chosen to supply the turbochargers, expanded its Bradford facilities and is planning to construct a new research and development centre. In addition to creating numerous jobs, BorgWarner also strengthened its close collaboration with the University of Huddersfield by establishing a master's degree in turbocharger engineering.

Ford extends commitment to manufacture engines in the UK

Ford has invested £1.5 billion over five years to develop new low-carbon vehicle technology in the UK, building upon its strong UK capability in engine design and production. Ford's 1.0L EcoBoost engine was designed at Ford's Technical Centre in Dunton. Ford also manufactures the 1.5L and 1.6L EcoBoost engines at its Bridgend plant, and produces a new, low-carbon 2.0L diesel engine at Dagenham, which was also designed and engineered in the UK. In October 2015, Ford announced an additional £181 million to develop a new range of low emission petrol engines with production to start late 2018.

Formula 1 drives fuel efficient engine technology

Formula 1 and passenger vehicles both have stringent targets to achieve regarding fuel economy and performance. In 2014 FIA regulations stipulated that F1 cars had to decrease fuel consumption by 35% compared to 2013. As a result, the 2.4 litre V8 engine used during the 2009–2013 season was replaced by a 1.6 litre turbocharged V6 engine. To achieve the same performance, constructors improved upon the original kinetic energy recovery system by introducing exhaust heat recovery and turbocharging. The power unit used by Mercedes Petronas AMG to win the 2014 and 2015 F1 World Constructors Championships was designed and built at its centre in Brixworth.

What future industry needs could the UK address?

A series of addressable industry needs relating to engines were identified by combining the capability assessment with market analysis and qualitative insight captured through the stakeholder interviews and consensus-building workshops:

- All vehicle manufacturers are seeking significant improvements in engine efficiency and reduction in pollutant emissions, which are being tackled through a number of measures, including:
  - Continuing increases in thermal efficiency and reduction of friction.
  - Adaptation to and optimisation for electrified / hybridised powertrains.
  - Recovering and utilising waste heat energy, either directly as heat (for faster engine warm-up and/or provision of cabin heating) or via conversion to electricity (to support the range of electrical consumers on the vehicle).
  - Using advanced boosting solutions to facilitate down / right-sizing of engine capacity; including whole system design and integration of electrically assisted compressors and turbines.
  - Developing emissions control solutions for Real Driving Emissions (RDE) that minimise CO_2 penalty in comparison with current New European Drive Cycle (NEDC) test cycle optimised systems, especially for diesel engines.
- Manufacturers of medium and heavy duty commercial vehicles are seeking viable solutions to meet future worldwide ultra-low emissions demands in urban areas, primarily though combustion of alternative fuels such as Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), Liquefied Petroleum Gas (LPG), Dimethyl Ether (DME) and hydrogen.
- Vehicle manufacturers using gas fuelled engines are seeking improved exhaust catalysts to prevent unburnt methane (methane slip) exiting the exhaust.

Engines

What are the key potential opportunities for the UK?

A series of potential opportunities for the UK arising from these addressable industry needs were defined and rated according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation. These hypotheses were subsequently refined with a broad range of experts through the consensus-building workshops.

Focus:

UK could provide focused support to build upon existing advantages in these attractive opportunity areas

Opportunity	Commercialisation Timeframe
Research, development and manufacture of advanced internal combustion engines with improved efficiency and reduced emissions that are adapted to hybridisation for low and high volume applications Development of improved exhaust aftertreatment and Tier 2 supply of high value aftertreatment sub-systems (including catalysts) to Tier 1 exhaust system suppliers Development and supply of alternative fuel engine solutions for medium and heavy duty commercial vehicles for both original equipment and retrofit applications	Short timeframe (by 2020)

Opportunistic:

UK has good positioning for these opportunities, though their relative attractiveness is lower – UK could take advantage of its position as opportunities emerge

Opportunity	Commercialisation Timeframe
Development of advanced boosting solutions, with commercialisation via in-house development by Tier 1 suppliers with a UK footprint and/or intellectual property licensing to Tier 1 suppliers without a UK footprint	Short timeframe (by 2020)
Development of advanced waste heat recovery solutions, with commercialisation most likely via intellectual property licensing to established Tier 1 suppliers of exhaust and/or thermal systems Development and Tier 1 supply of novel propulsion and auxiliary power engines to niche and specialist vehicle manufacturers to comply with emissions regulations and sustainability commitments	Medium timeframe (by 2025)

Research, development and manufacture of advanced internal combustion engines with improved efficiency and reduced emissions that are adapted to hybridisation for low and high volume applications

The study has reaffirmed the demand for affordable incremental efficiency improvements and adaptation to hybridisation, particularly for passenger car and light commercial vehicle manufacturers challenged by fleet average CO_2 emissions commitments. In addition, real driving emissions (RDE) legislation is challenging all vehicle manufacturers to reduce engine-out emissions in combination with delivering affordable emissions control solutions. The UK has a strong and well established combustion engine research-to manufacture capability. In addition to leading manufacturers choosing to produce over 2.4 million engines per year in the UK, the UK is home to principal engine R&D centres (including Aston Martin, Bentley, Cummins, Ford, Jaguar Land Rover, JCB and Perkins), leading academic research, world-class engineering service providers (such as Cosworth, Lotus Engineering, Prodrive, Ricardo and Revolve) and a vibrant motorsport capability (including Formula 1 world-championship winning Mercedes AMG High Performance Powertrains). Given suitable focus and investment, the UK can continue to play a leading role in combustion engine technology research, development and manufacture for as long as it remains a suitable technology for vehicle propulsion. However, UK organisations are operating in a highly competitive global market and are challenged by a manufacturing cost base that has resulted in a lot of Tier 2 component supply moving off-shore.

Development of improved exhaust aftertreatment and Tier 2 supply of high value aftertreatment sub-systems (including catalysts) to Tier 1 exhaust system suppliers

The study has highlighted the pressing demand for improved performance and reduced cost emissions control systems that are capable of meeting increasingly stringent air quality focussed legislation across all vehicle sectors. Innovation is required to cost effectively address the challenges of forthcoming legislation, such as Real Driving Emissions (RDE) for passenger cars (2017), Stage V for off-highway vehicles (2019) and methane slip for natural gas fuelled vehicles. Current aftertreatment systems are reliant upon a range of sophisticated catalysts, of which UK company Johnson Matthey is a global leading development partner and supplier to vehicle manufacturers and exhaust system Tier 1 suppliers. The UK has a well-established exhaust catalyst research-to-manufacture capability aligned with Johnson Matthey and the major oil companies located in the UK, in addition to strong relationships with global vehicle manufacturers and exhaust system suppliers. In addition the UK is home to a Tier 1 exhaust system supplier, Unipart, which serves the domestic market. Capitalising upon this opportunity requires the UK to continue focussing on innovation to produce world-leading catalyst and exhaust system solutions.

Development and supply of alternative fuel engine solutions for medium and heavy duty commercial vehicles for both original equipment and retrofit applications

The study has identified that the increasing prevalence of localised air quality regulations (such as the clean air zones planned for London and other UK cities by 2020) will drive increasing demand for alternative fuel technologies that can reduce the pollutant emissions of diesel engine commercial vehicles, since electric propulsion is not currently a viable option for most large commercial vehicle applications. This demand will also be prevalent outside of Europe in other air quality sensitive markets, such as North America and China. The potential for diversification of requirements based upon differing local fuel preferences will stretch engine manufacturer resources, leading them to seek implementable solutions from the supply chain. The UK is well positioned to capitalise upon this opportunity as it is perceived to have strong dual-fuel natural gas technologies, has a strong engine research and development base and is home to high volume commercial vehicle engine manufacturing in the form of Cummins, JCB and Perkins. In addition the UK is home to a number of technology developers and retro-fitters active in this area (including G-volution, Mercury Fuel Systems and Vayon Gas Technologies). However, if local regulations rapidly move towards zero emission zones, more radical solutions will be required for commercial vehicles. In addition, the UK will be challenged to form a manufacturing supply base that can compete with other countries that have strong natural gas markets, such as Germany and Italy.

Development of advanced boosting solutions, with commercialisation via in-house development by Tier 1 suppliers with a UK footprint and/or intellectual property licensing to Tier 1 suppliers without a UK footprint

The study has identified that the trend for down / right-sizing and boosting engines to increase efficiency will continue and extend across all sectors. Whilst this is already being exploited to a large degree in high volume passenger cars, there is significant remaining opportunity in lower volume segments including motorcycles and on and off-highway commercial vehicles. Electrification of the compressor enables engine response to be maintained whilst engines are more aggressively down-sized for efficiency, such as on the high specific output engine MAHLE Powertrain and Aeristech have demonstrated in the UK. Electrification of the turbine (sometimes referred to as electric turbo-compounding) enables waste energy in the exhaust to be converted to electricity for powering electrified compressors or supporting vehicle electrical loads, thereby increasing efficiency by reducing alternator load on the engine. Boosting technology is controlled by global Tier 1 suppliers, two of which (BorgWarner and Cummins Turbo Technologies) have research-to-manufacturing capability in the UK. Tier 1 suppliers will continue to control the boosting supply chain, but need to add electrification technology to their portfolio. There is precedent for boosting suppliers acquiring technology, such as Valeo's 2011 acquisition of Controlled Power Technologies electrified compressor technology. The UK has particularly strong university and SME led research and development in the areas of turbochargers and high speed and power density electric machines, with Aeristech, Bowman Power, Controlled Power Technologies and Integral Powertrain all active in this space. This, in combination with the number of projects reported through the online survey, positions the UK strongly to develop novel systems for applications across

multiple market sectors. In addition, UK-based engineers developed the novel electrified boosting system that Mercedes AMG Petronas used to win the 2015 Formula 1 world championship.

However the incumbent Tier 1 suppliers are already developing their own advanced boosting solutions and have large scale manufacturing capability and full service supply relationships with the vehicle manufacturers. Therefore the most likely route for commercialising of intellectual property developed in the UK is via Tier 1 activity located within the UK, or via research, engineering services and/or licensing to global Tier 1 suppliers. There is also a risk that vehicle manufacturers will choose to mitigate the need for advanced boosting solutions by using hybrid systems to provide equivalent performance and efficiency gains.

Development of advanced waste heat recovery solutions, with commercialisation most likely via intellectual property licensing to established Tier 1 suppliers of exhaust and/or thermal systems

Efficiency can be further increased by recovering the waste heat energy expelled through the exhaust system. Potential technologies have been evaluated for some time, including phase change materials (which can store heat and re-use it for engine warm-up or cabin heating) and thermoelectric generators (which can convert heat into electricity to support electrical loads on the vehicle thereby reducing load on the engine). However, these technologies have typically struggled to meet the size, mass and cost requirements for automotive applications so require innovative breakthroughs to achieve market acceptance.

The UK is well positioned to address this challenge and develop systems through its strong fundamental materials research capabilities and innovative SME culture, in addition to being home to a domestic Tier 1 exhaust systems and heat exchanger supplier (Unipart). For example, the Advanced Propulsion Centre is supporting a technology developer, Sunamp, to transfer its phase change technology from the domestic heating sector to the automotive sector. The first application is in buses, which are less size and mass sensitive than passenger cars and greatly benefit from reduced engine-warm-up time and support to cabin heating. The technology potentially also has strong applications in electric vehicles, where heating the cabin can significantly reduce the usable range of the vehicle.

The most likely route for commercialising intellectual property developed in the UK is likely to be via research, engineering services and/or licensing to a global Tier 1 exhaust system or thermal system supplier. However the scale of opportunity is uncertain as it relies upon fundamental technology breakthroughs and UK organisations will need to compete with the in-house development teams of exhaust and thermal systems suppliers typically located outside of the UK.

Development and Tier 1 supply of novel propulsion and auxiliary power engines to niche and specialist vehicle manufacturers to comply with emissions regulations and sustainability commitments

The study has highlighted the huge influence that the imperative to reduce emissions is having on the vehicle propulsion system, leading towards electrified vehicles with zero tailpipe emissions where possible. However, the range and recharging limitations of existing electro-chemical batteries limits their utility in long-range and heavy-duty applications. This means that there is still good opportunity for novel engine concepts that can further improve fuel economy and reduce pollutant emissions to levels compliant with future legislation and local low emission zone regulations.

High volume vehicle manufacturers will most likely continue to drive development of their propulsion engines and potentially range-extender engines through their considerable in-house capabilities, providing opportunities for academia, engineering service providers, technology suppliers and in-house teams located in the UK. However, manufacturers of lower volume and specialist vehicles may not be able to meet their low emissions and performance requirements using derivatives of these high volume engines and lack the resources to develop their own solutions, leading them to seek innovative Tier 1 solutions.

The UK has a significant domestic market of bus, on and off-highway commercial vehicle, motorcycle and niche passenger car manufacturers who will potentially fit into this category.

The UK has great strength in novel engine development through its academic research, technology developers and engineering service providers. This community is well supported by public funding. For example, Dearman has received Innovate UK, Office for Low Emission Vehicles and Advanced Propulsion Centre support in developing its zero tailpipe emissions liquid nitrogen expansion engine, which is expected to find its first commercial application in replacing auxiliary diesel engines in heavy duty truck refrigeration units. There is potential for the UK to build upon its experience in manufacturing engines at all volume levels to commercialise novel engine concepts within the UK. However, new entrants in this space need to either build full service Tier 1 supply capability or form an alliance with an incumbent supplier, whilst addressing the challenges of the UK manufacturing cost base that have led to a lot of Tier 2 internal combustion engine components being sourced abroad.

How well is the UK positioned to capitalise upon these opportunities?

This study has highlighted that the UK has a very strong and well established engine research-to-manufacture capability. Given suitable focus and investment, there is no reason why the UK cannot maintain and grow this position as long as internal combustion and novel engine concepts are required to satisfy long-range and high power application requirements.

The UK is home to world-class transmission design capability and world-class motorsport transmission production capability

The key potential opportunities for *transmission and driveline systems* can be found on page 57

The key potential opportunities for *kinetic energy recovery systems* can be found on page 60

Transmission, driveline and kinetic energy recovery systems

Overview

The transmission and driveline market is mature, using relatively stable technology produced by vehicle manufacturers and Tier 1 suppliers in parallel. However, new hybrid and electric powertrains are creating opportunity for disruptive transmission and kinetic energy recovery system (KERS) concepts.

High volume vehicle manufacturers will continue to source simplified transmissions for electrified powertrains either in-house or from established Tier 1 suppliers, but those suppliers may be driveline rather than transmission specialists. Low volume vehicle manufacturers will need to source electrified powertrains from Tier 1 suppliers that can provide tailored solutions. High volume transmission manufacturing is somewhat limited in the UK, but the UK is home to world-class transmission design and motorsport transmission production capabilities. This positions the UK strongly to provide engineering services and license IP for new transmission concepts, in addition to Tier 1 supply at low volumes if existing motorsport-derived supply chains can be scaled to provide cost effective solutions at higher than existing niche production volumes.

The kinetic energy recovery system market is embryonic, but with good potential for improving the efficiency of bus and off-highway applications that do not require zero emission running. The UK is a global leader in flywheel KERS technology and could be well placed to meet bus and off-highway manufacturers' needs if current niche volume manufacturing capability can be scaled to be cost effective for thousands to tens of thousands of units.

How is the global supply chain structured?

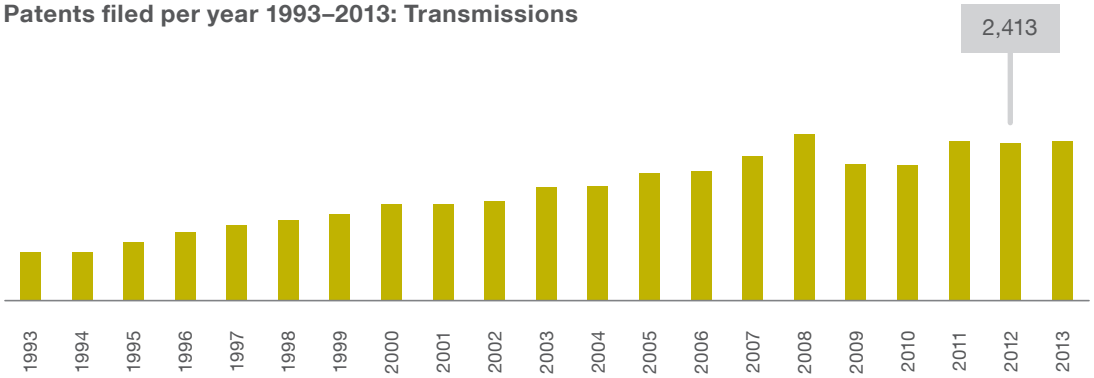
The global supply chain for transmission systems is well established, albeit comprising a complex mix of vehicle manufacturers producing their own systems in addition to buying complete systems from Tier 1 suppliers. For example, Volkswagen Group has produced over 8 million manual and dual clutch automated transmissions (DCT) since 2000 at its 2 plants in the Czech Republic, but also sources planetary gear automatic transmissions for its premium models from ZF and worked with BorgWarner to develop its DCT. Ford Motor Company has its own manufacturing capability in addition to a joint venture with leading Tier 1 supplier GETRAG (now part of Magna) producing transmissions in high volumes in Europe, including at a plant in Halewood that employs around 650 people. The picture is also mixed at the lower volume levels of premium manufacturers. For example, Mercedes-Benz manufactures its own planetary gear automatic transmissions, whilst BMW predominantly sources them from ZF. Some Tier 1 transmission suppliers specialise in low volume applications, such as Italian company Oerlikon Graziano that supplies to the likes of Aston Martin, Ferrari, Maserati and McLaren. Others leverage the motorsport supply chain for very low volume applications, such as UK company Xtrac that supplies the transmission for the Pagani Huayra. The supply chain for driveline systems (including side and propeller shafts) is broadly controlled by Tier 1 suppliers, with UK headquartered company GKN holding a dominant position. The picture is equally mixed for commercial vehicles, with off-highway applications requiring specialist solutions. For example, JCB has its own transmission and driveline facility, whilst global Tier 1 suppliers, such as Allison Transmissions, supply a broad range of on and off-highway applications.

The requirements of hybrid electric vehicles have already driven change, typically requiring either significant adaptation of existing transmission designs (such as ZF's integration of an electric motor into its planetary gear automatic transmission for BMW's plug-in hybrid electric vehicles) or novel transmission designs (such as the power split device used by the Toyota Prius hybrid electric vehicle). However, the requirements of battery electric vehicles will be much more disruptive and new transmission concepts supporting electrified powertrains are demonstrating an opportunity to challenge the incumbent supply chains. Most electric cars (including the Nissan Leaf, BMW i3 and Tesla Model S / X) use a single gear transmission, rather than the more complex and costly 5 to 10 speed or continuously variable transmissions (CVT) employed to maximise the efficiency of internal combustion engine vehicles. There is potential for multi-speed transmissions to improve the operating efficiency and speed range of electric vehicles, however only very heavy or high performance vehicles are likely to employ more than 2 or 3 gears. This presents a significant disruption to the incumbent transmission suppliers, who have built their engineering and production capability around complex multi-speed transmissions. This disruption creates opportunities for new transmission and driveline concepts integrating electric machines. Early evidence of this disruptive potential can be seen in the BMW i8's two-speed electric drive axle, which integrates a traction electric motor with a very simple two-speed transmission supplied by GKN, who historically has supplied differentials and driveshafts, but not transmissions. GKN also supplies a single-speed electric drive axle to the Volvo XC90 PHEV.

The global supply chain for kinetic energy recovery systems is nascent, with most applications comprising market tests. The few flywheel system suppliers are generally aligned with specialist transmission suppliers since Torotrak acquired Flybrid and GKN acquired Williams Hybrid Power, whilst Belgian company Punch powertrain developed its own solution. GKN Hybrid Power is the only supplier producing at significant volumes, which it does from its Telford facility. Alternatives to flywheels exist, but few have been commercialised. For example, hydraulic accumulator systems are offered by Caterpillar (in its 336E H excavator produced in Japan) and Lightning Hybrids (who retrofits on-highway trucks and buses in the United States).

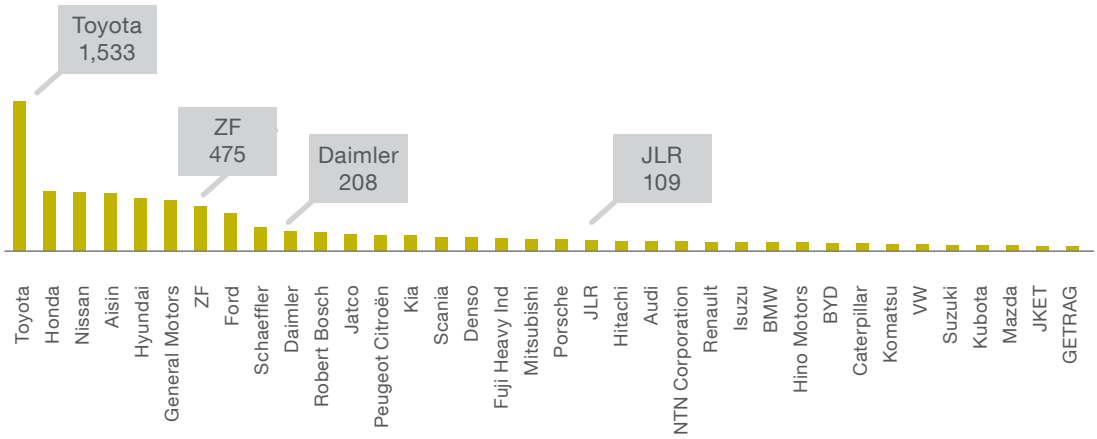
What does global patent filing activity tell us?

Patents filed per year 1993–2013: Transmissions



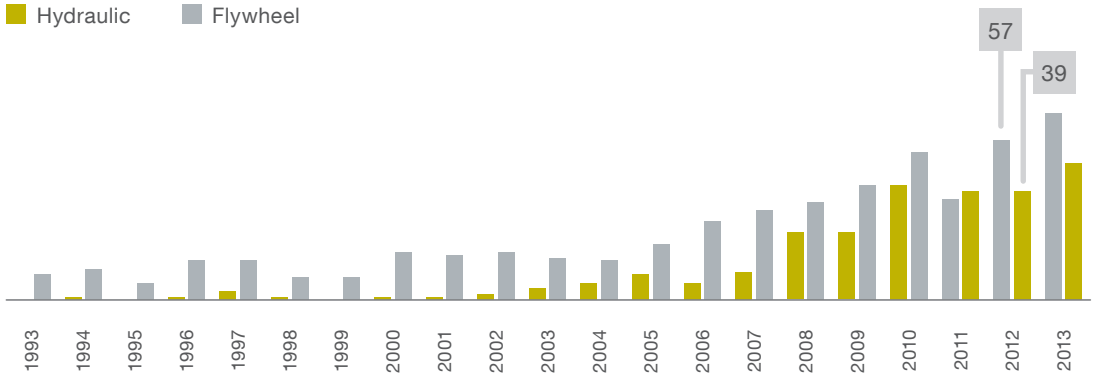
Global patent filing activity associated with transmission systems has been steady over the last 5 years, reflecting the relative maturity of the principal manual and automated transmission concepts. The majority of the patent filing activity since 2010 is accounted for by passenger car manufacturers (headquartered in Japan, Korea and North America) and Tier 1 suppliers (headquartered in Japan and Germany). A lot of activity is related to transmissions for hybridised vehicles, an area where Jaguar Land Rover has been an active filer over this period despite primarily buying-in transmissions from Tier 1 suppliers such as GETRAG and ZF. A number of on and off-highway commercial vehicle manufacturers and suppliers also appear in the list of top filers, reflecting the distinctly differing transmission needs of each segment. There are a number of businesses developing automotive transmission systems in the UK (including Drive System Design, JCB, Magnomatics, Ricardo, Romax Technology, Torotrak, Vocis and Xtrac) but they don't tend to be active patent filers with the exception of Torotrak, which has filed tens of patents related to its infinitely variable transmission (IVT) system in this period.

Top patent filers 2010–2016: Transmissions



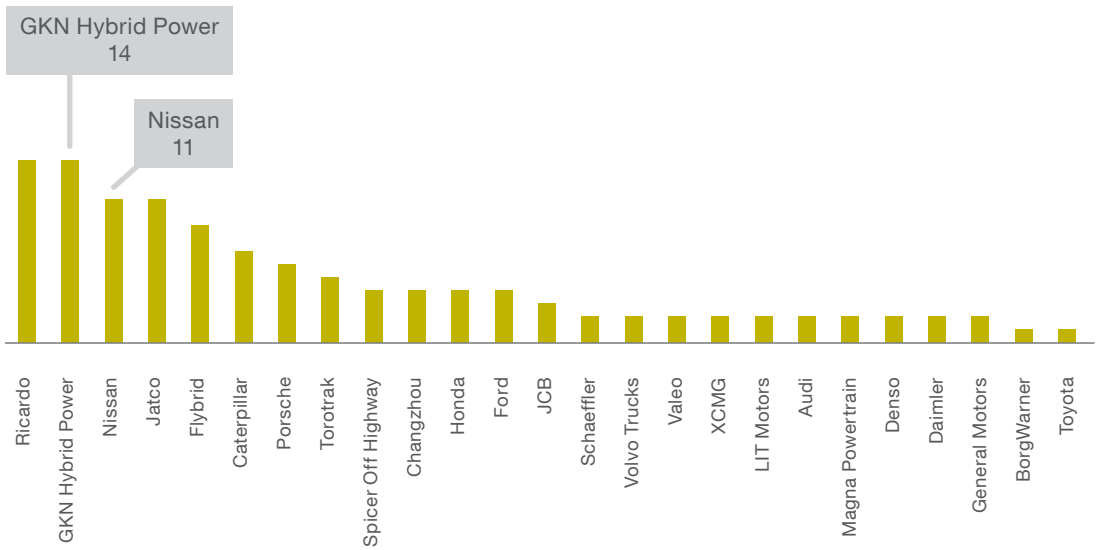
Patent filing activity for flywheel and hydraulic energy storage systems for automotive applications is relatively low with the most prolific filers only having tens of patents.

Patents filed per year 1993–2013: Kinetic Energy Recovery Systems



Most of the filing activity since 2010 related to hydraulic hybrid systems is accounted for by the collaboration between Robert Bosch and PSA Peugeot Citroën that sought to develop a system for passenger car application, but was shelved in 2015. Other notable filers include Parker (which offers its Runwise system for on-highway truck applications) and Dana (that offers its Spicer PowerBoost system for off-highway commercial vehicles). Most of the filing activity since 2010 related to flywheel systems is accounted for by the British companies Ricardo, GKN Hybrid Power (incorporating Williams Hybrid Power) and Torotrak (incorporating Flybrid) that have sought to transfer the carbon fibre flywheel technology developed for the 2009 Formula 1 KERS regulations to a range of sectors, including passenger cars, buses and off-highway commercial vehicles. In addition, Nissan and Jatco have together filed a number of patents since 2013 for lower cost flywheel systems aimed at passenger car applications.

Top patent filers 2010–2016: Flywheel KERS



(Footnote: The analysis of patents relating to transmissions, hydraulic hybrids and energy storage flywheels for automotive applications was conducted in February 2016. The search utilised a combination of International Patent Classifications, Cooperative Patent Classification and keyword searches; some patents may have been classified differently and will not have been captured by this analysis.)

What activity is taking place in the UK?

High volume transmission manufacturing is rather limited in the UK, with the notable exception of the GETRAG-Ford plant in Halewood that employs around 650 people manufacturing passenger car transmissions and the JCB plant in Wrexham that employs over 400 people and has produced over 2 million off-highway driveline systems since opening in 1978. However, the UK has a strong transmission and control system research and development capability through companies such as Drive System Design, JCB, Magnomatics, Ricardo, Romax Technology, Torotrak, Vocis and Xtrac. In addition the UK is home to a world-leading motorsport transmission production base, which has been successfully leveraged to produce very high performance car transmissions by Ricardo (for the Bugatti Veyron's dual clutch transmission) and Xtrac (for the Pagani Huayra's automated manual transmission). The UK is also the global headquarters for Tier 1 supplier GKN, whose driveline business is dominant in the automotive sector and employs over 650 people at its driveline manufacturing plant in Birmingham.

The UK has become a world leader in automotive flywheel energy storage systems, establishing strong intellectual property through the transfer of the carbon fibre composite flywheel technology developed for the 2009 Formula 1 KERS regulations. This has been supported by a number of publicly funded consortium projects, for example Flybrid (now part of Torotrak) and Williams Hybrid Power (now GKN Hybrid Power) have both received grant funding support through Innovate UK and the Advanced Propulsion Centre to adapt this motorsport technology to commercial vehicle applications. However, whilst GKN Hybrid Power has supplied a number of bus systems to early adopters from its Telford facility, there are significant challenges to overcome in reducing the cost of flywheel systems and establishing supply chains for higher volume manufacture. Accordingly, Nissan has an ongoing Innovate UK supported project investigating low cost laminated steel flywheel systems for passenger car applications in conjunction with City University, Tata Steel and Dynamic Boosting Systems. The UK is also home to hydraulic accumulator energy storage systems developers through UK company Artemis Intelligent Power and US company Lightning Hybrids, which established a facility at the MIRA Technology Park in 2015.

Where is UK public investment being channelled?

Approximately £34 million of public grant funding was co-invested by the UK Government (via EPSRC, Innovate UK, the Advanced Propulsion Centre and others) through 29 transmission, driveline and kinetic energy recovery system research and development projects for automotive applications during the period 2010 to 2015. Relatively little funding went to low technology maturity level research, most being focussed on development for specific applications. Projects tackled topics as diverse as reducing the weight of conventional drivelines, integrating electric drives to improve efficiency and exploring novel concepts for magnetic transmissions. In addition, a number of projects focussed on improving the performance and reducing the cost of flywheel energy storage systems for passenger cars, buses and on and off-highway commercial vehicles. Further to the projects identified by this analysis, the Energy Technologies Institute is funding Caterpillar to develop and demonstrate a continuously variable transmission suitable for heavy duty vehicles.

£34 million granted to 29 transmission, driveline and KERS related projects during 2010 to 2015

Technology Maturity	Principal Agency	Number of Projects	Total Grant Value £ millions
Early Stage	EPSRC	4	£3
Demonstrator	Innovate UK	21	£14
Applied	Advanced Propulsion Centre	4	£17

This level of funding is lower than the other technology areas covered by this study. The 17 transmission and driveline and 12 kinetic energy recovery system projects represent a small increase on the 11 transmission and driveline and 4 kinetic energy storage projects for passenger car applications supported during the period 2005-2010 (as reported by Ricardo in the 2010 *Automotive Technologies: The UK's current capability* report).

What did we learn from the industry survey and stakeholder interviews?

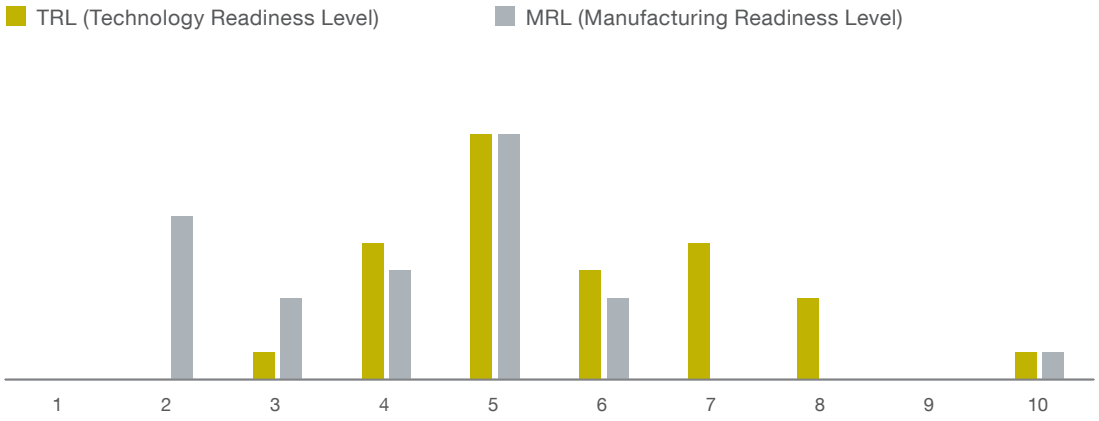
Whilst the overall level of funding is relatively low, over 60% of the transmission and KERS research and development projects captured via the industry survey are being conducted with public funding support, which indicates that grant funding support is well targeted.

The vast majority of respondents to the industry survey believe their research and development is either in-line with or leading the market. This reflects the array of different advanced transmission and KERS concepts being developed for most sectors. However, the difficulty in commercialising these technologies in the UK is reflected in the clustering of projects at mid TRLs. Respondents to the survey and participants in the consensus-building workshop highlighted production skills, facilities and equipment as key barriers to commercialising transmission, driveline and KERS technologies within the UK, in addition to some constraints in research, design and development skills.

The industry survey, stakeholder interviews and data analysis combine to highlight that the UK is leading the world in the research and development of flywheel based kinetic energy recovery systems, with a number of grant funded projects demonstrating the potential of the technology to significantly improve vehicle efficiency in stop-start duty cycles across passenger car, bus and on and off-highway commercial vehicle applications. However, the cost of the technology needs to be reduced to make it more attractive to a global market and a supply chain established that can support mass production if it is to grow beyond a niche proposition. The study also highlights the relative strength of the UK companies in developing novel transmission concepts and their control systems, plus managing their integration into complex powertrains. The UK motorsport industry has a thriving low volume production base, which has been successfully leveraged for very high performance car transmissions. However, high volume transmission manufacturing in the UK is limited, with most of the vehicles produced in the UK using imported transmissions from vehicle manufacturers own plants or foreign headquartered suppliers, which severely limits routes to market for UK innovation.

The UK is leading the world in the research and development of flywheel based kinetic energy recovery systems

Maturity of UK R&D projects reported to the industry survey



What new capabilities have been built in the UK since 2010?

- Torotrak manufactures an infinitely variable transmission for the Tata Pixel concept car (2011)
- As part of the Innovate UK RE-EVolution project, Xtrac supplies its 1092 transmission to the Infiniti EMERG-E concept car (2012)
- Vocis develops a twin-motor seamless-shifting 4-speed transmission in collaboration with Zytek (2013)
- Drive System Design forms Evolute Drives in order to accelerate the development of high efficiency driveline technologies (2014)
- Ricardo showcase its 'TorqStor' flywheel designed for the off-highway sector (2014)
- GETRAG-Ford invests £13 million into its plant at Halewood to build a new transmission line (2014)
- The Romax Technology Centre based on Nottingham University's Innovation Park was opened to design and develop conventional, hybrid and electric drivetrains (2014)
- GKN acquires Williams Hybrid Power and begins retrofitting its flywheel system in Alexander Dennis buses (2014)
- JCB Transmissions produces its two millionth drivetrain at its Wrexham facility (2015)
- Jaguar Land Rover unveils an ultra-light transmission and driveline package as part of an Innovate UK funded project (2015)
- Torotrak trials its clutched flywheel transmission system in a Wrightbus StreetLite midi bus (2016)
- Magnomatics announces it will be collaborating with Changan in an Innovate UK co-funded project to develop its MAGSPLIT Dedicated Hybrid Transmission (2016)

GETRAG-Ford reinforces commitment to making transmissions in the UK

Employing around 650 people, GETRAG-Ford was established in 2001 as a joint venture between Ford Motor Company and GETRAG with its plant in Halewood manufacturing manual rear and front wheel drive transmissions. In 2015 GETRAG-Ford committed to continue manufacturing transmissions in the UK by investing a further €15 million into its Halewood facility to produce a new rear wheel drive transmission, with further investment planned for future years. On January 1, 2016, GETRAG was acquired by Magna International and is now part of the Magna Powertrain organization.

Innovative magnetic gear technology developed in the UK

Magnomatics was spun out of Sheffield University in 2006 to develop transmissions using magnetic gear technology and has generated interest in its technology through Innovate UK funded projects with Ford Motor Company and Volvo Group. Using permanent magnets to transmit torque between an input and output shaft without mechanical contact, Magnomatics has developed a continuously variable transmission called the MAGSPLIT that can be used as a power split device in place of an epicyclical gearbox in a hybrid electric vehicle.

Drive System Design develop novel transmissions

New technology company Evolute Drives is developing its driveline technology in partnership with the Proving Factory to target the premium electric vehicle market. Its affiliated company, Drive System Design is also active in novel transmission designs and recently invested in a new test and development and low volume transmission build facility. In addition Drive System Design is also investigating the feasibility of using composite plastics in electric vehicle drivelines with chemicals company Solvay.

UK leads in advanced flywheel technology

The UK is a global leader in the development of flywheel energy storage systems. Originally developed to meet the stringent fuel efficiency targets set by Formula 1 KERS regulations, flywheels are being transferred from motorsport into road vehicles. Flybrid (now part of Torotrak) has developed a mechanical flywheel system that has been trialled in Volvo and Jaguar Land Rover passenger cars as well as Wrightbus' Streetlite buses. In addition, GKN Hybrid Power has a fleet of buses across the UK trialling their electro-mechanical flywheel whilst Ricardo has demonstrated its mechanical flywheel system in Optare buses with funding from Innovate UK.

What future industry needs could the UK address?

A series of addressable industry needs related to transmissions and drivelines were identified by combining the capability assessment with market analysis and qualitative insight captured through the stakeholder interviews and consensus-building workshops:

- All vehicle manufacturers developing electrified powertrains are seeking dedicated transmission solutions that better suit the specific requirements of the application than a transmission designed for a conventional combustion engine powertrain; e.g. most electric vehicles are expected to require only 1 or 2 gears; hybrid electric vehicles need to blend multiple power sources.
- Vehicle manufacturers developing electrified powertrains are seeking to maximise the efficiency and performance of the traction motor, transmission and driveline system through effective integration.
- Low volume vehicle manufacturers continue to seek high efficiency transmissions that can cost effectively meet the high performance requirements of applications ranging from sports cars to off-highway vehicles that are not well served by the standard transmissions available from high volume Tier 1 suppliers.
- Off-highway vehicle manufacturers are seeking transmission solutions (such as continuously variable systems) that can be cost effectively adapted from high volume applications to improve the powertrain system efficiency of mid-range machines.

Transmission and driveline systems

What are the key potential opportunities for the UK?

A series of potential opportunities for the UK arising from these addressable industry needs were defined and rated according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation. These hypotheses were subsequently refined with a broad range of experts through the consensus-building workshops.

Invest-to-Improve:

UK could invest to improve positioning since these opportunities appear to be attractive

Opportunity	Commercialisation Timeframe
Development and Tier 1 supply of transmissions that cost effectively meet the specific requirements of low volume hybrid and electric vehicles	Short timeframe (by 2020)

Opportunistic:

UK has good positioning for these opportunities, though their relative attractiveness is lower – UK could take advantage of its position as opportunities emerge

Opportunity	Commercialisation Timeframe
Development and licensing of innovative solutions to established transmission manufacturers (vehicle manufacturers and Tier 1 suppliers) for integrating the traction electric motor, transmission and driveline in electrified powertrains	Medium timeframe (by 2025)

Development and Tier 1 supply of transmissions that cost effectively meet the specific requirements of low volume hybrid and electric vehicles

The study has identified increasing demand for transmissions suited to lower volume applications, which have significantly different performance, mass and cost requirements to high volume passenger car applications. However, similar to high volume passenger cars, these low volume vehicles will increasingly adopt hybridised and electrified powertrains in the future.

The concentration of high performance, luxury and niche vehicle manufacturers in the UK provides a significant domestic market opportunity. In addition, UK companies have a proven track record of exporting transmissions for high performance passenger car applications, such as Ricardo supplying dual clutch transmissions to the Bugatti Veyron and Xtrac supplying automated manual transmissions to the Pagani Huayra. Typically vehicle manufacturers in low volume passenger car segments seek turnkey supply as they do not have sufficient in-house skills and capacity to develop and produce their own transmissions. However, these applications are not well served by international Tier 1 suppliers who are focussed on engineering and production programmes for mainstream passenger car applications.

Additional opportunities could be found in supplying off-highway manufacturers (such as JCB, which has its own transmission plant in Wrexham) who are seeking to adapt passenger car technologies for their mid-range machines.

The UK has a strong transmission and control system research and development capability in addition to a world-leading motorsport transmission production base that has been successfully leveraged for very high performance car transmissions. However, there are significant commercial challenges to overcome for UK organisations to provide cost effective full service (including warranty provision) Tier 1 supply at annual volumes greater than the hundreds required by motorsport or exotic vehicles such as the Veyron and Huayra. Capitalising on these opportunities requires development of solutions and supply chains that can be cost competitive with both re-engineered transmissions from the incumbent high volume suppliers and low volume specialists, such as the Italian company Oerlikon Graziano that supplies dual clutch transmissions to McLaren and has supplied automated manual transmissions to Aston Martin (One-77, Vantage S).

Development and licensing of innovative solutions to established transmission manufacturers (vehicle manufacturers and Tier 1 suppliers) for integrating the traction electric motor, transmission and driveline in electrified powertrains

The study has identified how electrification of the powertrain has the potential to disrupt the established transmission supply chain. The requirements of hybrid electric vehicles have already driven change and the requirements of electric vehicles (which typically use a single gear) are likely to be much more disruptive. The manufacturers of high volume electric vehicles will most likely continue to source transmissions either from the established Tier 1 transmission and driveline supply base or produce them in-house, limiting opportunities for completely new market entrants. However there is opportunity for UK businesses to provide engineering services and/or license technology related to new transmission concepts to both vehicle manufacturers and the incumbent transmission and driveline Tier 1 suppliers. The UK has a strong innovation capability across transmissions, electric machines, power electronics and systems integration and is not home to an incumbent high volume Tier 1 transmission manufacturer, which positions UK organisations well to develop disruptive concepts. UK organisations seeking to capitalise on this global opportunity will be challenged to develop technology that surpasses that of the vehicle manufacturers' and Tier suppliers' own innovation teams, in addition to forging the global relationships that will provide a route to market. There is a long term risk that more radical disruption in the form of direct drive wheel hub motors could remove the need for a transmission and drive shafts altogether. However, whilst UK-based Protean Electric has demonstrated the potential benefits of this technology, whether the mass market will adopt it remains unclear.

Kinetic energy recovery systems

What are the key potential opportunities for the UK?

In addition, a series of addressable industry needs related to kinetic energy recover systems were also identified:

- Bus manufacturers are seeking more cost effective flywheel kinetic energy recovery systems that can be scaled-up for low volume production.
- Off-highway vehicle manufacturers are seeking cost effective kinetic energy recovery systems (including flywheels and hydraulic accumulators) that are sufficiently robust to meet the demands of off-highway applications.

Similarly, potential opportunities for the UK arising from these addressable industry needs for kinetic energy recovery systems were defined and rated according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation. These hypotheses were subsequently refined with a broad range of experts through the consensus-building workshops into a single opportunity.

Opportunistic:

UK has good positioning for these opportunities, though their relative attractiveness is lower – UK could take advantage of its position as opportunities emerge

Opportunity	Commercialisation Timeframe
Development and low volume production of cost effective kinetic energy recovery systems, primarily for bus and off-highway applications	Short timeframe (by 2020)

Development and low volume production of cost effective kinetic energy recovery systems, primarily for bus and off-highway applications

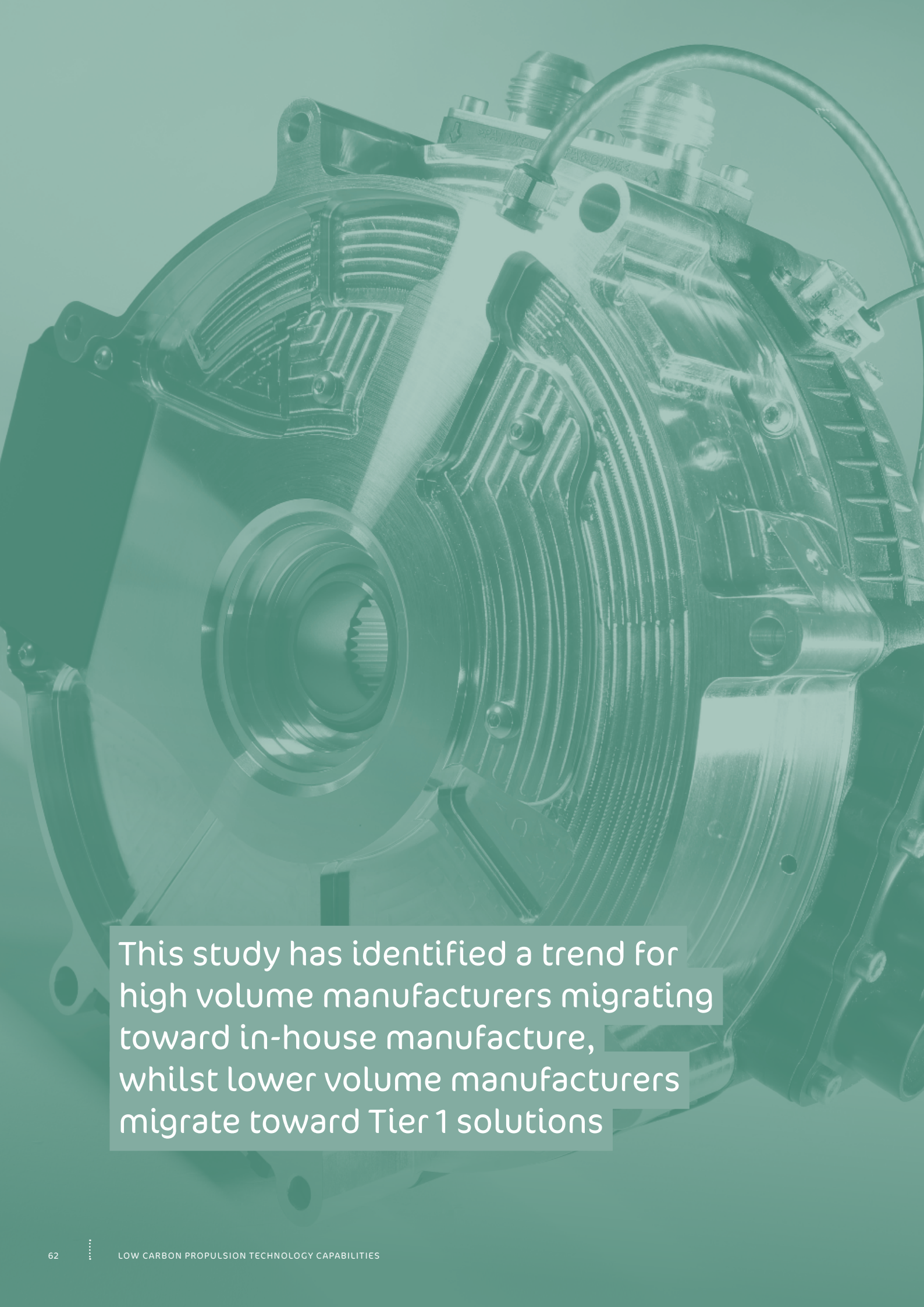
The study has confirmed the need for more cost effective solutions for hybridising large vehicles with stop-start duty cycles, particularly buses and mid-sized off-highway vehicles, to improve their efficiency and reduce emissions. Typically electrification of large vehicle powertrains is impractical with current electrochemical energy storage technology as the battery systems are too costly, large and heavy. A number of limited volume products have demonstrated the potential of kinetic energy recovery systems to deliver good performance and efficiency in commercial vehicle applications, including Alexander Dennis fitting GKN's Gyrodrive electro-mechanical flywheel system to a number of its buses and Caterpillar fitting its own hydraulic accumulator system to its 336E H large excavator. However, kinetic energy recovery systems are still considered to be too expensive for mass market adoption.

The UK's strong bus and off-highway vehicle manufacturing sector coupled with UK Government programmes to retrofit emissions reducing technologies (such as the Clean Bus and Clean Vehicle Technology Funds) has created a strong pull for UK technology capable of reducing the emissions of large commercial vehicles. The UK has become a global leader in automotive flywheel energy storage systems, establishing strong intellectual property through the transfer of technology from Formula 1 motorsport. However, whilst GKN Hybrid Power has supplied a number of systems to early adopters, there are significant challenges to overcome in reducing the cost of flywheel systems and establishing supply chains for higher volume manufacture.

The scale of the opportunity can be increased if acceptable payback and system packaging can be demonstrated to vehicle manufacturers outside the UK, particularly in the bus sector. The scale of the opportunity could be significantly further increased if higher volume markets adopted kinetic energy recovery system technology. Volvo built demonstrator vehicles in 2014 using Flybrid's carbon fibre composite flywheel technology, whilst Nissan has an ongoing Innovate UK supported project investigating laminated steel flywheel systems in conjunction with City University, Tata Steel and Dynamic Boosting Systems. However adoption of the technology for passenger cars and the formation of a high volume supply chain to support remains uncertain. KERS systems do not typically provide the engine-off (zero tailpipe emission) driving that is likely to be required in inner city clean air zones in the future, which will limit their attractiveness long-term versus plug-in hybrid, fuel cell and battery electric vehicles.

How well is the UK positioned to capitalise upon these opportunities?

This study has highlighted that the UK has a strong innovation base from which to offer high performance transmission and kinetic energy recovery system products for low volume applications and engineering services developing innovative electrified transmissions and drivelines for high volume applications. However, innovative design and new supply chain structures are required in order to produce cost effective products in the UK.



This study has identified a trend for high volume manufacturers migrating toward in-house manufacture, whilst lower volume manufacturers migrate toward Tier 1 solutions

The key potential opportunities for *traction electric machines and power electronics* can be found on page 73

Traction electric machines and power electronics

Overview

Irrespective of whether fuel cell, plug-in-hybrid or battery electric vehicles dominate in the future, electric machines and power electronics will be required to convert their stored energy into motion.

Vehicle manufacturers' supply chain strategies are still emergent, but this study has identified a trend for high volume manufacturers to migrate toward in-house manufacture, whilst lower volume manufacturers migrate toward Tier 1 solutions. There will potentially be strong future demand from UK manufacturers of buses and low volume luxury / high performance passenger cars for Tier 1 solutions and UK manufacturers of high volume passenger cars for Tier 2 components. This will present opportunities for Tier 2 and Tier 1 suppliers alike, in addition to engineering service providers and research organisations. The UK can leverage its strong research and development capability, a wealth of innovative SMEs, world-class engineering service providers and experience in manufacturing lower power electric machines and power electronics to capitalise upon these demands. However, capability investment and process innovation will be required to ensure large machines can be cost effectively manufactured in high volumes in the UK.

How is the global supply chain structured?

The current global supply chain for automotive traction electric motors and power electronics is relatively immature. However, the leading passenger car manufacturers are beginning to shape the market as electrified vehicle volumes grow to mass production levels. A number of high volume manufacturers are sourcing their traction electric motors in-house. Nissan manufactures motors for the Leaf EV in Japan and at its Decherd plant in the United States. Volkswagen manufactures motors for its EVs (such as the 2014 e-Golf) and PHEVs (such as the 2015 Golf GTE) at its Kassell plant in Germany. A number of mid-high volume vehicle manufacturers have leveraged supplier technology to quickly bring products to market, in parallel to developing their own traction electric motor capability. For example, BMW sourced motors for the 2015 X5 xDrive40e and 2016 330e PHEVs from ZF, who supply the motors integrated into the transmission system. However, BMW has in parallel manufactured motors for the i3 REEV at its Landshut plant since 2013 and has adapted this technology to its 2016 225xe PHEV. Daimler established a joint venture with Robert Bosch in 2011 called EM-motive, which supplies the motors for Mercedes-Benz HEVs (such as the 2012 E300 Hybrid) from a plant located in Hildesheim, Germany. However, Daimler sourced the powertrain for its 2014 B-Class EV from Tesla, which manufactures all its motors at its Fremont plant in the United States.

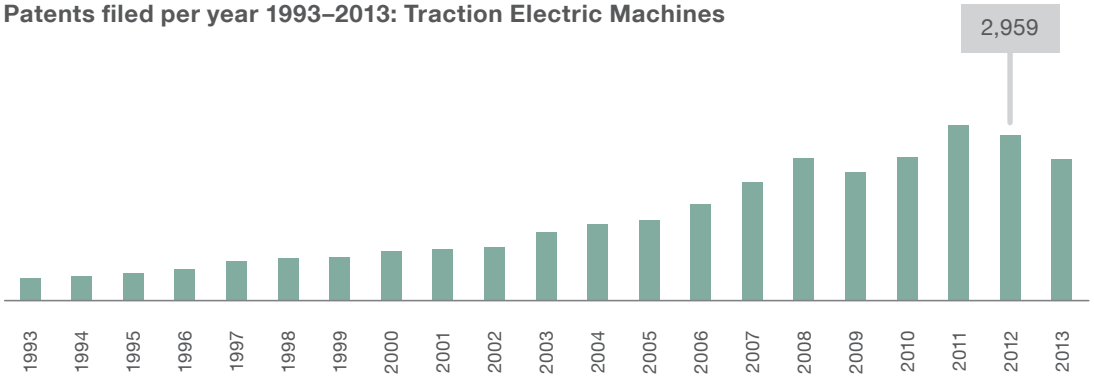
Mid-volume manufacturer Volvo Cars sourced the traction motor and power electronics for the 2015 XC90 PHEV from Siemens, with the motor being integrated into an axle unit supplied by GKN. Mid-volume Jaguar Land Rover also sourced from a Tier 1, using ZF's integrated hybrid transmission system for its Range Rover and Range Rover Sport models, but has also demonstrated an intent to develop its own motor technology through the Innovate UK supported Evoque_e project.

Activity beyond passenger cars is currently limited to niche markets, such as electric forklift trucks (as supplied by UK company Nexen), or market explorations. Some manufacturers are offering small electric vans utilising passenger car derived technology, such as Nissan (e-NV200), Renault (Kangoo Z.E.) and Peugeot (Partner Electric). Electrification of larger vehicles is limited by the energy density of current electrochemical energy storage, however some manufacturers are offering hybrid variants in limited volumes, such as FUSO (7.5T Canter Eco Hybrid) and Volvo (26T FE Hybrid). In addition, some independent businesses are retrofitting electric powertrains to vans and small trucks (such as USA and UK based Smiths Electric Vehicles). There are few electric motorcycles available, with some major manufacturers and new market entrants testing the market, such as Yamaha (EC-03 scooter) and California-based Zero Motorcycles.

Passenger car manufacturers are beginning to shape the market as electrified vehicle volumesgrow to mass production levels

What does global patent filing activity tell us?

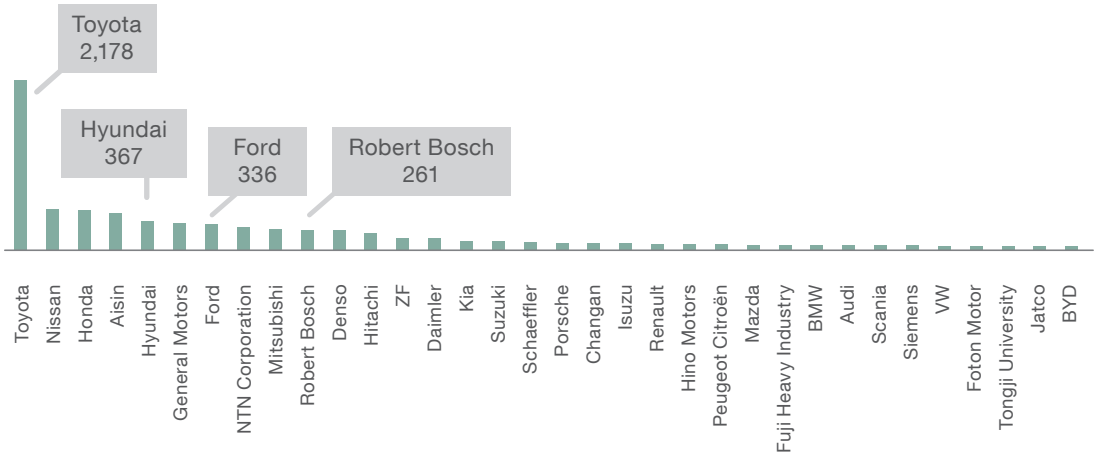
Patents filed per year 1993–2013: Traction Electric Machines



Global patent filing activity in this area provides some insight into future supply chain strategy, suggesting that high volume passenger car manufacturers are seeking to control traction electric machines (and the associated control strategy) as core technology. The majority of patent filing activity since 2010 associated with traction electric machines for automotive applications is accounted for by Japanese, Korean and North American vehicle manufacturers, followed by Japanese and German Tier 1 suppliers.

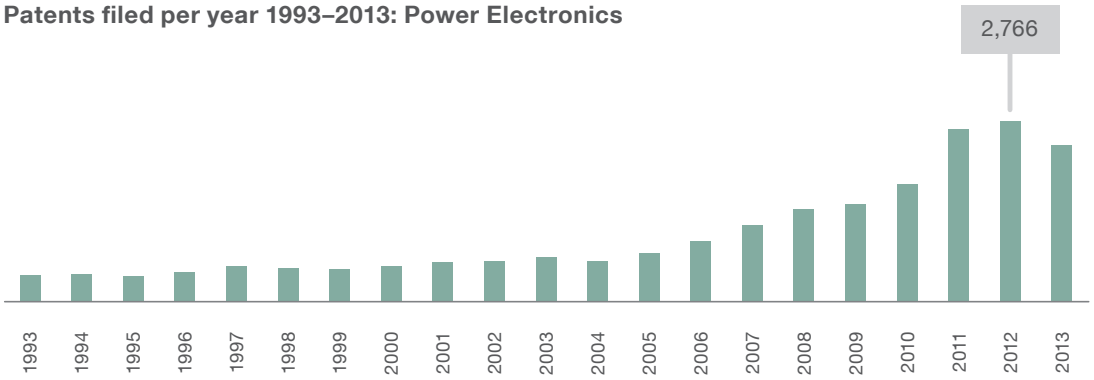
High volume passenger car manufacturers are seeking to control traction electric machines as core technology

Top patent filers 2010–2016: Traction Electric Machines



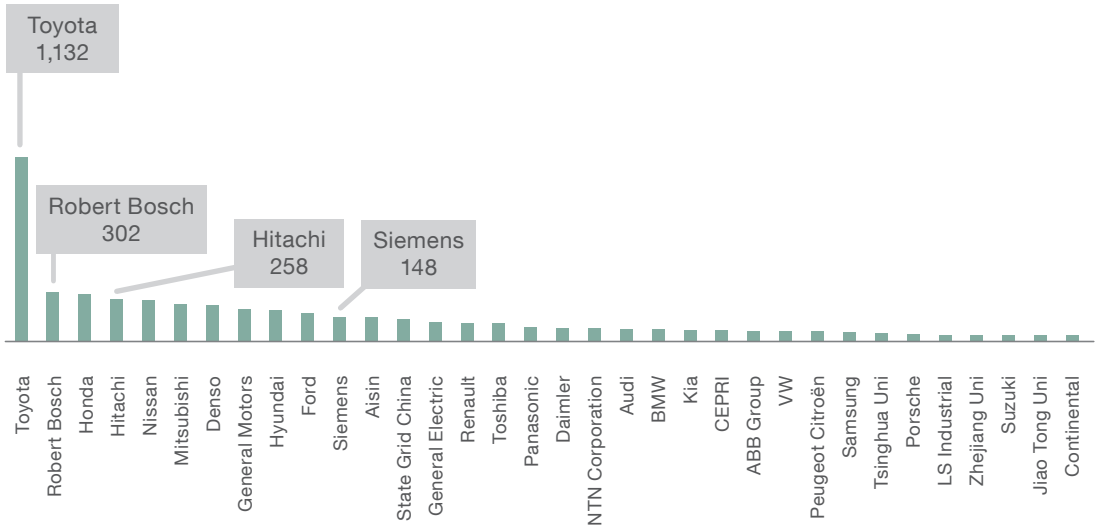
Whilst the majority of patent filing activity from 2010 to 2015 associated with power electronics for automotive applications is accounted for by Japanese vehicle manufacturers and Japanese and German Tier 1 suppliers.

Patents filed per year 1993–2013: Power Electronics



Notably industrial players such as Hitachi, Siemens and Toshiba are increasingly active in filing patents related to automotive power electronics, each holding hundreds of patents in this area.

Top patent filers 2010–2016: Power Electronics



(Footnote: The analysis of patents relating to traction electric machines and power electronics for automotive applications was conducted in February 2016. The search utilised a combination of International Patent Classifications, Cooperative Patent Classification and keyword searches; some patents may have been classified differently and will not have been captured by this analysis.)

What activity is taking place in the UK?

Within the UK there are numerous companies conducting electric traction machine and power electronics related research and development, including many SMEs and some international Tier 1 suppliers (such as Continental Engineering Services, following the acquisition of Zytek Automotive). Some companies are manufacturing above prototype volumes in the UK with YASA Motors planning to open a motor facility capable of manufacturing 60,000 motors per annum. Other SMEs are finding applications for their new technologies in niche volume markets (such as Ashwoods Electric Motors supplying the Morgan EV3), whilst some larger companies (such as McLaren Applied Technologies and Williams Advanced Engineering) are transferring motorsport technologies into low volume, high performance passenger car applications. In the motorcycle sector, Saietta have developed a high power brushless motor that was initially used in the electric motorcycle championship MOTO-E and will now be used in Saietta Motorcycles' future product range. In power electronics, Sevcon has successfully established itself as a low volume Tier 1 supplier of power electronics, including for the Renault Twizzy, albeit leveraging off-shore manufacturing. Similarly Protean Electric conduct engineering work in their facility in Farnham but will manufacture their in-wheel motors in China with their factory opening in 2017. Nonetheless there is precedent for manufacturing lower power machines in the UK, with TRW's plant in Sunderland mass manufacturing around one million electric machines for steering systems. Jaguar Land Rover, Protean Electric, YASA Motors and Sevcon all possess significant patents relating to traction electric machines and/or power electronics for automotive applications developed in the UK, but the scale of filing activity is relatively low vs. the most prolific global filers (Jaguar Land Rover possessing tens of patents vs. Toyota's thousands and Nissan, Honda and Robert Bosch each possessing hundreds).

Sevcon has successfully established itself as a low volume Tier 1 supplier of power electronics for the Renault Twizzy

Where is UK public investment being channelled?

Approximately £122 million of public grant funding was co-invested by the UK Government (via EPSRC, Innovate UK, the Advanced Propulsion Centre and others) through 94 electric machine and power electronics research and development projects for automotive applications during the period 2010 to 2015. The projects sought to improve the performance and reduce the cost of electrified powertrains by improving manufacturing methods, reducing rare earth material content in machines, utilising new materials (e.g. Silicon Carbide) in power electronics and employing smarter management of power systems. The majority of the funding was focussed on mid to high technology maturity level activities, showing good support to commercialising these technologies in the UK. In addition, a significant amount of funding is being invested in equivalent technologies for aerospace and industrial applications, with strong cross-over potential particularly for power electronics.

This compares favourably with the 18 electric machine and power electronics projects for passenger car applications that were supported during the period 2005-2010 (as reported by Ricardo in the 2010 *Automotive Technologies: The UK's current capability* report).

£122 million granted to 94 electric machine and power electronics related projects during 2010 to 2015

Technology Maturity	Principal Agency	Number of Projects	Total Grant Value £ millions
Early Stage	EPSRC	22	£13
Demonstrator	Innovate UK	63	£68
Applied	Advanced Propulsion Centre	9	£41

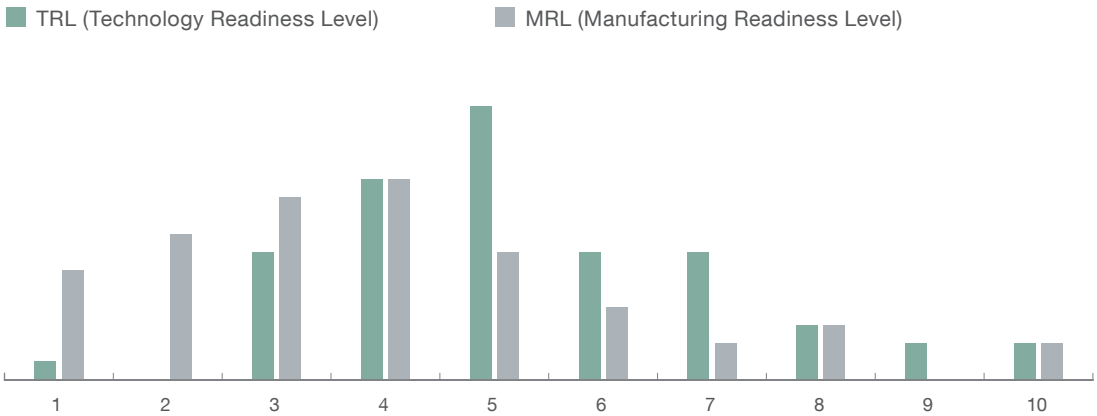
What did we learn from the industry survey and stakeholder interviews?

65% of the electric traction machine and power electronics research and development projects captured via the industry survey are being conducted without public funding, which suggests that UK businesses are growing in confidence in investing in this technology area. The majority of respondents believe their research and development, which covers a broad range of topologies and applications, is either in-line with or leading the market. However, there remains a peak of activity at mid-TRL highlighting the need to accelerate commercialisation of these promising new technologies within the UK. This will be aided by the recent and significant UK Government investment in high technology maturity grant funding, delivered by the Advanced Propulsion Centre. Respondents to the industry survey and participants in the consensus-building workshops considered production skills, facilities and equipment as the key constraints to commercialising these innovations within the UK.

The industry survey, stakeholder interviews and data analysis combine to suggest the UK is developing genuinely innovative electric traction machine and power electronics technologies, with a number of Universities being renowned for their electric machine technology and a number of SMEs developing innovative concepts, particularly for high speed / high power applications. However, the UK currently has limited Tier 1 traction electric machine and power electronics supply capability, with the existing capability fragmented amongst a number of SMEs and reliant upon imported materials. Sevcon's success in supplying power electronics to Renault for the Twizzy demonstrates that UK companies can grow to operate as Tier 1 suppliers for lower volume products, acknowledging that Sevcon has leveraged off-shore manufacturing to achieve competitive costs.

The UK is developing genuinely innovative electric traction machine and power electronics technologies – however, the UK currently has limited Tier 1 traction electric machine and power electronics supply capability

Maturity of UK R&D projects reported to the industry survey



What new capabilities have been built in the UK since 2010?

- GKN establish a joint venture with Evo Electric called GKN EVO eDrive Systems (2011)
- Cummins opens a new Innovation Centre for research on Electrical Machines and related technologies at the University of Nottingham (2012)
- Sevcon supplies its Gen4 motor controller unit to the Renault Twizzy (2012)
- Zytek develops a 25kW electric motor for the Gordon Murray Design T.27 city car (2013)
- Prodrive successfully trial a silicon-carbide DC-DC converter on a Tata Vista EV demonstrator as part of an Innovate UK funded project (2014)
- AVID Technology implements its eFan micro-hybrid system on trentbarton buses (2014)
- McLaren Applied Technologies supplies the electric motor and power electronics for the 1st Formula E series (2014)
- Controlled Power Technologies open its new technical centre in Coventry to complement its facility in Basildon (2015)
- MAHLE and Protean Electric showcase a prototype plug-in hybrid electric vehicle with in-wheel electric motors (2015)
- London Taxi Company opens a new £150m research, development and assembly facility in Coventry in preparation for the launch of the TX5 range-extended electric taxi (2015)
- Ashwoods Electric Motors supplies the 46kW motor for the new, all-electric Morgan EV3 (2016)
- Saietta debuts its latest high power brushless motor in a new electric motorcycle (2016)
- YASA, supplier of electric motors for hybrid and electric vehicles, opens a 40,000 sq ft manufacturing facility with capability to manufacture 60,000 motors per annum (2016)

Evoque_e project develops a novel traction motor

As part of the £16.3 million Evoque_e project co-funded by Innovate UK, a consortium of UK based companies and universities developed an innovative high performance traction electric machine. The rare-earth free motor delivered performance approaching that of motors containing the commonly used but expensive rare earths Neodymium and Dysprosium at a much lower cost. The motor, designed to provide traction for the battery electric Concept-E vehicle, used ferrite magnets and low cost aluminium windings in place of copper.

Vayon Group strengthens its electric machine and power electronics capabilities

Vayon Group supplies a range of low carbon technology products and provides engineering services for electrified propulsion systems. Vayon (via its Frost EV Systems company) is collaborating with Intelligent Energy through an Advanced Propulsion Centre funded project to integrate a fuel cell range extender into a battery electric van. Vayon further strengthened its power electronics, electric machine and battery management system capabilities in 2016 through the acquisition of California-based Mission Motors.

McLaren Applied Technologies supplies Formula E

Teams competing in the first season of Formula E utilised a series of standard components developed and manufactured in the UK. McLaren Applied Technologies utilised the experience it gained in high performance passenger cars and Formula 1 to supply electric machines and power electronics to the entire Formula E grid. McLaren claims the Formula E electric motor is three to four times more powerful than the average series hybrid electric motor and is now harnessing the knowledge gained for future products.

Sevcon positioned as a UK Tier 1 supplier of power electronics

Sevcon is a UK-based Tier 1 supplier of power electronics that has supplied its Gen4 motor controller globally into a wide range of applications and vehicles including over 20,000 units to Renault for the Twizzy city car. Sevcon increased its capability in March 2016 by purchasing battery charging company Bassi, enabling it to integrate battery charger and power management technology.

What future industry needs could the UK address?

A series of addressable industry needs related to electric traction motors and associated power electronics were identified by combining the capability assessment with market analysis and qualitative insight captured through the stakeholder interviews and consensus-building workshops:

- High volume passenger car vehicle manufacturers are seeking Tier 2 component supply chains to support ramp-up of in-house manufacture of traction electric machines, which they consider to be a core technology due to a range of factors, including: high bill of materials cost, opportunity for competitive cost and performance differentiation and utilisation of existing engineering and manufacturing resources.
- Low volume vehicle (including luxury car, bus and off-highway) manufacturers are seeking cost effective turnkey Tier 1 supply of electric traction machines and power electronics as they do not have sufficient in-house skills capacity to develop their own systems. In general they prefer to source the machine and electronics from the same supplier.
- All vehicle manufacturers are challenged with securing appropriately skilled resources to conduct the complex application and systems engineering required for electrified powertrain systems.
- Vehicle manufacturers are seeking significant gains in cost and performance (particularly high temperature capability) from next generation power electronics systems employing wide band gap materials such as silicon carbide (SiC) and gallium nitride (GaN)

What are the key potential opportunities for the UK?

A series of potential opportunities for the UK arising from these addressable industry needs were defined and rated according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation. These hypotheses were subsequently refined with a broad range of experts through the consensus-building workshops.

Focus:

UK could provide focused support to build upon existing advantages in these attractive opportunity areas

Opportunity	Commercialisation Timeframe
Application and systems engineering services for next generation traction electric machine and associated power electronics technology focussing on low volume and specialist applications, in addition to in-house activity conducted by high volume vehicle manufacturers' R&D centres in the UK	Short timeframe (by 2020)

Invest-to-Improve:

UK could invest to improve positioning since these opportunities appear to be attractive

Opportunity	Commercialisation Timeframe
Development and Tier 1 supply of electric machines and associated power electronics for low volume / high performance traction applications	Short timeframe (by 2020)
High volume manufacturing of electric traction machines by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of components and/or sub-assemblies	Medium timeframe (by 2025)

Application and systems engineering services for next generation traction electric machine and associated power electronics technology focussing on low volume and specialist applications, in addition to in-house activity conducted by high volume vehicle manufacturers' R&D centres in the UK

In addition to securing supply of traction electric machines and associated power electronics, vehicle manufacturers will also need to conduct the application and systems engineering required to successfully integrate electrified powertrains. The study indicates that vehicle manufacturers will continue to consider systems engineering a core competence providing competitive advantage and will continue to add electrified powertrain skills to their in-house capability. This will provide opportunity for vehicle manufacturer R&D centres located in the UK. However manufacturers of vehicles in lower production volume sectors are likely to be limited by a shortage of internal capacity and relevant skills in the labour market, forcing them to seek external support. The study has highlighted the strong electrified powertrain systems engineering capabilities of UK-based engineering services providers and a new generation of SMEs. This positions UK organisations strongly to capitalise upon consultancy opportunities with the luxury car, bus and off-highway commercial vehicle manufacturers prevalent in the UK. Capitalising upon the opportunity will require access to suitable infrastructure as well as skills, in particular dyno tests systems suitable for complete electrified powertrains.

The scale of the opportunity can feasibly be increased by offering services to clients outside the UK, a common model for UK-based engineering services providers. The scale of the opportunity could potentially be further increased by offering services to vehicle manufacturers engaged in high volume passenger production, but it would require those manufacturers outsourcing some of their core systems engineering work.

Development and Tier 1 supply of traction electric machines and associated power electronics for niche or low volume high performance applications

The study has identified demand for electrified powertrain technology capable of being introduced to the market by 2020 and suited to the specific requirements of the lower production volume sectors that are strong in the UK. These requirements include high power density, lightweight electric machines suited to luxury / high performance car traction applications and high power, durable electric machines suited to bus and off-highway commercial vehicle traction applications. Whilst the production volumes are relatively low, system values are relatively high and therefore could provide attractive opportunity when multiple vehicle manufacturers' requirements are aggregated. Typically vehicle manufacturers in these segments are seeking turnkey supply as they do not have sufficient in-house skills capacity to develop their own systems and have expressed a preference to source the machine and electronics from the same supplier. However, these applications are not currently well served by international Tier 1 suppliers who are focused on commercialising their existing technology at higher volumes for mainstream passenger car applications. The UK has academic and SME strength in the field of high power automotive electric machines and power electronics, which has been fostered through motorsport and a number of collaborative research and development projects over the last 5 years. There are significant commercial and technical challenges to overcome in order for UK organisations to provide cost effective full service Tier 1 supply to meet this need. It will certainly require transferable supply chain skills and manufacturing technologies

(including automation to mitigate high labour costs) to be leveraged from within the automotive sector and adjacent industries to scale-up niche volume manufacturing capability to cost effectively support applications with production volumes of thousands to tens of thousands of units per annum.

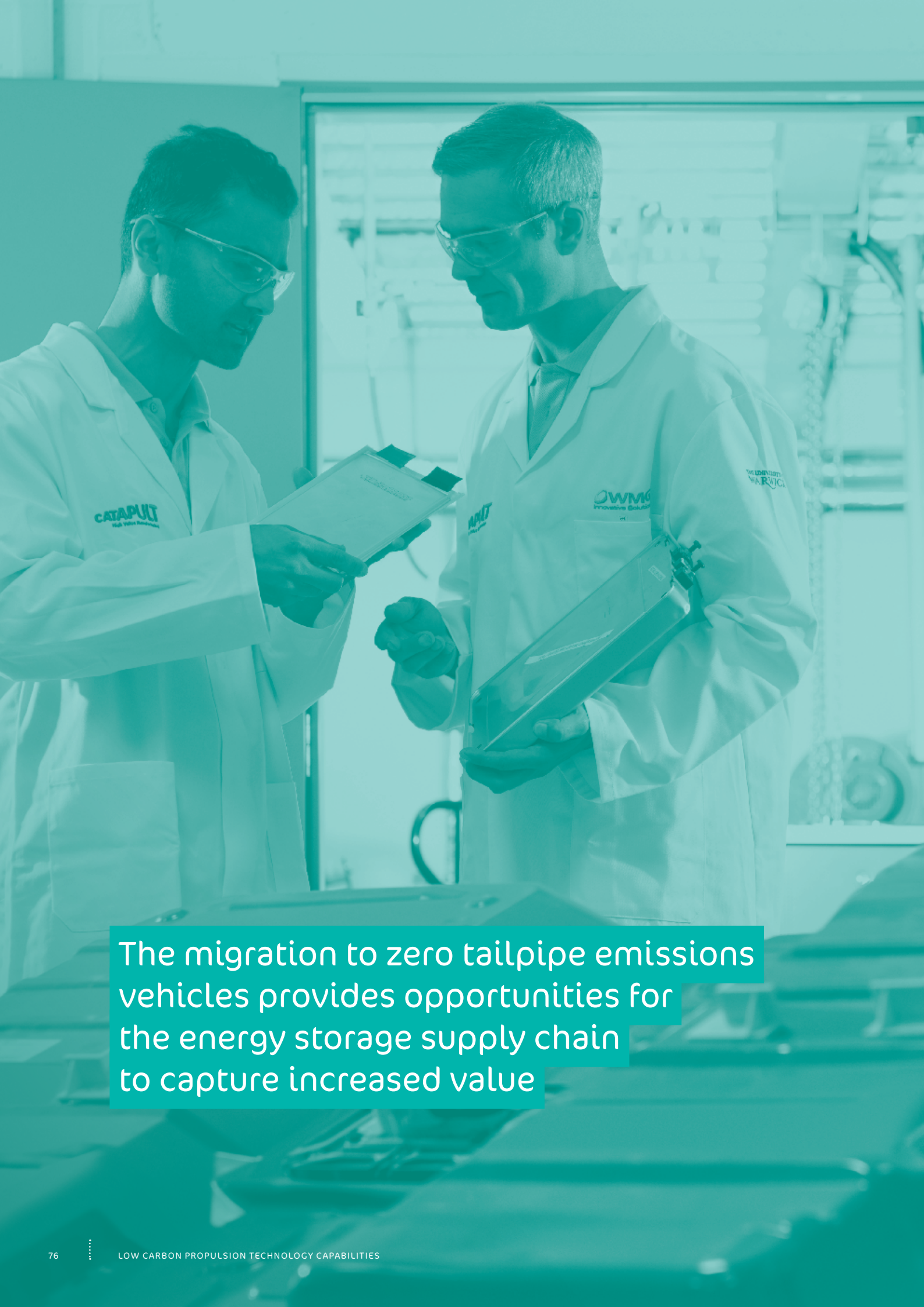
The scale of the opportunity could be increased if higher volume (i.e. mainstream passenger car) markets could be addressed, but the analysis conducted for this study indicates those needs are already being served by a combination of the vehicle manufacturers themselves and the incumbent international Tier 1 supply base.

High volume manufacturing of electric traction machines by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of components and/or sub-assemblies

The study has identified that many high volume passenger car vehicle manufacturers are considering traction electric machines to be a core technology due to a range of factors, including: high bill of materials cost, opportunity for competitive cost and performance differentiation and utilisation of existing engineering and manufacturing resources. This implies that development and manufacturing will migrate away from Tier 1 suppliers to vehicle manufacturers in the short to medium term. The UK's history of attracting foreign direct investment in high volume vehicle and engine manufacturing plants serving the European market positions the UK strongly to attract vehicle manufacturer led electric machine manufacturing as their mainstream products migrate to electrified powertrains. However, the consequences of the 2016 UK referendum vote to leave the European Union are uncertain at the time of writing. This potential demand combined with the potential demand from the UK's sole domestic high volume passenger car manufacturer, Jaguar Land Rover, could create a requirement for Tier 2 supply of components and/or sub-assemblies direct to the vehicle manufacturers electric machine plant. UK suppliers will be presented with a new high volume supply opportunity that could supplement long-term decline in demand for internal combustion engine components, albeit for commodity type products for which there will be strong competition from low cost country suppliers and magnetic materials for which there is limited existing UK supply chain. The UK supply base will need to demonstrate its willingness and ability to transfer and develop new capabilities and skills to cost effectively supply these new products. Significant capability has already been built in this area, including through the Jaguar Land Rover led Evoque_e project (supported by Innovate UK), which established innovative new machine concepts and the HVEMS project (supported by the Advanced Propulsion Centre), which is using a new make-like-production facility at Warwick Manufacturing Group to establish the feasibility of new high volume manufacturing processes.

How well is the UK positioned to capitalise upon these opportunities?

This study has highlighted that the UK has a strong research and development capability base from which to offer a combination of products and engineering services that capitalise upon these opportunities. However, significant capability investment is required to be able to support cost effective manufacturing in the UK.



The migration to zero tailpipe emissions vehicles provides opportunities for the energy storage supply chain to capture increased value

The key potential opportunities for *traction batteries* can be found on page 87

The key potential opportunities for *fuel cells* can be found on page 90

Traction batteries and fuel cells

Overview

Whether the liquid fossil fuel tank becomes an electrochemical battery in an electric vehicle or a hydrogen tank in a fuel cell vehicle, the migration to zero tailpipe emissions vehicles provides opportunities for the energy storage supply chain to capture increased value.

Whilst the supply chain for traction battery packs is nascent, the study has identified a trend for high volume vehicle manufacturers to migrate toward in-house traction battery system assembly, using either bought-in cells or cells manufactured in-house (most likely through joint venture with a specialist cell supplier). Conversely the trend is for lower volume manufacturers migrate toward turnkey Tier 1 battery system supply. This potentially presents opportunities for Tier 1 and Tier 2 suppliers, in addition to engineering service providers and research organisations. The UK is well positioned to meet emerging domestic low volume Tier 1 demand through its renowned systems integration skills and experience producing battery systems in niche volumes. The UK could also capitalise on high volume Tier 2 material and component supply opportunities as it has a strong track record of attracting high volume vehicle manufacturing, which will need close to plant final assembly of battery systems to minimise logistics costs. However, beyond Nissan the UK lags behind on the high volume experience curve and needs to invest to capitalise on this opportunity.

Opportunities related to fuel cells are less clear as the immaturity of the technology is such that the major vehicle manufacturers are still in the early stages of market exploration. The UK already capitalises upon Tier 2 supply opportunities to the major vehicle manufacturers, specialising in high intellectual property components. The UK is also positioned to capitalise on any potential low volume Tier 1 supply opportunities as it is home to a number of world-leading businesses developing complete fuel cell systems.

How is the global supply chain structured?

The supply chain for automotive traction battery systems is nascent, but is leveraging the experience of relatively mature supply chain providing electrochemical cells to the consumer electronics industry. Cell chemistry research is conducted around the world, but production is centred in Asia close to the heart of the consumer electronics industry. Consumer electronics cell producers such as BYD (China), LG Chem (South Korea), Panasonic (Japan) and Samsung (South Korea) have asserted a strong position in the embryonic automotive battery cell supply chain. Some passenger car manufacturers are forming strategic partnerships with established cell providers. For example, Nissan develops Li-ion cells with NEC Corporation through their Automotive Energy Supply Corporation joint venture, with the cells manufactured in Nissan facilities in Japan, the United Sates and the UK. Whilst Tesla is currently building a new battery plant in Nevada (US) that will house a dedicated Panasonic cell production facility. The plant is estimated by Tesla to comprise a $4-5bn total investment, including $2bn by Tesla and $1.6bn by Panasonic. Most other passenger car manufacturers are sourcing cells from the established providers. For example, LG Chem supplies cells to General Motors (Chevrolet Spark and Volt electric vehicles), Volkswagen Group (for its plug-in hybrid models) and Daimler (forthcoming Smart electric vehicle).

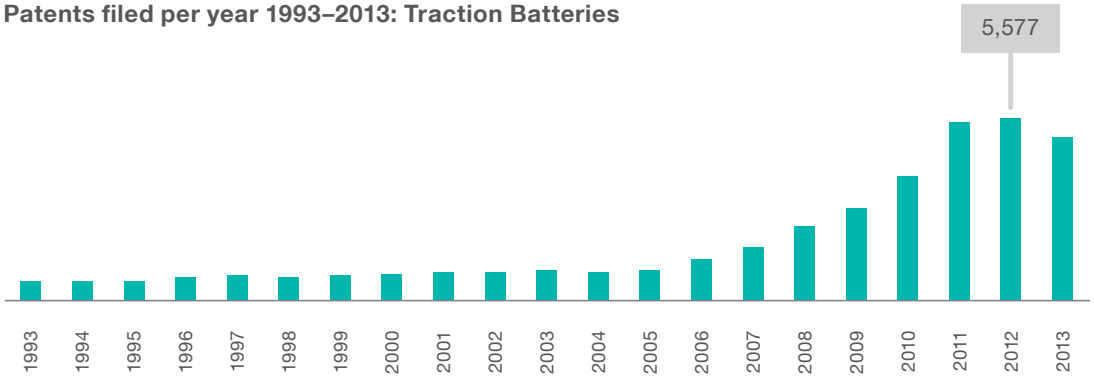
In order to create a functional traction battery, the cells need to be integrated into a pack system, which typically incorporates connectors, a cooling system, a battery management system and a crash resistant structure. Traction battery packs are relatively large and heavy (the Nissan Leaf's 24kWh battery weighs 290kg) making them expensive to transport, which encourages production close to the vehicle assembly plant. There is a trend for high volume passenger car manufacturers to integrate pack systems in their own plants. For example, BMW imports cells for the i3 and i8 from Samsung SDI, assembling them into packs at its manufacturing plant in Leipzig, Germany. Similarly General Motors and Volkswagen assemble battery packs at their plants in Brownstown (United States) and Braunschweig (Germany) using cells sourced from LG Chem.

Battery cell chemistry research is being conducted around the world with the aim of finding the technology that will deliver a breakthrough in energy and power density versus current Li-ion solutions. Leading institutes such as Oak Ridge National Laboratory (US), Fraunhofer Institute (Germany), RS2E (France) and the US-China Clean Energy Research Centre (China/US) are actively exploring alternative battery materials. For example, RS2E developed the first 18650 sodium ion cell whilst the Joint Centre for Energy Storage Research produced the first rechargeable calcium ion cell. The automotive industry is also investing in alternate battery technology, with VW purchasing a 5% stake in a solid state battery start-up QuantumScape in 2014 and Bosch acquiring a solid-state battery company Seeo in 2015.

The global supply chain for fuel cells is embryonic with a number of collaborative fuel cell research and development programmes being conducted by the leading global vehicle manufacturers. Toyota is working with BMW, Honda with GM and Ford with Daimler and Nissan on fuel cell technologies for market introduction after 2020. Production of fuel cells for automotive applications is currently very limited on a global basis with, for example, Toyota targeting to ship only 2,000 of its Mirai vehicles in 2016 and Honda (Clarity) and Hyundai (ix35) also offering limited numbers of vehicles. The supply chain for these market testing fuel cell products is currently controlled by the vehicle manufacturers themselves, with Toyota, Honda and Hyundai producing their own fuel cells.

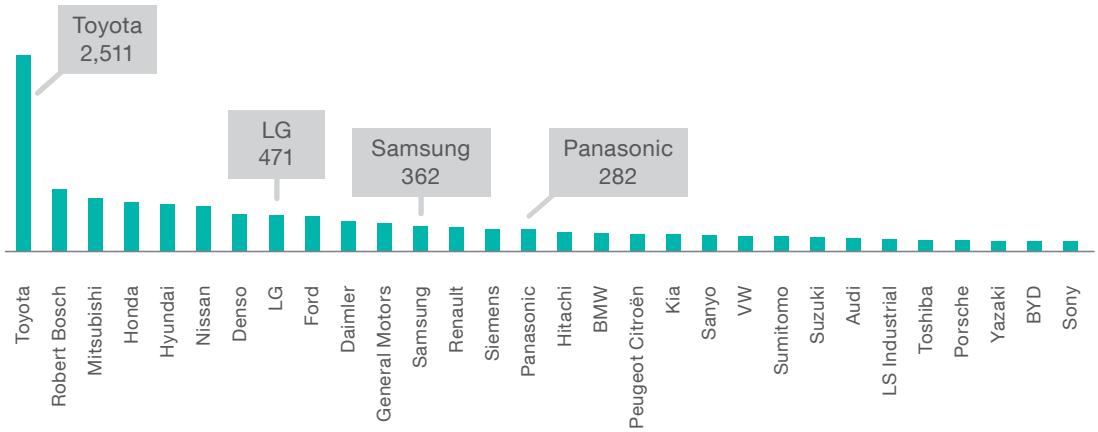
What does global patent filing activity tell us?

Patents filed per year 1993–2013: Traction Batteries



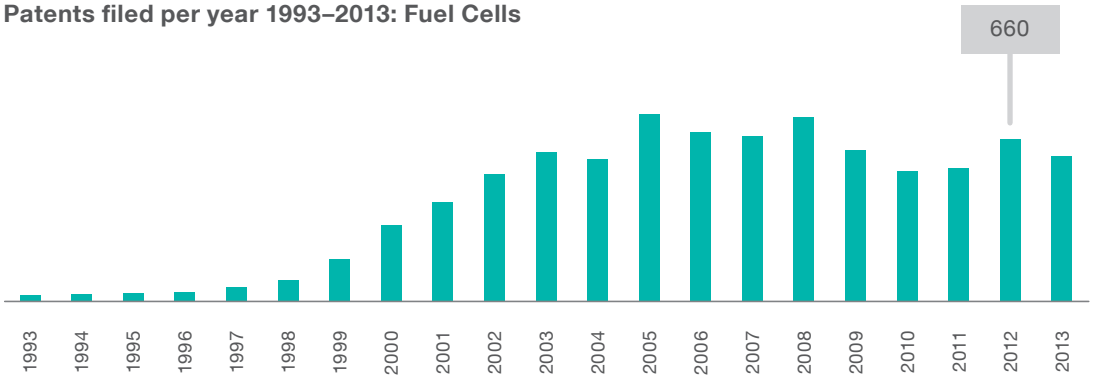
Patent filing activity associated with electrical energy storage systems for automotive applications has increased markedly since 2010, reflecting the large scale competitive investment in electrochemical cell technology. The majority of filing activity since 2010 is accounted for by Japanese and Korean vehicle manufacturers, plus a German Tier 1 supplier. The established cell producers (including BYD, LG, Panasonic and Samsung) are also very active. Within the UK, Oxis Energy, Johnson Matthey and Jaguar Land Rover each possess over 45 patent families relating to electrical energy storage, though this is far lower than the hundreds filed by Robert Bosch and the thousands filed by Toyota since 2010.

Top patent filers 2010–2016: Traction Batteries



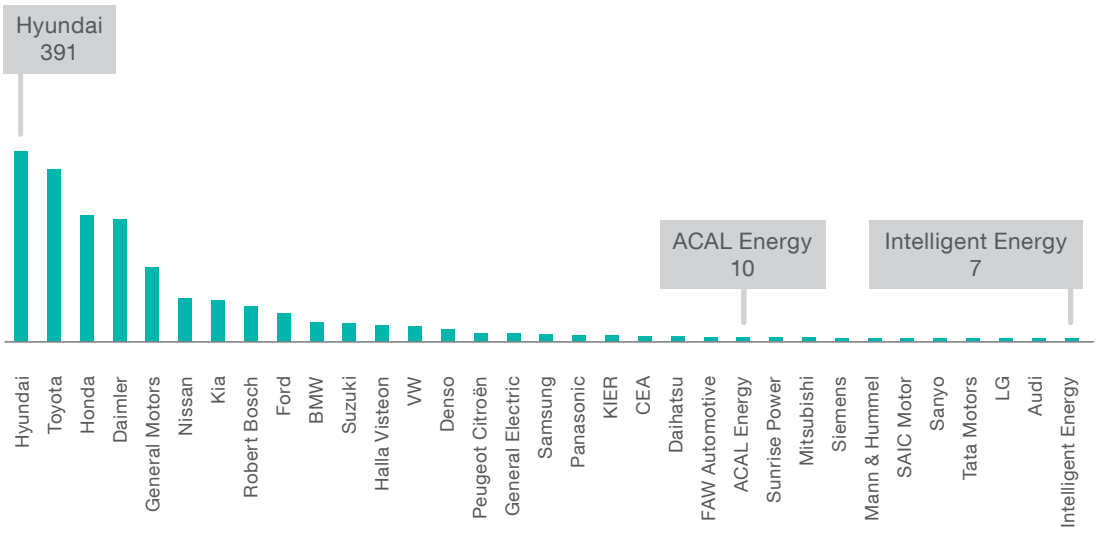
Conversely patent filing activity associated with hydrogen fuel cells for automotive applications has been steady since 2005. Toyota released thousands of its patents related to hydrogen fuel cells for royalty free use in 2015 in an effort to encourage innovation.

Patents filed per year 1993–2013: Fuel Cells



The majority of filing activity since 2010 is accounted for by global vehicle manufacturers, with Hyundai notably filing more patents than Toyota since 2010. Within the UK, both ACAL Energy and Intelligent Energy are relatively active filers of patents for proton exchange membrane fuel cell technology with automotive applications. In addition, Johnson Matthey is active in patenting fuel cell catalyst technologies, though not specifically related to automotive applications.

Top patent filers 2010–2016: Fuel Cells



(Footnote: The analysis of patents relating to electrochemical traction batteries and fuel cells for automotive applications was conducted in February 2016. The search utilised a combination of International Patent Classifications, Cooperative Patent Classifications and keyword searches; some patents may have been classified differently and therefore will not have been captured by this analysis.)

What activity is taking place in the UK?

The UK has built capability in electrical energy storage through a number of key investments since 2010. Most notably Nissan invested £420m to manufacture battery cells and packs in Sunderland to supply the European market Leaf (over 50,000 of which have since been produced in Sunderland) and e-NV200 van (produced in Spain). There are few other manufacturers of Li-ion cells in the UK and those that do operate at low volumes, such as AGM Batteries that offers scale-up and low volume cell manufacturing services. There are a small number of UK-based companies seeking to commercialise next generation battery cell chemistries for automotive applications. These include Oxis Energy (who specialise in Lithium Sulphur technology and are supported by Innovate UK through the ongoing Revolutionary Electric Vehicle Battery project), Faradion (Sodium-ion technology; supported by Innovate UK and the OLEV research and development fund; working in partnership with AGM Batteries) and Nexeon (Li-ion technology; recently raised £30m to open a development facility in Asia). The 2014 investment of £13 million in a battery scale-up facility at Warwick Manufacturing Group is intended to strengthen UK research and development capability. In addition, there are a number of UK businesses offering battery pack design and low volume assembly services, including Johnson Matthey Battery Systems (supplier of the battery pack for the McLaren P1), Williams Advanced Engineering (the sole supplier to the Formula E race series) and Vayon Energy Systems (which is in the process of expanding capacity from 1,000 to 10,000 systems per year).

The UK is also home to a number of notable players in the embryonic fuel cell supply chain. Johnson Matthey Fuel Cells is a leading global supplier of membrane electrode assemblies (a fuel cell component with a high degree of intellectual property), which it supplies from its Swindon plant. Whilst Intelligent Energy engineers and prototypes complete automotive fuel cell systems at its Loughborough facility, in addition to having a joint venture manufacturing facility with Suzuki in Japan. In addition, Ceres Power has secured funding from Innovate UK and the Office for Low Emission Vehicles to explore the application of its Steel Cell technology for range extender applications, in addition to signing a joint development agreement with Honda in 2016 focussed on power equipment applications. The UK is also home to two niche fuel cell vehicle developers (Riversimple and Microcab), companies offering systems engineering, such as Arcola, and university spin-outs offering new technologies, such as Bramble Energy (manufacturing techniques) and Amalyst (catalysts).

Nissan invested £420m to manufacture battery cells and packs in Sunderland

Where is UK public investment being channelled?

Approximately £124 million of public grant funding was co-invested by the UK Government (via EPSRC, Innovate UK, the Advanced Propulsion Centre and others) through 114 electrical energy storage and fuel cell research and development projects for automotive applications during the period 2010 to 2015. Approximately £95m was co-invested in electrical energy storage projects that included developing new cells, developing battery and super capacitor packs and developing recycling, remanufacturing and reuse methods. The majority of the funding was at low technology maturity levels, predominantly relating to cell development, with higher maturity level funding predominantly focussed on pack systems and application development. Approximately £35m was co-invested in fuel cell related projects, predominantly early in the period and focussed on vehicle applications.

This compares favourably with the 13 fuel cell and 16 electrical energy storage projects for passenger car applications that were supported during the period 2005-2010 (as reported by Ricardo in the 2010 *Automotive Technologies: The UK's current capability* report).

£124 million granted to 114 traction battery and fuel cell related projects during 2010 to 2015

Technology Maturity	Principal Agency	Number of Projects	Total Grant Value £ millions
Early Stage	EPSRC	46	£53
Demonstrator	Innovate UK	61	£43
Applied	Advanced Propulsion Centre	7	£28

Approximately £124 million of public grant funding was co-invested by the UK governmentthrough 114 electrical energy storage and fuel cell research and development projects during 2010 to 2015

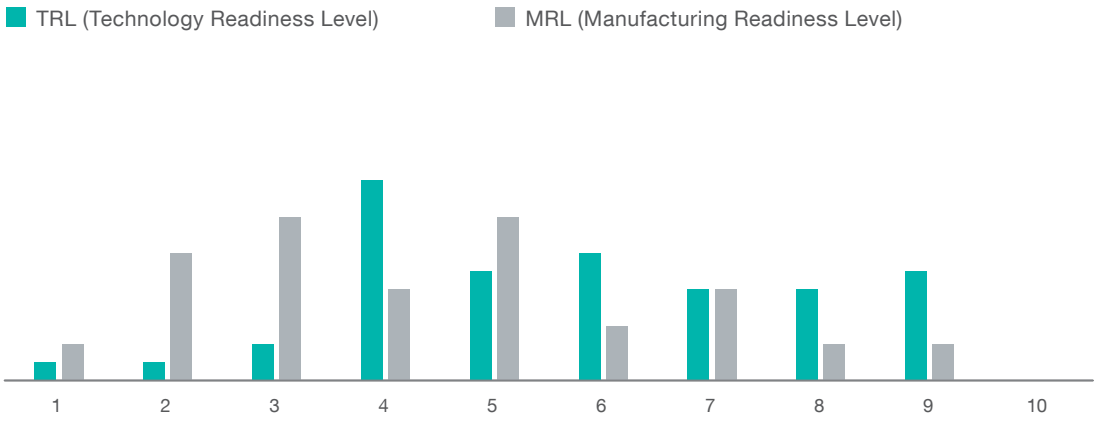
What did we learn from the industry survey and stakeholder interviews?

Three quarters of the electrical energy storage and fuel cell related projects captured via the industry survey are being supported by external funding, which highlights the relative immaturity of the technology and the supply chain in the UK. Well over half of respondents believe their research and development is in-line with or following the market, which indicates that the UK has some way to go to be globally competitive in this crucial technology area. However, the projects are addressing a broad range of market sectors and a relatively large proportion of the projects reported have achieved high TRL and MRL levels, reflecting the UK's strength in integrating complex systems and indicating the potential to bring traction battery systems to market in the near term.

Respondents to the industry survey and participants in the consensus-building workshops considered production skills, facilities and equipment as the key constraints to commercialising these innovations within the UK, noting that fuel cells are still at the prototype volume stage and battery systems are only assembled in relatively low volumes. In addition the lack of hydrogen safe test facilities were noted as a particular constraint for fuel cell system development.

The industry survey, stakeholder interviews and data analysis combine to suggest the UK retains competitive capability in electrochemical cell material research, in addition to growing strength in the design, development and low volume manufacturing of battery packs including the battery management system. However, the UK is yet to convert this potential into higher volume supply of battery packs and is not a player in the volume manufacture of lithium-ion cell technology. Similarly the UK has significant capability in the research and development of fuel cell membrane electrode assemblies (MEA), but there is not yet a strong market pull for production of complete automotive fuel cell systems.

Maturity of UK R&D projects reported to the industry survey

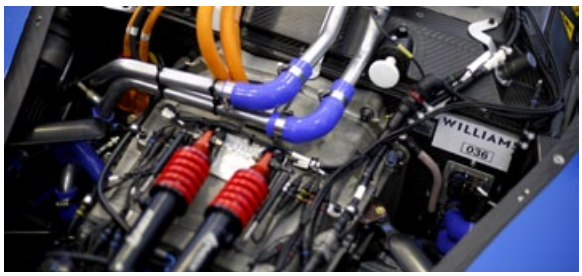


What new capabilities have been built in the UK since 2010?

- Intelligent Energy provides the fuel cell stack for a small fleet of hydrogen powered taxis for the London Olympics (2012)
- Nissan establishes the Zero Emissions Centre of Excellence and begins producing lithium-ion cells and battery packs at its Sunderland facility (2013)
- Johnson Matthey Battery Systems (formerly Axeon) provides the battery pack for the McLaren P1 hybrid supercar (2013)
- Intelligent Energy and Suzuki form a joint venture to manufacture fuel cell systems for motorcycles (2013)
- Mercedes AMG designs and manufactures the battery pack for the electric SLS-E supercar in Brixworth (2013)
- WMG opens its £13 million Energy Innovation Centre, including a battery scale up plant (2014)
- Williams Advanced Engineering provides the battery packs for the first ever electric racing series, Formula E (2014)
- Komatsu starts producing a new hybrid excavator with an ultra-capacitor based energy storage system in Birtley (2014)
- Oxis Energy demonstrates its lithium sulphur battery technology in collaboration with Ricardo Engineering, Cranfield University and Imperial College London through the £3.5m Innovate UK Revolutionary Electric Vehicle Battery (REVB) project (2015)
- Vayon Group acquires Goodwolfe Energy, Ashwoods Energy and RDVS to become Vayon Energy Systems, which supplies lithium ion battery packs (2015)
- Hyperdrive Innovation opens its battery production facility in the North-East of England (2015)
- Bramble Energy, a spin-out company from UCL and Imperial College, develops fuel cell stack technology using scalable manufacturing techniques (2016)
- Ceres Power signs a joint development agreement with Honda to develop Steel Cell fuel cell technology for a number of applications (2016)
- Start-up Riversimple reveals its fuel cell two-seat car, the Rasa (2016)
- Start-up Faradion announces a partnership with AGM Batteries to commercialise low cost sodium ion batteries (2016)

Nissan's continued support for manufacturing in the UK

In 2013 Nissan launched production of its all-electric LEAF and the associated battery packs and lithium ion cells at its facility in Sunderland, following a £420m investment. In addition to being fitted to the Leaf, the battery packs manufactured at the plant are also exported to Nissan's plant in Barcelona where they are fitted to the e-NV200 electric van. In January 2016 Nissan committed a further £26.5 million to develop the second generation of battery packs at its Sunderland facility.



Williams Advanced Engineering leverages motorsport expertise

Since its establishment in 2010, Williams Advanced Engineering has developed capability in designing and manufacturing high power battery packs. Using the knowledge gained in developing battery systems for the WILLIAMS MARTINI RACING Formula One team, Williams collaborated with Jaguar to design a 19.6kWh battery pack for the range-extended Jaguar C-X75 hybrid supercar. Since 2014, Williams Advanced Engineering has also been the exclusive battery pack supplier to Formula E, the world's first fully electric racing series. More recently Williams Advanced Engineering has announced that they are working with Finnish firm Vilakone Oy to create a new zero-emission multi-function machine, and also with Aston Martin to co-develop the all-electric RapideE luxury car.

Johnson Matthey expands its low carbon capability

Initially a chemicals company that specialised in catalysts and advanced materials, Johnson Matthey has recently expanded into low carbon technology. Johnson Matthey Fuel Cells is a global supplier of fuel cell components and is researching new catalyst materials with a range of industry partners as part of the European Commission funded CATAPULT project. In 2012 Johnson Matthey enhanced its portfolio by acquiring battery supplier Axeon and subsequently supplied the battery pack for the high performance McLaren P1 hybrid car. In 2014 Johnson Matthey bought a cathode manufacturing plant from A123 and also acquired Swiss battery materials business Clariant AG.

Image Anthony Dawton

Riversimple announce their new hydrogen car, the Rasa

In February 2016 Wales based company Riversimple released a prototype two-seat car powered by an 8.5kW hydrogen fuel cell. In 2017, Riversimple are planning to run a 12-month public trial on UK roads with 20 prototype vehicles, before entering full production at the end of 2018. Fitted with a carbon composite chassis and four in-wheel motors, Riversimple's Rasa prototype weighs approximately 580kg and has well-to-wheel CO_2 emissions of approximately 40g/km.

What future industry needs could the UK address?

A series of addressable industry needs related to traction batteries were identified by combining the capability assessment with market analysis and qualitative insight captured through the stakeholder interviews and consensus-building workshops:

- High volume passenger car vehicle manufacturers are seeking Tier 2 supply chains to support ramp-up of in-house manufacture of traction battery systems, which they consider to be a core technology due to a range of factors, including: high bill of materials cost and opportunity for competitive differentiation (performance and cost).
- Low volume vehicle manufacturers (including luxury car and bus) are seeking cost effective turnkey supply of traction battery systems as they do not have sufficient in-house skills capacity to develop their own systems. In general they are prepared to consider package configurable systems built upon standardised modules in order to share development costs across multiple applications and vehicle manufacturers.
- All vehicle manufacturers are seeking fundamental advances in cell chemistry and materials to achieve the step-change improvements in the cost and performance of electrochemical cells required to improve the mass-market viability of electrified vehicles.
- All vehicle manufacturers expect the final assembly of the battery pack to be conducted close to their vehicle assembly plant due to the logistics cost and complexity of moving large and heavy battery packs.

Traction batteries

What are the key potential opportunities for the UK?

A series of potential opportunities for the UK arising from these addressable industry needs for traction battery systems were defined and rated according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation. These hypotheses were subsequently refined with a broad range of experts through the consensus-building workshops.

Focus:

UK could provide focused support to build upon existing advantages in these attractive opportunity areas

Opportunity	Commercialisation Timeframe
High volume manufacturing of traction battery packs (and/or cells) by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of materials and components	Medium timeframe (by 2025)
Research, development and low volume manufacturing leading to licensing of next and next + 1 generation battery cell chemistry	Long timeframe (after 2025)

Invest-to-Improve:

UK could invest to improve positioning since these opportunities appear to be attractive

Opportunity	Commercialisation Timeframe
Development and Tier 1 supply of modular traction battery packs for low volume vehicle applications	Short timeframe (by 2020)

High volume manufacturing of traction battery packs (and/or cells) by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of materials and components

The study has identified that many high volume passenger car vehicle manufacturers are considering traction battery system integration to be a core competence, due to a range of factors, including high bill of materials cost and the opportunity for competitive differentiation (performance and cost). However, these packs will most commonly be built upon bought-in cell technology or complete cells. Vehicle manufacturers expect the final assembly of the battery pack to be conducted close to their vehicle assembly plant due to the logistics cost and complexity of moving large and heavy lithium-ion battery packs (the Nissan Leaf's 24kWh battery weighs 290kg). This implies there are potentially opportunities for Tier 2+ supply of non-cell materials and components (such as connectors, cooling systems and impact resistant structures) close to all high volume vehicle assembly plants.

The UK's track record of attracting foreign direct investment in high volume vehicle assembly plants serving the European market (including Honda Swindon, Nissan Sunderland and Toyota Burnaston) positions the UK strongly to attract vehicle manufacturer-led traction battery system assembly as their mainstream products migrate to electrified powertrains. However, the consequences of the 2016 UK referendum vote to leave the European Union are uncertain at the time of writing. This potential demand combined with the potential demand from the UK's sole domestic high volume passenger car manufacturer, Jaguar Land Rover, could create a significant Tier 2+ supply requirement. In turn, global scale battery cell suppliers could be attracted to UK localisation opportunities if demand is sufficiently concentrated.

UK suppliers will be presented with a new high volume supply opportunity that could supplement long-term decline in demand for internal combustion engine components and fuel systems, albeit likely for commodity type products for which there will be strong competition from low cost country suppliers. The UK supply base will need to demonstrate its willingness and ability to transfer and develop new capabilities and skills to cost effectively supply these new products.

Research, development and low volume manufacturing leading to licensing of next and next + 1 generation battery cell chemistry

The study has highlighted the ongoing need for a step-change improvement in electrochemical battery cell cost and performance to improve the mass-market viability of electrified powertrains. Huge investments are being made globally in research and development of new cell chemistries and materials, with many promising lines of investigation but no clear path.

UK academia has a strong history in fundamental cell technology, including the breakthroughs that made lithium-ion technology viable. The UK retains strong fundamental academic and industrial research in cell chemistry and technology that is well supported by publicly funded projects, as evidenced by Faradion's sodium-ion (Na-ion) and Oxis Energy's lithium-sulphur (Li-S) technologies. However the UK has lacked the capability to scale-up this research, leading to intellectual property leaking outside the UK. The establishment of an open access battery materials scale-up pilot line at Warwick University in 2014 is a significant development in addressing this strategic capability gap and complements the capabilities of business such as AGM Batteries, who are able to offer low volume cell manufacturing services in the UK. However, the lack of high volume cell manufacturing in the UK limits the route to market options for these technologies, unless very large scale investment for new manufacturing capability could be attracted, which is difficult to envisage in the current environment of global over-capacity.

Development and Tier 1 supply of modular battery packs for low volume vehicle traction applications

The study has identified demand for electrified powertrain technology capable of being introduced to the market by 2020 and suited to the specific requirements of the lower production volume sectors that are strong in the UK. These requirements include high volumetric power density battery systems suited to luxury / high performance car applications and high durability battery systems suited to bus and off-highway commercial vehicle traction applications. The systems will be built around mass produced cells imported from leading global suppliers in order to maintain manageable development and bill of materials costs. Whilst the production volumes are relatively low, system values are relatively high (albeit with significant pass-through to the cell supplier) and therefore could provide attractive opportunity when multiple vehicle manufacturers' requirements are aggregated, especially if modular architectures can be used to effectively share costs across multiple applications. Typically vehicle manufacturers in these segments are seeking turnkey supply as they do not have sufficient in-house skills capacity to develop their own systems. However, these applications are not currently well served by international Tier 1 suppliers who are focused on commercialising their existing technology at higher volumes for mainstream passenger car applications.

The UK has a strength in general systems engineering, battery pack development and niche volume pack manufacture, but there is a need to scale-up capabilities to higher production volumes. A number of publically funded projects are addressing this gap, including the AMPLiFII project led by Warwick Manufacturing Group and supported by Innovate UK and OLEV, which will develop processes for higher volume modular battery production. There are significant commercial and technical challenges to overcome for a UK organisations to provide cost effective full service Tier 1 supply to meet this need. It will certainly require transferable supply chain skills and manufacturing technologies (including automation to mitigate high labour costs) to be leveraged from within the automotive sector and adjacent industries to scale-up niche volume manufacturing capability to cost effectively support applications with production volumes of thousands to tens of thousands of units per annum. In addition, a shortage of suitably skilled battery systems engineers could limit research and development capacity.

The scale of the opportunity could be increased if higher volume (i.e. mainstream passenger car) markets could be addressed, but the analysis conducted for this study indicates those needs are already being served by a combination of the vehicle manufacturers themselves and a supply base encompassing both the incumbent international Tier 1s and new entrants from the consumer electronics industry.

Fuel cells

What are the key potential opportunities for the UK?

A series of addressable industry needs related to fuel cell systems were also identified:

- High volume passenger car vehicle manufacturers are seeking significant improvements in the cost and performance of fuel cell systems before committing to mass market deployment.
- Low volume and niche vehicle manufacturers seeking to be early adopters of hydrogen fuel cell technology will require full service Tier 1 supply and integration of systems with appropriate cost and performance for primary drive, range-extender or auxiliary power unit applications.

Potential opportunities for the UK arising from these addressable industry needs for hydrogen fuel cell systems were defined and rated according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation. These hypotheses were subsequently refined with a broad range of experts through the consensus-building workshops.

Opportunistic:

UK has good positioning for these opportunities, though their relative attractiveness is lower – UK could take advantage of its position as opportunities emerge

Opportunity	Commercialisation Timeframe
Development and Tier 1 supply of integrated fuel cell systems to low volume vehicle manufacturers R&D, co-development and Tier 2 supply of high value components to fuel cell manufacturers	Long timeframe (after 2025)

Development and Tier 1 supply of integrated fuel cell systems to low volume vehicle manufacturers

The study has highlighted the multiple development paths for automotive fuel cells being pursued by the leading vehicle manufacturers, but also the ongoing reluctance to launch mass market products; the Toyota Mirai, Honda Clarity and Hyundai ix35 all being limited to low volumes by their technology immaturity and cost. Fuel cells are finding their way to market via demonstrations (such as the buses operating on the RV1 route in London) and niche vehicles (such as the Riversimple Rasa). If these demonstrations progress to low volume production, the vehicle manufacturers will require cost effective full service Tier 1 supply of fuel cell systems. However there is great uncertainty regarding the timing of market development and the emergence of this demand.

If the market does develop for low volume applications, the UK is well positioned to exploit it being home to a number of businesses conducting globally significant research and development and building prototype stacks (such as Intelligent Energy and Ceres Power) with relatively few competitors globally.

R&D, co-development and Tier 2 supply of high value components to fuel cell manufacturers

If Toyota, Honda, Hyundai and the other leading global vehicle manufacturers do succeed in introducing hydrogen fuel cell technology to the mass market, they are likely to employ manufacturing location strategies similar to those currently employed for their combustion engines. A track record of attracting foreign investment in high volume engine plants serving the European market positions the UK strongly to attract vehicle manufacturer led fuel cell production, especially as manufacturing can be highly automated and therefore relatively tolerant of high labour costs. However, the consequences of the 2016 UK referendum vote to leave the European Union are uncertain at the time of writing. The UK already has a strong global position in membrane electrode assemblies through Johnson Matthey's R&D and Swindon production facility. The UK supply base will need to demonstrate its willingness and ability to develop new capabilities and skills to cost effectively supply fuel cell stack components. However there is great uncertainty regarding the timing of market development and the emergence of this demand.

How well is the UK positioned to capitalise upon these opportunities?

This study has highlighted that strong research and development capabilities coupled with system engineering strength and ability to attract foreign direct investment to high volume vehicle and powertrain manufacturing positions the UK well to capitalise upon the shift in energy storage technologies. However the UK is behind the leading global players and needs to invest to assert a competitive position.

The UK is globally recognised as a leader in lightweight technologies, with a reputation forged in the aerospace, defence and motorsport industries

The key potential opportunities for *lightweight technologies* can be found on page 103

Lightweight technologies

Overview

Lighter vehicles are more efficient, whether they be an electric powered car, a hybrid powered bus or a combustion engine powered earth moving machine. The imperative to reduce vehicle weight is very strong, particularly as electrified powertrains are tending to increase mass.

The design and construction of the body structure, which often grabs the headlines through large mass reductions, tends to be controlled by the vehicle manufacturer but every single component from each different supplier contributes to the overall vehicle mass and needs to be optimised. The study has highlighted the strong UK domestic demand for lightweighting in premium and high performance passenger cars. The study has also identified a risk that manufacturers of lower volume vehicles will be disadvantaged as the majority of lightweighting R&D activity is focussed on the requirements of high volume passenger cars, which differ significantly from those of specialist vehicles. This potentially presents opportunities for engineering service providers and component suppliers that can help low-to-mid volume and specialist vehicle manufacturers harness advanced materials and design and process techniques to lightweight their products.

The UK is globally recognised as a leader in lightweight technologies, with a reputation forged in the aerospace, defence and motorsport industries. This reputation, combined with strong R&D capability, positions the UK to capitalise upon lightweighting opportunities, including supply to domestic manufacturers and engineering services to global manufacturers. Longer-term, an evolving sustainability agenda is likely to drive demand for lightweight materials with lower embedded carbon and improved recyclability, presenting opportunities to the UK's capable materials research community.

How is the global supply chain structured?

A lighter vehicle is more efficient, whether it is propelled by a combustion engine or an electric motor. Increasing levels of comfort, convenience and safety features have driven mass into passenger cars over the past decades, such that significant effort is required just to maintain total vehicle mass from one generation to another. Lightweighting has become a more attractive way of reducing tailpipe CO_2 emissions as incremental improvements in powertrain efficiency have become increasingly expensive. Furthermore as the market transitions towards electrification, manufacturers are using lightweight materials to mitigate the mass added by electric motors, power electronics and battery systems.

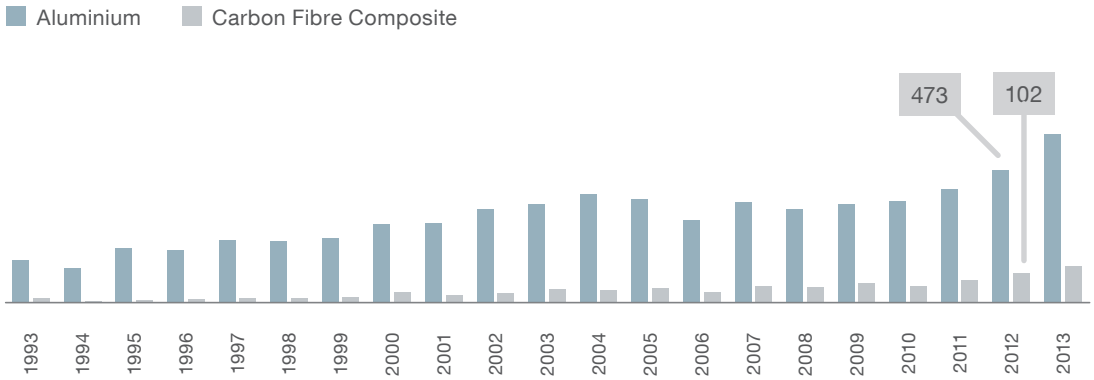
Aluminium is often used to reduce mass versus an equivalent steel component. Aluminium alloys are widely used in passenger cars for a range of applications from body panels to engine cylinder heads, though their use for complete vehicle structures is less common. For example, Mercedes-Benz manufactured its first series production vehicle using a complete aluminium structure in 2012, reducing mass by 110kg compared with the previous generation SL's steel structure. A significant milestone was passed in 2015 when Ford used aluminium for the United States' best-selling vehicle, the F150 pickup truck's new aluminium structure was over 200kg lighter than the previous generation steel structure. The vehicle manufacturers tend to control production of vehicle structures in-house, sourcing materials directly from material suppliers. The aluminium for both the F150 and the SL is provided by Novelis, a global supplier which also supplies Jaguar Land Rover. Another global supplier, Alcoa, has recently invested $300 million to expand its Tennessee facility to supply aluminium sheets for body panels to Ford, Fiat Chrysler, and General Motors.

Composite materials are less commonly used than aluminium in the passenger car sector and are most extensively used in high performance applications. However in recent years a number of vehicle manufacturers have formed strategic partnerships to introduce composite materials into higher volume products. BMW and SGL Group formed a joint venture in 2009 to produce carbon fibre materials and in 2014 invested a further $200 million to triple the capacity of their North American plant. These investments enabled BMW to sell over 24,000 i3s featuring a predominantly composite structure in 2015. The success of the i3 and i8 range is leading BMW to utilise the technology to a more limited extent in other models such as its 7 series. In 2011 General Motors and Teijin began co-developing advanced carbon fibre reinforced thermoplastic composite technologies and this year revealed a high volume manufacturing process called Sereebo. In addition, last year Ford signed a joint agreement with DowAska to advance the adoption of cost-effective carbon fibre components with the agreement forming part of the Institute for Advanced Composites Manufacturing Innovation (IACMI), announced by President Obama.

Looking to other sectors, motorcycles have to a lesser but still significant extent been subject to increasing mass through comfort, convenience and safety features. However the performance driver for many motorcycle segments has kept a sharp focus on overall mass. Commercial vehicles have somewhat different drivers. On-highway commercial vehicles are limited to maximum permissible gross vehicle weight by regulation, but reducing vehicle mass can improve their productivity by increasing their payload potential. For example to mitigate the weight of the battery system in the New Routemaster buses, Wrightbus used carbon fibre composites supplied by Gurit Automotive to save hundreds of kilograms from the body structure. Many off-highway commercial vehicles, such as excavators, rely on high vehicle mass to provide stability; however selective lightweighting can improve productivity by increasing payload potential. For example, CAT used aluminium in the CT660 truck to reduce the weight of the cab by 113kg compared to an equivalent steel structure.

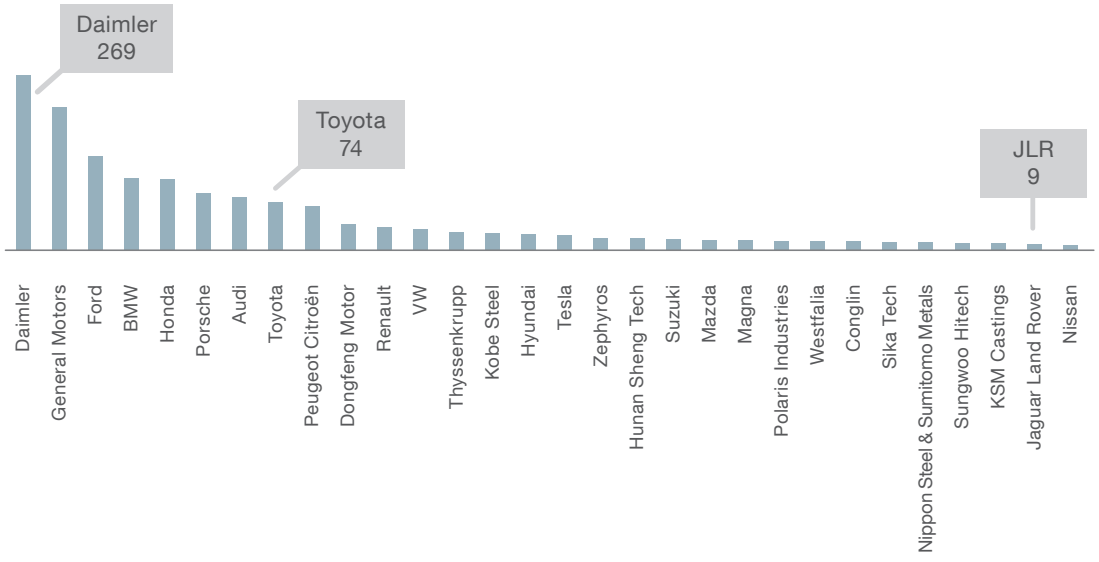
What does global patent filing activity tell us?

Patents filed per year 1993–2013: Lightweight Vehicle Stuctures



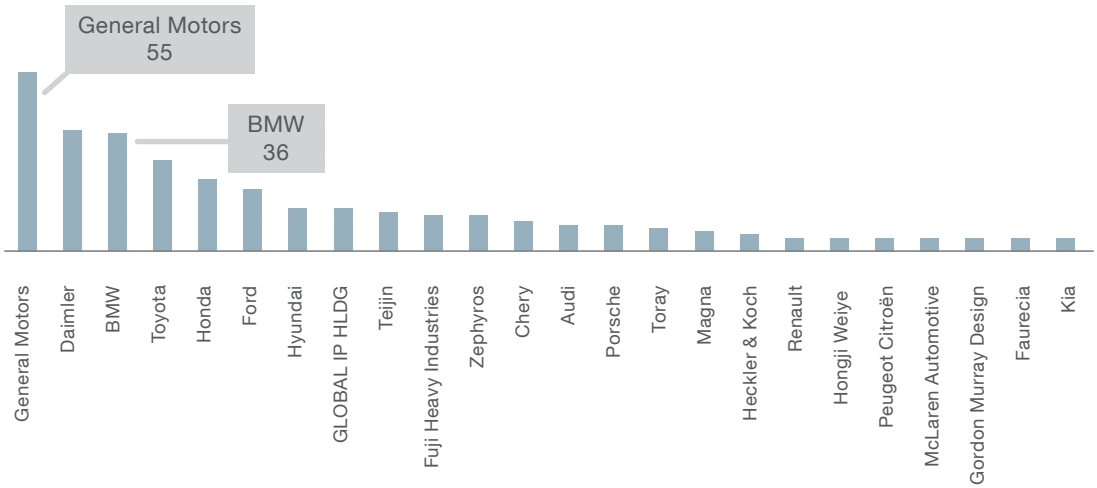
The varied nature of lightweighting technologies and materials makes meaningful patent analysis difficult. Patent activity related to aluminium and carbon fibre composite vehicle structures is relatively low compared with other technology areas considered by this study, but the application trend follows the same upward trajectory as other low carbon technologies.

Top patent filers 2010–2016: Lightweight Aluminium Vehicle Structures



European vehicle manufacturers and material suppliers are amongst the most active patentees in this area, despite a passive culture to patenting, whilst US companies such as General Motors, Ford and Tesla also feature prominently. Whilst a number of Asian companies (such as Honda, Hyundai, Teijin and Dongfeng Motors) appear on the top filers list, they appear lower down compared to other technology areas considered. UK companies also feature with Jaguar Land Rover possessing a number of patents in aluminium structures and McLaren Automotive, Gordon Murray Design and Aston Martin owning a handful relating to carbon fibre composite structures.

Top patent filers 2010–2016: Lightweight Carbon Fibre Composite Vehicle Structures



(Footnote: The analysis of patents relating to aluminium and carbon fibre composite structures for automotive applications was conducted in February 2016. The search utilised a combination of International Patent Classifications, Cooperative Patent Classifications and keyword searches; some patents may have been classified differently and therefore will not have been captured by this analysis.)

What activity is taking place in the UK?

The UK possesses a strong capability in aluminium vehicle structure technologies through Jaguar Land Rover's prolific use of aluminium monocoque structures, Lotus' use of aluminium tubs for all its models since the 1996 Elise and Aston Martin using an aluminium architecture across its series production range. The 2012 Range Rover was the first sports utility vehicle (SUV) to feature a complete aluminium body structure, which was 39% lighter than the previous generation Range Rover's steel body structure. Jaguar Land Rover also utilises aluminium structures for the 2013 Range Rover Sport, 2013 F-Type, 2014 XE, 2015 XF and 2016 F-Pace. Jaguar Land Rover is also innovating in the sustainability of lightweight structures through the Innovate UK supported REALCAR project, which is targeting inclusion of up to 75% recycled content in aluminium body structures, starting with the adoption of a new high-strength aluminium alloy developed by Novelis for the 2014 XE. This rooted capability in aluminium has helped support UK based companies such as Innoval Technology whilst also attracting Tier 1 supplier Magna International to build a new factory in Telford that will be dedicated to aluminium casting.

The UK also has considerable strength in composite materials through fundamental materials research supported by the EPSRC and the UK's well-established motorsport and high performance vehicle sectors. McLaren was the first team to race a carbon-fibre composite moulded monocoque in Formula 1 (1981 MP4) and is today a relatively high volume producer of carbon-fibre composite structures, having sold over 1650 so equipped vehicles in 2015. Gordon Murray Design has built upon its own Formula 1 experience to provide an innovative low cost composite panel and metallic tube structure to the forthcoming TVR sports car project and to the Yamaha Sports Ride concept vehicle. There is significant low volume capability within the UK supply chain, for example Prodrive manufactures the composite bodywork for the McLaren P1, whilst FAR-UK launched its own lightweight platform chassis concept in 2014. At higher volume levels, Sigmatex is leading an AMSCI funded project bringing together Bentley, Nissan and Emerald Automotive aiming to manufacture composite components in medium to high volumes at affordable prices.

The UK's strength in composite materials is further enhanced by a number of other adjacent industries such as aerospace and defence. Sector collaboration is fostered through the Composite Leadership Forum with the cross sector opportunities for composite materials being articulated in the 2016 UK Composites Strategy.

Jaguar Land Rover is innovating in the sustainability of lightweight structures through the Innovate UK supported REALCAR project, which is targeting inclusion of up to 75% recycled content in aluminium body structures

Where is UK public investment being channelled?

Approximately £101m of grant funding was co-invested by the UK Government (via EPSRC, Innovate UK, the Advanced Propulsion Centre and others) through 68 lightweighting research and development projects for automotive applications during the period 2010 to 2015. The projects sought to cost effectively reduce mass through design and manufacturing processes and the application of alternative materials, including metal-matrix composites, bio-composites, carbon-fibre composites and nanomaterials. The majority of the funding was focussed on mid to high technology maturity level activities, reflecting the strong market pull for lightweight technologies.

However, the high technology maturity level funding was focussed into few projects, reflecting the challenge in commercialising new materials technologies through the UK's limited high volume manufacturing capability in this area. In addition a significant amount of funding is being invested in comparable technologies for applications in other sectors (such as aerospace) through mechanisms such as the National Composites Centre (part of the High Value Manufacturing Catapult). There is good cross-over potential for affordable composites between automotive and aerospace, e.g. for aircraft interior systems.

£101 million granted to 68 lightweighting related projects during 2010 to 2015

Technology Maturity	Principal Agency	Number of Projects	Total Grant Value £ millions
Early Stage	EPSRC	19	£44
Demonstrator	Innovate UK	42	£38
Applied	Advanced Propulsion Centre	7	£19

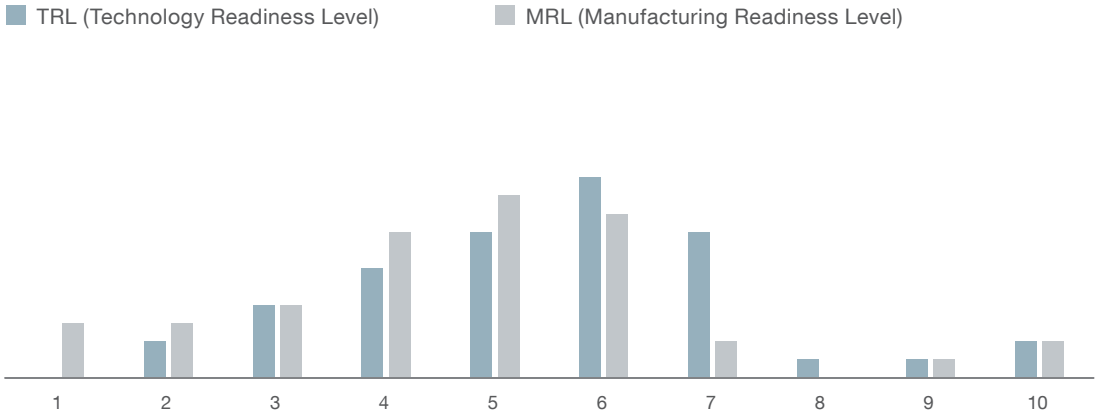
These 68 projects compare favourably with the 8 lightweight structures and components projects for passenger car applications that were supported during the period 2005-2010 (as reported by Ricardo in the 2010 *Automotive Technologies: The UK's current capability* report).

Approximately £101m of grant funding was co-invested by the UK government through 68 lightweighting research and development projects during 2010 to 2015

What did we learn from the industry survey and stakeholder interviews?

Nearly 60% of the lightweighting research and development projects captured via the industry survey are being supported by public funding, which in combination with a sharp drop in activity at high technology and manufacturing readiness levels highlights the challenge in scaling new lightweight technologies to the high volume levels required by the automotive industry. Respondents to the survey and participants in the consensus-building workshops considered high volume production skills, facilities and equipment as the key constraints to commercialising innovative material based technologies within the UK. In addition the workshop participants felt that the relationship between engineering designers and material scientists has weakened as engineers increasingly draw upon standardised material property databases, making it more difficult to introduce innovative new materials. Acknowledging this challenge, half of the respondents believe their research and development, which encompasses metal matrix composites, fibre reinforced polymer composites and advanced aluminium and steel alloys, is leading the market.

Maturity of UK R&D projects reported to the industry survey



The UK is globally recognised as a centre for lightweighting technology, with a reputation forged through the use of high cost composites and exotic metallic alloys in the aerospace and motorsport industries. The industry survey, stakeholder interviews and data analysis combine to suggest the UK has a world-class pipeline of more affordable lightweighting technologies that align with strong automotive industry demand. However, the UK has lost manufacturing capability in some areas (such as metal casting and forging) as Tier 2 supply chains have moved off-shore and lacks manufacturing capability in some new material areas (particularly polymer composites and their constituent materials for high volume applications), which is inhibiting commercialisation of material based innovations.

What new capabilities have been built in the UK since 2010?

- EPSRC established the Centre for Innovative Manufacturing in Composites (2011)
- The HVM Catapult was set up to bridge the gap between innovation and commercialisation in advanced manufacturing (2011)
- McLaren begins production of the MP4-12C with its innovative carbon fibre composite tub (2011)
- The Composite Leadership Forum was established (2012)
- Innovate UK funds Ariel to develop a lightweight titanium version of the Atom sports car chassis (2013)
- WMG opens the International Institute for Nanocomposite Manufacturing and the Automotive Composite Research Centre (2014)
- Axon Automotive builds carbon fibre spaceframe for Hyundai's Intrado concept car (2014).
- Jaguar Land Rover invests over £400 million in its Castle Bromwich facility to manufacture aluminium body structures (2015)
- Lotus produces its 40,000th small car with its ground breaking aluminium chassis (2015)
- Leyland Trucks develops a running concept that reduces the weight of its DAF LF truck by 500kg using an aluminium chassis and lightweight components (2015)
- Yamaha showcases a lightweight concept car called the Sport Ride designed by Gordon Murray Design (2015)
- Unipart develops lightweight exhaust systems with Aston Martin for application in future models (2015)

Innovate UK and OLEV collaborate to fund automotive lightweighting

In 2015 the Office for Low Emissions Vehicles and Innovate UK invested £20 million in collaborative research and development projects focussed on reducing the mass of road-going vehicles. The projects are encompassing a range of topics, including developing structures using composites of bio, metallic and fibre reinforced polymer materials, in addition to building a supply chain for them. Funding projects at higher technology maturity levels levels will enable the UK to leverage its strength in lightweight design to increase the efficiency and reduce the tailpipe CO_2 emissions of future vehicles.

High Value Manufacturing Catapult enhancing development

The High Value Manufacturing Catapult helps manufacturing businesses of all sizes and sectors turn ideas into commercial applications by addressing the gap between technology concept and commercialisation. Its seven centres across the country offer open access to world-class equipment, expertise and collaborative opportunities. Research into lightweighting is an important focus of the HVM Catapult's work with a number of its seven centres focusing on automotive lightweighting research and development. Projects to date have included: lightweight seating; carbon fibre wheels; and recyclable bio composites.

Jaguar Land Rover embraces lightweight aluminium bodies

Jaguar Land Rover has developed a world leading capability in aluminium body structures as a result of multiple investments over a number of years. The £400 million investment in 2015 to upgrade the Jaguar XF means that a host of JLR products (XE, F-Pace, F-Type and Range Rover) now contain aluminium. To improve the manufacturing footprint of using aluminium, JLR's REALCAR initiative funded by Innovate UK has encouraged collaboration across the supply chain in recycling. The project makes innovative use of waste collection techniques and has prevented more than 500,000 tonnes of CO_2 equivalent from entering the atmosphere over the course of a year.

Gordon Murray Designs pioneers affordable composite body structures

Gordon Murray Designs is using innovative manufacturing techniques and composite materials to produce lower cost lightweight vehicle structures. Innovate UK supported the development of two compact city car prototypes (T.25 and T.27) that demonstrated the feasibility of the iStream® production process, which is claimed to deliver a 40% reduction in CO_2 emissions over the entire vehicle lifecycle.

What future industry needs could the UK address?

A series of addressable industry needs related to lightweighting were identified by combining the capability assessment with market analysis and qualitative insight captured through the stakeholder interviews and consensus-building workshops:

- All vehicle manufacturers are seeking more affordable lightweighting solutions, harnessing new material, design and manufacturing process technologies.
- All vehicle manufacturers are looking to their supply chains for cost effective, lighter weight alternatives to existing bought-in components.
- Lower volume vehicle (including luxury car, bus and off-highway) manufacturers are seeking innovative tooling solutions to enable cost effective deployment of lightweight polymer structures in lower volume applications.
- Manufacturers of specialist vehicles are seeking lightweight solutions suitable for their specific market requirements, e.g. advanced steels are favoured over fibre reinforced polymer composites for construction equipment body structures due to steel's superior impact resistance and durability in off-highway environments.

What are the key potential opportunities for the UK?

A series of potential opportunities for the UK arising from these addressable industry needs for lightweighting solutions were defined and rated according to their relative attractiveness and the strength of UK positioning in order to determine strategic prioritisation. These hypotheses were subsequently refined with a broad range of experts through the consensus-building workshops.

Focus:

UK could provide focused support to build upon existing advantages in these attractive opportunity areas

Opportunity	Commercialisation Timeframe
Development and supply of lower cost, shorter cycle time lightweight components, focussing at least initially on the low to mid volume requirements of domestic UK vehicle manufacturers Provision of research and development services to lower volume and specialist vehicle manufacturers, leveraging advanced design and process techniques to deliver affordable lightweighting solutions	Short timeframe (by 2020)

Invest-to-Improve:

UK could invest to improve positioning since these opportunities appear to be attractive

Opportunity	Commercialisation Timeframe
Development of new sustainable lightweight materials that are low cost, low embedded energy and recyclable, with commercialisation via licensing to established material producers	Long timeframe (after 2025)

Development and supply of lower cost, shorter cycle time lightweight components, focussing at least initially on the low to mid volume requirements of domestic UK vehicle manufacturers

All manufacturers are seeking affordable actions to reduce vehicle CO_2 emissions and running costs and in the case of commercial vehicles increase productivity. The study has highlighted that as incremental powertrain actions become increasingly complex and expensive, lightweighting actions become increasingly attractive and affordable. Proximity of manufacturing to the vehicle assembly plant to limit logistics costs is usually a requirement to for physically large components. This somewhat localises supply opportunities, but high volume manufacturers producing the same vehicle concurrently at multiple global locations require globally consistent solutions, favouring global scale suppliers. The study has identified that the UK is home to a very relevant domestic market through its premium passenger car manufacturers who are seeking to achieve significant improvements in CO_2 performance and offset the significant incremental mass of hybrid and long-range battery electric propulsion systems. These manufacturers typically consider the main vehicle structures (where large mass reductions are possible through new material technologies) as a core competence, such as Jaguar Land Rover's adoption of pressed aluminium structures. However these manufacturers do seek external support to develop step-changes in main structure technology, such as TVR's adoption of the iStream® system developed by Gordon Murray Design with the support of Innovate UK funding. The UK's domestic manufacturers are certainly looking to their supply chains to provide lighter weight alternatives to existing bought-in components and sub-systems, using new materials, component rationalisation through functional integration and design and process techniques.

The study has highlighted the strong low to mid TRL capabilities within the UK with respect to lightweight materials (including carbon fibre reinforced polymer composites, aluminium and steel) and innovative process techniques (including near-net shape manufacturing techniques, such as additive layer and isostatic pressing). This capability builds upon the UK's globally recognised leadership in aerospace and motorsport lightweight design and construction, with an established manufacturing base focussed predominantly on very high performance applications with very low volume requirements. However, there are significant technical and cost challenges to be overcome for the UK supply chain to deliver solutions at automotive cost and volume levels. The innovative nature of the UK's engineering talents fits well with harnessing the capabilities of new composite materials that require innovative design (such as integrating multiple components into a new form with equivalent functionality) to fully realise their mass reduction potential. In addition, significant process innovation is required to reduce manufacturing cycle times to automotive norms and reduce cost for composite and net shape metal manufacturing techniques.

However, the UK is hampered by a weakening position in the material supply chain (lacking significant relevant polymer, resin or fibre material manufacturing) in addition to facing strong competition from other European nations with strong composites capabilities (such as France and Germany). The UK also has a weakened Tier 2 supply base, with many cast and forged metallic parts moving off-shore to lower cost countries.

Provision of research and development services to lower volume and specialist vehicle manufacturers, leveraging advanced design and process techniques to deliver affordable lightweighting solutions

The study has highlighted that high volume vehicle manufacturers and Tier 1 suppliers continue to make large investments in advanced design and process techniques to deliver lightweighting solutions affordable for mass manufactured passenger cars. This includes use of advanced software tools and design method change to optimise material usage and integrate the functionality of multiple components, in addition to integrating the process changes that enable the utilisation of new materials, such as moving from welded steel structures to bonded composite structures.

Manufacturers and suppliers operating in lower volume and specialist vehicle segments share the same desire to leverage lightweighting technology to improve their products' CO_2 emissions, running costs and productivity, but have distinctly different specification and volume requirements to passenger cars. For example, construction equipment manufacturers need lightweighting solutions to improve productivity that are sufficiently robust to be durable in an off-highway environment, thus favouring advanced steels over fibre reinforced composites. However, these manufacturers typically have insufficient in-house resources to support this objective and so need to leverage capability from the supply chain and engineering service providers. The UK is home to strong domestic market of such manufacturers, including producers of luxury cars, buses and construction equipment.

The UK is home to strong lightweight design capabilities, with organisations in academia, engineering service providers and the supply chain well placed to leverage lightweight design and process techniques from aerospace, defence, motorsport and high volume passenger car manufacturing into the low volume and specialist vehicle market. In addition, the UK's globally recognised position as a leader in innovative lightweight technologies provides an excellent platform from which UK organisations can market their services to a global audience.

Development of new sustainable lightweight materials that are low cost, low embedded energy and recyclable, with commercialisation via licensing to established material producers

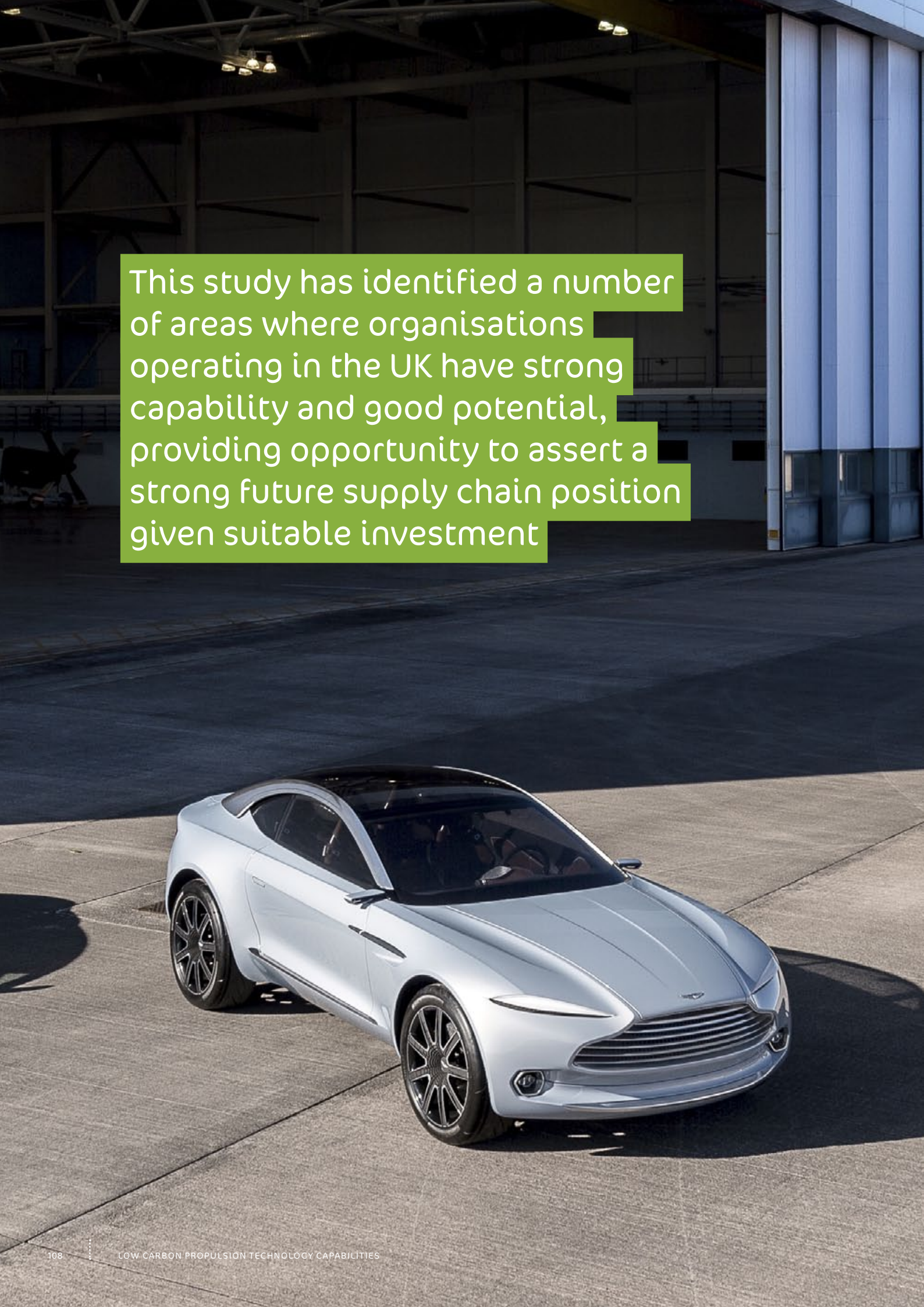
The current push to lightweight vehicles is primarily driven by tailpipe CO_2 emissions legislation. In the long-term as vehicles migrate toward zero tailpipe emissions it is likely that other sustainability measures will become more prevalent to distinguish between the environmental impacts of one electric vehicle from another. Lifecycle emissions analyses, which encompass carbon embedded during production and disposal of the vehicle in addition to its usage, are already reported by a number of vehicle manufacturers as part of their sustainability agendas. If lifecycle emissions become legislated, or at least subject to sufficient scrutiny to be considered a strong competitive differentiator, the prioritisation of different lightweighting techniques could change. This is because different materials have different levels of embedded carbon and typically materials used for automotive lightweighting (such as aluminium, magnesium and carbon fibre reinforced polymers) tend to have higher levels of embedded carbon than the steels they replace, relying on a reduction in in-use carbon emissions to deliver a net lifecycle benefit. Currently material selection is primarily driven on a cost-benefit basis and constrained by legislation such as the end-of-life vehicle directive (which sets targets for reuse, recycling and recovery

thereby discouraging use of non-recyclable or hazardous substances) not lifecycle emissions.

Assuming that a sufficiently strong legislative or competitive driver emerges in the medium to long-term, the market for more sustainable lightweight materials could grow significantly with application in all vehicle segments. The UK has a good foundation in fundamental materials science and research across multiple sectors, which potentially positions the UK well to develop the next generation of materials with improved properties, reduced embedded emissions and increased recyclability. However, the new material development market is highly competitive on a global basis and targeted investment would be required to achieve a leadership position. Commercialisation of intellectual property is most likely to be viable via licensing to the incumbent material providers, who are naturally incentivised to deliver incremental improvements to their technology rather than disruptive innovations.

How well is the UK positioned to capitalise upon these opportunities?

The imperative for lightweighting to improve vehicle efficiency is strong for all vehicle types and propulsion concepts (whether powered by fossil fuels stored in a tank, electricity stored in a battery or by other means). This study has highlighted that the UK is globally recognised as a leader in lightweight technologies, with a reputation forged in the aerospace, defence and motorsport industries. This reputation, combined with good academic and supply chain capability positions the UK well to capitalise upon lightweighting opportunities, including supplying products to domestic manufacturers and engineering services to global manufacturers.



This study has identified a number of areas where organisations operating in the UK have strong capability and good potential, providing opportunity to assert a strong future supply chain position given suitable investment

The implications for key stakeholders

Overview

The evidence base and definition of the UK's current capability and future opportunities were used to identify a series of implications and recommendations targeted toward each of the key stakeholder groups for this report: UK Government and supporting agencies, academia, industry and investors.

Approach

The study has analysed the supply chain positioning of hundreds of companies, the investment of public funds in 427 projects, the registration of thousands of patents, the submission of 125 surveys and the insight of 76 influential industry stakeholders in order to determine notable aspects of UK capability, define likely future industry needs and identify potential opportunities for the UK related to low carbon propulsion technologies. This analysis has been refined through consensus-building workshops with 59 industry experts leading to the summary presented in this report. Contributions from organisations headquartered inside and outside the UK, and from respondents located inside and outside the UK provided a balanced view of the UK's perceived and actual capability strengths and weaknesses.

The drive to dramatically reduce emissions and the resultant electrification of the vehicle powertrain is disrupting incumbent supply chains and providing opportunity for organisations orientated toward the change. This study has identified a number of areas where organisations operating in the UK have strong capability and good potential, providing opportunity to assert a strong future supply chain position given suitable investment. The opportunities identified by this study are balanced across multiple technology areas and timeframes.

Prioritisation

It is important to focus on priorities in order to unite industry, government and academia regarding the technology-led opportunities that are most likely to be of importance in the future, and upon which the UK can deliver. Therefore the opportunities have been prioritised based upon how attractive the market appears and how strongly the UK is positioned to be competitive. A framework was used to facilitate prioritisation, which assigned weighting and scoring to multiple attributes in order to assign each opportunity to one of 3 categories: Focus, Invest to Improve; Opportunistic. The opportunities have been organised into 5 technology areas: Engines; Transmissions, Driveline and Kinetic Energy Recovery Systems; Traction Electric Machines and Power Electronics; Traction Batteries and Fuel Cells; Lightweight Technologies.

It is important to focus on priorities in order to unite industry, government and academia regarding the technology-led opportunities that are most likely to be of importance in the future, and upon which the UK can deliver

Opportunity

In addition to the opportunities identified in each of the 5 technology areas, the study also identified an opportunity that cuts across multiple technology areas: the provision of vehicle system integration services to high and low volume vehicle manufacturers and Tier 1 suppliers.

Provision of vehicle system integration services to high and low volume vehicle manufacturers and Tier 1 suppliers

Electrification of the powertrain, along with driver assistance systems and connected features, is greatly increasing the complexity of vehicle systems. This is a significant challenge for all vehicle manufacturers and Tier 1 system suppliers who need to integrate multiple systems into a vehicle optimised for the best balance between fuel economy / CO_2 emissions, pollutant emissions, performance and driveability. This optimisation can also extend to new hardware concepts that simplify the system by combining the functionality of multiple legacy components into a single new component. Proliferation of powertrain architectures, though the addition of mild hybrid, strong hybrid, plug-in, battery, range-extended and fuel cell electric vehicle architectures to the existing gasoline and diesel engine portfolio is severely stretching vehicle manufacturers' in-house engineering capacity, leading them to seek more external support. The UK is considered to have great strength in vehicle architecture design and complex systems integration, which has positioned the UK's engineering service providers strongly to exploit these opportunities with their global client base. UK-based engineering service providers engaged with the UK's thriving innovation ecosystem will be well placed to continue exploiting this opportunity through this period of rapid change in the automotive industry.


INFINITI
INFINITI EMERG-E

Potential opportunities for the UK

Focus:

UK could provide focused support to build upon existing advantages in these attractive opportunity areas

Theme	Opportunity	Commercialisation Timeframe
	Provision of vehicle system integration services to high and low volume vehicle manufacturers and Tier 1 suppliers	Short timeframe (by 2020)
	Research, development and manufacture of advanced internal combustion engines with improved efficiency and reduced emissions that are adapted to hybridisation for low and high volume applications	
	Development of improved exhaust aftertreatment and Tier 2 supply of high value aftertreatment sub-systems (including catalysts) to Tier 1 exhaust system suppliers	
	Development and supply of alternative fuel engine solutions for medium and heavy duty commercial vehicles for both original equipment and retrofit applications	
	Application and systems engineering services for next generation traction electric machine and associated power electronics technology focussing on low volume and specialist applications, in addition to in-house activity conducted by high volume vehicle manufacturers' R&D centres in the UK	
	Development and supply of lower cost, shorter cycle time lightweight components, focussing at least initially on the low to mid volume requirements of domestic UK vehicle manufacturers	
	Provision of research and development services to lower volume and specialist vehicle manufacturers, leveraging advanced design and process techniques to deliver affordable lightweighting solutions	
	High volume manufacturing of traction battery packs (and/or cells) by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of materials and components	Medium timeframe (by 2025)
	Research, development and low volume manufacturing leading to licensing of next and next + 1 generation battery cell chemistry	Long timeframe (after 2025)

= System integration

Invest-to-Improve:

UK could invest to improve positioning since these opportunities appear to be attractive

Theme	Opportunity	Commercialisation Timeframe
	Development and Tier 1 supply of transmissions that cost effectively meet the specific requirements of low volume hybrid and electric vehicles Development and Tier 1 supply of electric machines and associated power electronics for low volume / high performance traction applications Development and Tier 1 supply of modular traction battery packs for low volume vehicle applications	Short timeframe (by 2020)
	High volume manufacturing of electric traction machines by vehicle manufacturers (and/or Tier 1 suppliers) generating demand for Tier 2 supply of components and/or sub-assemblies	Medium timeframe (by 2025)
	Development of new sustainable lightweight materials that are low cost, low embedded energy and recyclable, with commercialisation via licensing to established material producers	Long timeframe (after 2025)

Opportunistic:

UK has good positioning for these opportunities, though their relative attractiveness is lower – UK could take advantage of its position as opportunities emerge

Theme	Opportunity	Commercialisation Timeframe
	Development of advanced boosting solutions, with commercialisation via in-house development by Tier 1 suppliers with a UK footprint and/or intellectual property licensing to Tier 1 suppliers without a UK footprint Development and low volume production of cost effective kinetic energy recovery systems, primarily for bus and off-highway applications	Short timeframe (by 2020)
	Development of advanced waste heat recovery solutions, with commercialisation most likely via intellectual property licensing to established Tier 1 suppliers of exhaust and/or thermal systems Development and Tier 1 supply of novel propulsion and auxiliary power engines to niche and specialist vehicle manufacturers to comply with emissions regulations and sustainability commitments Development and licensing of innovative solutions to established transmission manufacturers (vehicle manufacturers and Tier 1 suppliers) for integrating the traction electric motor, transmission and driveline in electrified powertrains	Medium timeframe (by 2025)
	Development and Tier 1 supply of integrated fuel cell systems to low volume vehicle manufacturers R&D, co-development and Tier 2 supply of high value components to fuel cell manufacturers	Long timeframe (after 2025)

Implications

The evidence base and definition of the UK's current capability and future opportunities were used to identify a series of implications targeted toward each of the key stakeholder groups for this report: UK Government and supporting agencies, academia, industry and investors.

For UK government and supporting agencies

Engines will remain an important focus for UK research-to-manufacture activities for some time

The study affirms that the UK is a significant player in the internal combustion engine research-to-manufacture supply chain. Internal combustion engines will play a critical role for many years to come by underpinning an affordable pathway to long-range zero emission capable vehicles through hybrid and range-extended electric propulsion systems, in addition to providing the primary motive solution for commercial on and off-highway vehicles. There is significant potential for the UK's research-to-manufacture supply chain to play a leading role in further improving the efficiency of the internal combustion engine system, whilst the Automotive Council Supply Chain Group continues to seek opportunities to increase the value of manufactured components sourced from UK businesses. However, the role of the internal combustion engine will diminish in the long-term (at least in the high volume passenger car segment, acknowledging a longer term role in commercial on and off-highway vehicle applications) as we migrate toward a zero tailpipe emission transport world.

The prioritisation of propulsion technologies is intertwined with the future state of the global energy system

The study has identified a number of potentially attractive opportunities for organisations operating in the UK to capitalise upon technology-led disruptions to established automotive supply chains. These opportunities span a range of low carbon propulsion technologies, encompassing: internal combustion engines, transmissions, electric machines, power electronics, batteries, fuel cells, kinetic energy recovery systems and lightweight technologies. However, the prioritisation of future automotive powertrain technologies is closely intertwined with the future global energy system via the availability of energy carriers (e.g. biofuels; hydrogen) and their storage and delivery infrastructure (e.g. refuelling and charging networks). Further cross-industry and cross-government department collaboration will ensure that the UK can capitalise upon aligned strategies for transportation and energy systems; strategies that could alter the prioritisation of the opportunities described in this report.

The technologies compatible with megatrends and resilient to foreseeable scenarios provide good potential

Ensuring the UK environment is supportive to the development of technologies compatible with megatrends, resilient to foreseeable future scenarios and with cross-sector application will provide good medium to long-term potential. For example, sustainable lightweight solutions, traction batteries and high performance traction motors and power electronics have significant future growth potential, are compatible with a range of future propulsion solutions (whether hybrid, battery electric or fuel cell electric) and align with the UK strengths identified through this study. However, whichever specific technology options are pursued by UK organisations, the support environment needs to ensure unexpected opportunities are also able to flourish.

Exploiting cross-sector links will maximise opportunities

Many of the technologies identified in the study can be transferred to other sectors (e.g. electric machines and power electronics in industrial applications; affordable composites in aerospace interior systems). Exploiting cross-sector links in common technology areas will maximise opportunity and learning effects.

The UK's internationally renowned academic research and R&D funding support provide competitive advantage

The UK is internationally recognised as possessing great strength in fundamental academic research and early-stage industrial research and development. This study has confirmed that through tax relief (via R&D tax credits and Patent Box) and the addition of the Advanced Propulsion Centre programme to the existing support provided by the EPSRC, Innovate UK and OLEV, the UK is considered to have one of the best aligned R&D funding support mechanisms in the world and is perceived to be very open to collaboration with foreign organisations. This makes the UK a very attractive place to develop new low carbon propulsion technologies, helping to root high value activities in the UK.

The UK supply chain needs to collaborate to challenge incumbent Tier 1 positions

The relative lack of international Tier 1 suppliers with significant research-to-manufacture activity in the UK continues to be a critical issue and stifles the route to market for home-grown innovation. Collaboration between large scale suppliers and businesses with differentiated IP is critical if UK businesses are to offer products and services that can compete with the incumbent Tier 1s. The study has demonstrated how collaborative R&D support programmes funded by UK Government through Innovate UK and the Advanced Propulsion Centre have proven effective at bringing together and developing UK supply chain capability. There is a continuing opportunity to proactively support the development of competitive supply offers aligned with future automotive needs.

The UK needs to attract inward investment in zero emission capable propulsion technologies

Reducing demand for internal combustion engines will result in decline in the UK's manufacturing output and capability unless we secure the manufacture of displacement technologies, such as the electric traction motors and traction battery systems identified in this study. It is crucial that the UK continues to attract investment in high volume manufacturing of future propulsion technologies and that the UK research-to-manufacture supply chain is positioned to support. Nissan's decision to base its first European electric vehicle and traction battery plant in Sunderland is a strong foundation upon which to attract other overseas headquartered companies with UK vehicle and powertrain manufacturing footprints (such as BMW, Caterpillar / Perkins, Ford, Honda, Nissan, General Motors and Toyota) in addition to attracting investment in future propulsion technology manufacturing by our domestic vehicle manufacturers. However, the consequences of the 2016 UK referendum vote to leave the European Union are uncertain at the time of writing.

The UK needs to enable SMEs to commercialise their intellectual property within the UK

In addition to attracting inward investment we need to encourage growth of UK SMEs who aspire to manufacture low carbon propulsion technologies in volume, whether in-house, through strategic partnership or via licensing. SME support mechanisms, such as the Knowledge Transfer Network, Catapult Reach, Innovate UK and the Advanced Propulsion Centre's Technology Developer Accelerator Programme all have a role to play in commercialising SME's technologies.

Attractive opportunities may not always encompass on-shore manufacturing

Not all of the identified opportunities will necessarily lead to manufacturing within the UK. The study affirms that UK organisations are recognised as being strong sources of innovation and effective system integrators. These skills have underpinned a strong engineering services sector and attracted a number of inward investments in research and development facilities, both of which support high quality engineering jobs. Current collaborative R&D grant funding programmes do support the development of system integration skills (a key element of all of the Advanced Propulsion Centre's projects), but do not align well with the typical engineering services business model, which does not generate income from the subsequent manufacturing of any product developed, or align well with businesses leveraging off-shore manufacturing.

The UK needs to be recognised as leading the world in specific and significant areas of technology

The automotive industry is increasingly globalised, formed of multi-national companies serving multiple markets. The study underscored the need for both UK headquartered organisations and UK divisions of multi-national organisations to be competitive on an international playing field in terms of technological capability and operational standards in order to capitalise upon the identified opportunities. The study highlighted the need for UK academia and business to be recognised as leading the world in specific and significant areas of automotive technology in order to generate export opportunities and attract inward investment in research, development and manufacturing. The Advanced Propulsion Centre is developing a Spoke Network to foster closer collaboration and joint promotion between universities and industry around specific automotive technology themes.

There are opportunities to more effectively market the specific capabilities of UK organisations

The government already provides a great deal of promotional support to the UK automotive industry through the Britain is GREAT campaign, and the UK Pavilion that coordinates UK Trade & Investment, Innovate UK and Advanced Propulsion Centre presence at a number of international trade shows. However further effort is needed to market the specific technical capabilities of UK organisations and improve their visibility both internationally and within the UK supply chain. UK businesses have a limited presence in international shop windows such as the European Commission's Horizon 2020 funding programme and leading international technical conferences. UK organisations need to be encouraged to access these opportunities in order to improve global recognition of UK automotive innovation and specific supply chain capabilities.

The impact of autonomy and Industry 4.0 will need to be addressed by this study in the future

The long term impact of autonomy on road transport is still uncertain, but in combination with other developments such as Industry 4.0 it is likely to have great impact on propulsion technologies, e.g. through potential commoditisation of the powertrain and new manufacturing models. The UK will need to be positioned to capitalise upon these shifts and therefore these themes will need to be addressed through future iterations of the capability study.

For automotive industry organisations operating in the UK

Technology-led disruptions to incumbent supply chains are creating opportunities

The study has identified a number of potentially attractive opportunities across a range of low carbon propulsion technologies (encompassing internal combustion engines, transmissions, electric machines, power electronics, batteries, fuel cells, kinetic energy recovery system and lightweight technologies) where organisations operating in the UK could capitalise upon technology-led disruptions to established automotive supply chains. In addition, there are cross-sector opportunities to be found in these emerging technology areas, for example the automotive industry is expected to take the lead (from the aerospace and industrial sectors) in developing the next generation of higher performance and lower cost power electronics.

The UK can't focus on everything at once, priorities need to be established for the nation

These opportunities warrant further investigation and due diligence to determine the specific attractiveness and relative positioning for any individual organisation. The opportunities highlighted in this study as a priority for the UK do not mean that any individual business should not pursue an alternative technology avenue that presents a good business case, even if it is not aligned with the identified priority areas for the UK as a whole.

Competition for these emerging opportunities is already fierce; the UK needs to act quickly

Migration to lower carbon propulsion systems opens up new opportunities where the supply chain is not yet well established (e.g. electric vehicle powertrains) but the study has confirmed that plays are already being made by a combination of the incumbent powertrain supply base and new players on an international level. Therefore careful selection of opportunities and swift action is needed.

The UK needs to be recognised as leading the world in specific and significant areas of technology

The study has confirmed that organisations operating in the UK are internationally recognised as being innovative and effective system integrators. UK industry needs to build on this to be recognised as leading the world in specific and significant areas of automotive technology in order to create export opportunities and attract inward investment in research, development and manufacturing. Companies operating in the UK can capitalise upon the Advanced Propulsion Centre's Spoke Network to form strong communities with universities and other companies around specific technology themes. Picking the technology options compatible with megatrends, resilient to foreseeable future scenarios and with cross-sector application will provide good medium to long-term potential. For example, sustainable lightweight solutions, traction batteries and high performance traction motors and power electronics have significant future growth potential, are compatible with a range of future propulsion solutions (whether hybrid, battery electric or fuel cell electric) and align with the UK strengths identified through this study.

The UK can capitalise upon the strength of its reputation for lightweight technologies

The study highlighted that the UK is internationally perceived to lead the world in lightweight technologies and design, so UK business can capitalise upon this reputation and the expertise available in the High Value Manufacturing Catapult to deliver the affordable and sustainable lightweight solutions required to improve the efficiency and reduce the emissions of all vehicle types. The expansion of the Advanced Propulsion Centre's programme scope to encompass lightweight powertrain and vehicle structures provides

improved support to ensure that more of the pipeline of promising sustainable lightweight technologies progress through the EPSRC and Innovate UK programmes to be successfully commercialised.

The UK needs a sustainable pipeline of market leading innovation that can be commercialised with benefit to the UK

Many respondents to the survey believe the technologies they are currently developing are market-leading, which is encouraging but will ultimately be fruitless if the innovation is not delivered to market and its value is not recognised by the global automotive industry. UK businesses need a clear focus on route to market and commercialisation opportunities to ensure that value can be maximised from their innovation. The Advanced Propulsion Centre will continue to work with industry to drive this focus through the Technology Developer Accelerator Programme and collaborative R&D programme.

The UK supply chain needs to accelerate its efforts to capitalise upon a window of domestic opportunity

The study has identified a window of opportunity for the UK supply chain as the UK's resurgent domestic vehicle manufacturers seek affordable premium / high performance electrification and lightweight solutions that are not readily available from the international Tier 1 suppliers, who are focussed on higher volume applications. However, the UK supply chain needs to accelerate its efforts and act quickly as the UK domestic vehicle manufacturers will be forced to secure supply from abroad if the UK supply chain cannot provide competitive full service supply solutions. In parallel the off-highway, commercial, bus and motorcycle sectors are seeking affordable low carbon propulsion solutions adapted from proven automotive technology to suit their specific needs, which provides opportunity for a supply base willing to engage at lower production volumes and higher degrees of complexity.

The UK can use collaboration to challenge incumbent Tier 1 supply chain positions

The relative lack of international scale Tier 1s with significant research-to-manufacture activity in the UK means the UK supply chain needs to collaborate to be able to offer competitive products and services that present a viable sourcing solution for vehicle and powertrain manufacturers. There is potential for the UK's existing higher volume suppliers to align with SMEs to secure differentiated IP (whether through licensing, partnership, joint venture or acquisition) and to leverage collaborative R&D mechanisms (such as Innovate UK, the Advanced Propulsion Centre and High Value Manufacturing Catapult) to develop new technology solutions ready for commercialisation. The Advanced Propulsion Centre will work with the Automotive Council Supply Chain Group to proactively seek these supply chain collaboration opportunities.

Marketing specific capabilities on a global stage is a key enabler to attracting export opportunity

The window of domestic opportunity potentially provides a platform for further UK supply chain growth via serving the non-domestic automotive manufacturer presence in the UK and beyond for businesses with the aspiration to compete in what is increasingly a globalised automotive supply chain. The study asserts that international recognition will be a key enabler and to that end UK businesses need to embrace opportunities to market their technical capabilities on a global stage, whether that be by engaging in an international collaborative R&D programme, presenting a paper at a leading international conference, patenting strategic IP or delivering a pilot product to the market for the world to see. In addition, industry should take advantage of the promotional support the UK Government already provides through the Britain is GREAT campaign and the UK Pavilion presence at international trade shows.

The supply chain must support new technologies to attract foreign direct investment in high volume plants

The established UK high volume producers of vehicles and powertrains (BMW, Caterpillar / Perkins, Ford, Honda, Nissan, General Motors, Toyota etc.) will increasingly migrate toward lower carbon and electrified propulsion systems. Nissan's investment in electric vehicle and battery production in Sunderland demonstrates that this can be an opportunity for the UK. The UK supply chain needs to demonstrate its ability and willingness to support new technologies in order to help attract further inward investment, using the Advanced Propulsion Centre's Spoke Network and collaborative R&D funding programme to develop networks and capability.

The impact of autonomy and Industry 4.0 will need to be addressed by this study in the future

The long term impact of autonomy on road transport is still uncertain, but in combination with other developments such as Industry 4.0 it is likely to have great impact on propulsion technologies, e.g. through potential commoditisation of the powertrain and new manufacturing models. The UK will need to be positioned to capitalise upon these shifts and therefore these themes will need to be addressed through future iterations of the capability study.

For UK academia

UK academia's reputation for being open to international business provides a competitive advantage

The study confirmed that the strength of fundamental UK research is internationally recognised, which is a strong platform on which to strengthen our reputation for commercialising automotive research. The study also highlighted that UK academia has a strong reputation for being open to international business, which provides a competitive advantage to the UK's academic institutions and a great opportunity to proactively engage with disruptive organisations (such as Google and Apple) entering the automotive space.

There are further opportunities to strengthen alignment between academia an industry

However, the linkage between academia and the automotive industry is perceived to be weaker than in Germany, the benchmark for many of the study participants. There is a clear need for UK academia and industry to strengthen dialogue regarding the research needs arising from future automotive industry challenges in order to develop technologies compatible with megatrends, resilient to future scenarios and with cross-sector application. For example, sustainable lightweight solutions, traction batteries and high performance traction motors and power electronics all have significant future growth potential and align with the UK strengths identified through this study. The Automotive Council Challenge Networks will play a key role in fostering partnership and alignment between academia and industry with the support of EPSRC, Innovate UK and the Advanced Propulsion Centre's Spoke Network. In addition, there is further opportunity for innovative approaches to engagement, such as The Institute for Advanced Manufacturing and Engineering collaboration between Coventry University and Unipart Manufacturing Group.

Strategic planning by academia with industry is required to help mitigate future skills shortages

The UK engineering skills shortage is well reported. In addition to planning research activity, new academic and industry collaborations can work with the Automotive Industrial Partnership to plan future education, training and upskilling requirements, plus work together to attract students by providing visibility of potential career paths.

The UK should aspire to create the next great automotive breakthrough

There are also longer-term opportunities for technological breakthroughs (such as next generation battery cell chemistry, low embedded energy lightweight materials and harnessing the potential of graphene and similar materials) to achieve disruptive impact for the benefit of the UK. The Advanced Propulsion Centre will continue to work with the EPSRC, Innovate UK and the Automotive Council Challenge Network to match ground-breaking innovations with automotive industry needs and provide a clear path toward commercialisation for innovation.

For organisations investing in UK automotive

There is a technology-led window of opportunity for UK organisations that requires bold investment

The study has identified a number of potentially attractive opportunities for the UK to capitalise upon technology-led disruptions to established automotive supply chains across a range of low carbon propulsion technologies. The study has also identified a window of opportunity for the UK supply chain to capitalise on the new technologies required by low carbon and electrified powertrains as domestic UK vehicle manufacturers seek solutions not readily available from the established international Tier 1 supply base. Capitalising upon these opportunities will require bold strategic investments and patient capital, but investors can find confidence in the alignment with the globally significant technology trajectories outlined in the Automotive Council technology roadmaps and the opportunities outlined in this study.

The UK needs to innovate to ensure that more intellectual property is commercialised for the benefit of the UK

The study highlighted that the UK has a strength in fundamental research and early-stage research and development but consistently struggles to build businesses capable of taking new technology to market. Innovative funding mechanisms will be required to support SMEs in taking complex technologies with long maturation cycles to the automotive market, whether that be through licensing, acquisition, partnership, joint venture or in-house manufacture.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Working together to capitalise on opportunities

This report is intended to be a catalyst for further dialogue between UK Government, academia and industry regarding future opportunities relating to low carbon propulsion technologies. The report's value will only be realised if you engage in the debate and work collaboratively to deliver any identified actions.

The Advanced Propulsion Centre will be organising a series of events to provide a forum for this dialogue and formation of plans to capitalise upon identified opportunities, including:

- Public presentations and workshops at established industry conferences and events.
- Public workshops organised in partnership with the Advanced Propulsion Centre's Spoke Community.
- Meetings with specific stakeholder groups.

The Advanced Propulsion Centre is establishing an iterative process for updating the Automotive Council's propulsion roadmaps and capability reports, forging a stronger link between them in order to:

- Maintain the relevance and prominence of the technology roadmaps, considering the changing technological landscape.
- Support the development of more consistent and targeted R&D agendas.
- Identify the need for intervention to address gaps in UK capability to deliver key technologies.
- Identify opportunities to strategically build UK capability to capitalise upon innovative technologies disrupting established supply chains.

This will enable the Advanced Propulsion Centre to target its activities toward the areas where intervention will yield the greatest strategic impact.

Please contact the Advanced Propulsion Centre if you would like any further information regarding these activities:

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References and acknowledgements

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www.automotivecouncil.co.uk
https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy

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www.epsrc.ac.uk
www.gov.uk/government/organisations/innovate-uk

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www.apcuk.co.uk
www.ricardo.com
www.e4tech.com

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