



Department for
Business, Energy
& Industrial Strategy

ADVANCED PROPULSION CENTRE

External Process Evaluation

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Executive Summary

Ipsos MORI and Ecorys (in association with George Barrett) were commissioned in January 2017 to undertake an external process evaluation of the Advanced Propulsion Centre (APC) by the Department for Business, Energy and Industrial Strategy (BEIS). This report provides early findings relating to the effectiveness of APC funding and emerging technological and economic outcomes across the portfolio of core projects which have been funded. The central focus of the study is on the R&D projects that have been funded, rather than the wider effects of the APC Ltd which was established as part of the programme to support the co-ordination of R&D activity in the sector.

Evaluation Aims and Methodology

The core aims of this evaluation of the Advanced Propulsion Centre (APC) were to provide early evidence on 'what works,' the emerging benefits of the programme, and early lessons for programme delivery and implementation. The evaluation involved the collection and triangulation of analysis of Innovate UK monitoring records, interviews with key stakeholders of the programme and detailed case studies of 10 projects receiving public support through the APC.

Advanced Propulsion Centre

The Advanced Propulsion Centre (APC) was launched by the UK Government and the Automotive Council in 2013 to:

- Achieve significant progress in developing low carbon propulsion technologies; and,
- Anchor and attract R&D capability in the UK and leverage high value manufacturing opportunities that market exploitation may provide.

The APC is comprised of £1bn in funding commitments from the public and private sector to support industry led R&D and the creation of APC Ltd, an independent body tasked with the coordination of R&D activity in the sector. £245m in grant funding was committed to 29 projects over the first six competition rounds. Appraisals of these proposals give an expectation that the future exploitation of technologies development could lead to £705m in net economic and environmental benefits between 2014 and 2030 (though significant sales of vehicles integrating APC funded technology were not expected until 2018).

Motivations of Applicants

Applicants mainly sought APC funding to support the development of low carbon propulsion technology to be integrated into new product launches, overcoming the challenges of integrating new technologies into real world applications, and enhancing the capabilities of suppliers based in the UK. Commercial motivations were both aggressive and defensive in character, aligning with a broader shift in corporate R&D strategies towards electrification as a means of meeting future emissions requirements in many vehicle segments. It was recognised that the upscaling production of electric propulsion systems could represent a challenge for the UK supply chain (though there may still be a medium-term future for internal combustion engines in smaller and lower margin vehicles, and electrification is not currently a viable option for some vehicle categories such as HGVs and larger off-highway vehicles).

Additionality

Grant beneficiaries most frequently suggested that their investment in R&D projects was constrained by issues with access to finance, although the specifics of these challenges varied across different groups. Large firms tended to claim that public funding was primarily needed to accelerate existing plans. SMEs may have faced more acute challenges in financing their activities given the tendency to rely on OEMs to fund their R&D and reported difficulties in accessing equity finance. Large OEMs and Tier 1 firms also reported facing competitive pressures constraining their efforts to secure internationally mobile R&D or production investments in the UK, exacerbated by perceived limitations on the capabilities of domestic suppliers to upscale production. These arguments are difficult to validate, however, as evidence collected through the study both supported and conflicted with these claims.

Collaboration

Applicants to the APC were required to submit collaborative proposals. The evidence suggested that collaborative relationships were rarely novel, with many links being formed through the delivery of precursor projects (through the Innovate UK IDP programme for example).¹ There was evidence that collaboration requirements forced OEMs to work with domestic suppliers when they may have otherwise preferred to have worked with firms overseas, helping to anchor R&D in the UK and in some cases securing the position of SMEs in the supply chain (even where the production was largely to take place overseas). The signature of the Collaboration Agreement also helped to give certainty and momentum

¹ Integrated Delivery Programme funding competition series.

to collaborative endeavours (though in some cases, restricting the ability of some junior partners to exploit the technologies under development).

Project Delivery

Though many projects encountered technical challenges and suffered delays, the underlying difficulties have mainly been overcome. However, rapid changes in the external context have altered the economics of some of the technologies being explored – falling diesel prices have increased payback periods for consumers while ‘diesel-gate’ has accelerated pressures to reduce emissions. In a small number of cases where projects had relatively limited emissions reduction objectives, OEMs shelved technologies to pursue alternative options. The level of risk associated with APC projects appears to be higher than judged at the appraisal and assessment stage and could merit further attention in future competitions.

Early Outputs and Outcomes

As of August 2017, the APC was thought to have delivered the following outcomes:

- **Technical Focus and Progress:** The case studies suggested that projects made substantial progress in commercialisation (to around TRL7 and MRL4-5), though there appeared to be some optimism bias associated with prior expectations regarding the potential technical performance of the technologies under development.
- **Exploitation:** Only one of the projects reviewed was at the stage where the partners were ready to launch a new product to market, though in many cases there was greater clarity regarding future commercial plans. Nevertheless, current expectations in relation to future sales of vehicles integrating APC technology exceed those formed at the point of the application (though largely due to unexpectedly high demand for EVs and hybrids). Much of the anticipated production activity is expected to be undertaken in the UK, albeit with a small number of examples of unplanned offshoring. Additionally, the case studies have suggested that even where OEMs have abandoned the systems under development, the SMEs involved tended to be able to find markets for the subsystems for which they were responsible.
- **Spill-overs:** There was evidence of a variety of spill-overs in which the technologies under development found unexpected application in other products. These types of effect were largely internal to the collaborating parties, though the scope for future application of some technologies (such as Kinetic Energy Recovery Systems) in adjacent industries was widely acknowledged by those engaged.

The evaluation did highlight occasions where the risks of benefits being leaked overseas were elevated – particularly stemming from use of overseas subcontractors in the delivery

of projects and the risk that SMEs deploying ‘virtual’ manufacturing models seek to offshore production capabilities.

Recommendations

Summary of Key Recommendations

- (1) APC, BEIS and Innovate UK should consider the implementation of monitoring of post-completion exploitation outcomes to determine how far OEMs and Tier One suppliers go on to produce the technology in the manner claimed at the application stage. On the expectation that the APC will involve a long-term relationship - with OEMs submitting repeat applications - this type of evidence could be helpful in informing expected leakage corrections in the VFM appraisal process. Excessive administrative burdens could be avoided by ensuring any follow-up is periodic and light touch.
- (2) APC, BEIS and Innovate UK should consider accelerating the implementation of arrangements to monitor the technological and economic outcomes associated with the projects which have received funding. This will provide benefits in terms of assessing performance management (by enabling a clear assessment of how projects have performed against expectations), as well as in facilitating communication of the results of the programme to wider stakeholders and informing the assessment of bids for further public funding.
- (3) The APC should work with applicants to help resolve any issues that may arise in situations where collaboration agreements may inhibit the exploitation of the technology developed with public funding.
- (4) APC, BEIS and Innovate UK should consider whether it would be feasible to require applicants to provide additional documentation at the due diligence stage describing the extent and results associated with the tests completed to take the development of the core systems to TRL5. This could potentially help validate the technical claims made by applicants and identify risks that could form the focus of any ‘gateway reviews’ introduced to support risk management, the increased use of which is suggested in recommendation 7.
- (5) The separate presentation of BCRs with and without environmental benefits following the VFM assessment is appropriate given the uncertainties involved. However, BEIS should consider whether it may be appropriately conservative to also apply an optimism bias adjustment in the VFM assessment given the evidence that the technologies developed did not always deliver their anticipated fuel economy savings.
- (6) BEIS should also consider whether it may be desirable for the VFM analysis to assign higher weight to expected fuel economy gains produced in excess of emissions legislation targets, given that these targets need to be met in any case. The VFM

Summary of Key Recommendations

analysis could potentially be refined by discounting any emissions savings below regulatory requirements (or exploring this through sensitivity analysis). Additionally, a timing adjustment for any emissions savings above those targeted or required by the lead applicant may be desirable to allow for possibility of technologies for future product launches.

- (7) APC, BEIS and Innovate UK should consider making greater use of 'gateway review' processes (or staged grant awards linked to the achievement of technical milestones) to more effectively manage the risks associated with committing funding to large programmes of technical development. The implementation of any such processes should involve rapid timescales for decision making to provide certainty and avoid unnecessary delays in project delivery.
- (8) If APC, BEIS and Innovate UK seek to make greater use of staged payments or 'gateway reviews' as means of improving risk management, consideration should also be given to the potential exploitation of sub-systems being developed by collaborating parties. In cases where there is a compelling reason to withdraw funding from the core project, there may be a case for continuing funding the development programmes led by collaborating parties.
- (9) APC, BEIS and Innovate UK should consider whether there may be value in repeating the VFM assessment in cases where projects are subject to major re-scoping and fundamental changes to the basis on which public funding was awarded (to provide assurance that the further public investment offers sufficient value for money, discounting sunk costs). A clear definition of what is understood by 'major rescoping' will need to be introduced.
- (10) BEIS and Innovate UK should undertake specific research exploring the extent to which SMEs in the automotive manufacturing sector face specific financial market constraints that prevent them building their manufacturing capabilities, and whether there may be a need and demand for complementary instruments to help SMEs upscale production (i.e. capital investment rather than R&D subsidies) – or how far the apparent challenges are driven primarily by challenges in producing at an acceptable unit cost. There may also be comparable issues in other advanced manufacturing industries to which such instruments would be relevant.

1.0 Introduction

Ipsos MORI and Ecorys (in association with George Barrett) were commissioned in January 2017 to undertake an external process evaluation of the Advanced Propulsion Centre (APC) by the Department for Business, Energy and Industrial Strategy (BEIS). This report provides early findings relating to the effectiveness of APC funding and the emerging technological and economic outcomes across the portfolio of projects that have been funded.

1.1 Study Objectives

The core aims of the external process evaluation of the Advanced Propulsion Centre (APC), as set out in the Invitation to Tender, are to provide early evidence on ‘what works,’ the emerging benefits of the programme, and early lessons for programme delivery and implementation. The main focus of the evaluation has been on gathering detailed evidence on outcomes from a sample of projects that have received APC funding. Specifically, the study was required to address the following research questions:

- What are the motivations of firms participating in the programme? Why did they apply for funding? What is the nature of the challenge that they were seeking to address? What in their view would have happened if funding of their project had not materialised?
- What has been their experience in commencing the implementation of their projects? What have been some of the success factors? What have been the barriers?
- What is the nature and extent of collaboration in the programme, e.g. horizontal or vertical linkages in the supply chain, collaboration with academia, research institutions and Catapults? To what extent was APC funding responsible for stimulating this collaboration? How sustainable are these collaborations beyond the life of the project?
- What are some of the early outputs of the programme (such as number of additional R&D jobs created; upskilling of staff; additional R&D or capital spend; progress in technology readiness levels; types and nature of collaborations; types of projects and technologies)?
- What has been the early impact of APC projects on innovation in the sector? Has APC been successful in targeting technologies and manufacturing processes that are expected to achieve the policy objectives?
- Have there been any unintended consequences to companies or the wider economy, beneficial or not, of the APC programme so far?

1.2 Methodology

The evidence generated as part of this evaluation was collected using the following methods:

- **Stakeholder consultations:** Consultations with a group of eight stakeholders, both internal and external to the delivery of the APC, were completed to obtain strategic perspectives on progress and early results achieved across the portfolio of projects funded to date, identify general issues encountered in post-award delivery, and secure perspectives on how far internal processes were able to maximize progress and the realisation of the anticipated economic impacts. The stakeholder organisations engaged in the consultations included: The Department for Business, Energy and Industrial Strategy, Innovate UK, The Advanced Propulsion Centre Ltd., the Automotive Council and The Engineering and Physical Sciences Research Council.
- **Analysis of monitoring information:** An analysis of available monitoring records collected through the delivery of the programme was completed to provide an overview of the performance of the APC portfolio against expectations at an aggregate level and to identify sources of variability across the projects funded.
- **Case studies:** Ten case studies were completed of approved APC projects. A purposive sampling approach was adopted to achieve a mix of cases that considered: stage of completion, competition round, incremental versus radical innovation, synergies with other public funding sources, additionality arguments made by applicants and the Automotive Council R&D priority areas. The case studies involved a review of application and monitoring information, a desk based review of relevant material available publicly, and interviews with lead applicants, monitoring officers and project collaborators. In some cases, the relevant APC Project Associate was also interviewed.

The case studies focused primarily on establishing the range of technical, commercial and economic results achieved to date and benchmarking these results against the ex-ante expectations defined in the application, technical assessments, value for money (VfM) appraisals, delivery plans and exploitation plans. Qualitative evidence was used to characterise quantitative outcomes in more depth, and test explanations for programme wide performance offered by stakeholders. Comparative analysis of cases was employed to develop insights into the relationships between the results achieved and aspects of the institutional and external context, to yield an understanding of 'what works' and consider where adjustments to internal processes might have produced greater value for money from the projects funded.

- **Synthesis:** The above sources of evidence were synthesised by mapping the variety of findings to an evaluation framework agreed with BEIS, Innovate UK and the APC at the outset of the study. Where the data sources produced contrasting results (such as differences between views of stakeholders or between the overall assessment of stakeholders or applicants), these differences were reconciled by weighting the

evidence collected by quality, consistency and its broader context (such as the likely interests of different stakeholders) and where possible using objective data gathered from the management information to validate the views offered by stakeholders.

1.3 Limitations

This report is subject to the following limitations:

- **Results are primarily based on qualitative evidence:** The evidence is mostly based on thematic analysis drawing on the views and perceptions of applicants and stakeholders. While outcomes have been quantified where possible in the case study research, systematic quantitative information on the results achieved by APC projects is not collected (either during the delivery of projects or post-completion). Although the case studies covered a sizeable share of the projects receiving funding from the programme (34 percent), there are some limits to how far the findings of their evaluations can be generalised.
- **Economic impacts are not generally expected to have materialised at this stage:** The APC provides financial support for product development in an industry characterised by long product development cycles. Although the projects funded typically start at a relatively high level of technological readiness (TRL5), they often need to deal with major engineering challenges in integrating technologies proven under laboratory conditions in operational vehicles, as well as establishing manufacturing processes to produce components and systems at an acceptable unit cost. The first APC projects received funding in 2014, and it remains too early to identify concrete economic benefits from the portfolio of projects funded.
- **Level of risk:** The APC funds R&D projects which are characterised by a relatively high level of risk. As such, it is to be expected that projects may encounter challenges that necessitate a change in direction and that results will not always align with expectations.

1.4 Report Structure

The remainder of the report is structured as follows:

- **Section 2** provides an overview of the APC, covering its current commitments, expected benefits and the economic, technological and political context within which it has been delivered.
- **Section 3** explores the progress made by APC projects against expectations and provides an assessment of issues encountered by applicants.
- **Section 4** examines the technical and economic outcomes associated with the portfolio of projects that have been funded.

- **Section 5** provides overall conclusions from the evaluation and sets out recommendations to be considered in the on-going development of the programme.

2.0 Advanced Propulsion Centre

This section provides an overview of the APC. It covers the aims and objectives of the programme, the rationale for intervention and provides a summary of the Theory of Change. This is followed by a review of the projects funded through the APC by the end of 2016, covering fund commitments and expected benefits and an assessment of progress with delivery versus expectations. The section concludes with an outline of the economic, political and technological context in which the APC programme is operating.

2.1 Programme Overview

The Advanced Propulsion Centre (APC) was launched by the UK Government and the Automotive Council in 2013 as part of the Coalition Government's Industrial Strategy. The objectives of the programme are to:

- Achieve significant progress in developing low carbon propulsion technologies; and,
- Anchor and attract R&D capability in the UK and leverage high value manufacturing opportunities that market exploitation may provide.

The APC involves two main elements. The UK Government and the Automotive Council made a commitment to invest £1bn (including £0.5bn in public subsidies) in research and development projects aimed at commercialising low carbon propulsion technologies. The second element of the APC was the creation of an independent body (APC Ltd.) tasked with coordinating research and development activity in the technology area. The role of APC Ltd. in the Business Case included: maintaining technology roadmaps for the sector, matching products to customers, and catalysing new collaborations. The services offered by the APC now include support for applicants in engaging with the competition process and assistance with the development of consortia bids, a Technology Developer mentoring scheme, development of communities focussed around strategic technologies (spoke network) and co-ordination and management of International Events. A review of those activities is outside of the remit of this study.

The Automotive Council and Government undertook a horizon scanning exercise in 2013, mapping out the anticipated path of technological development in the automotive industry in five key areas. In 2016, a revised set of five technology areas were identified as central to the UK's future competitive advantage in the low carbon vehicles sector:

- Thermal propulsion systems (TPS)²
- Transmission, driveline and kinetic energy recovery systems;
- Traction electric machines and power electronics;
- Traction batteries and fuel cells; and,
- Lightweight technologies.

2.1.1 Strategic Rationale

The Climate Change Act of 2008 places a legal requirement on the UK to reduce its emissions to 80 percent of 1990 levels by 2050. As a key contributor to UK emissions, the automotive and transportation sectors have been identified as a priority area in which transformative low carbon propulsion technologies are needed³. The implication is that supply chains centred on the production of conventional internal combustion engines (ICEs) will be replaced by a supply chain focused on the production of new types of low carbon propulsion technology.

This change presents both a threat and an opportunity to the sector in the UK owing to the large automotive manufacturing base and its specialisation in the production of TPS. On the one hand, these anticipated changes could diminish the long-term competitiveness of the automotive sector if OEMs and the supply chain are unable to respond to these regulatory drivers⁴. On the other, if firms in the UK can acquire a ‘first-mover’ advantage in the development of the relevant capabilities, there may be opportunities to reverse the ‘hollowing-out’ of automotive supply chains observed since the 1980s.

2.1.2 Economic Rationale⁵

Several arguments have been put forward to suggest that the private sector will not respond to these challenges in the absence of intervention:

- **Network Externalities:** The widespread adoption of low carbon vehicles may require a network of complementary infrastructure. A form of technical ‘lock-in’ will likely emerge

² Thermal Propulsion Systems are an evolution of internal combustion engines that reflect significant advancements in the complexity and interdependency of pre and post combustion technologies.

³ There is in addition a broader strategic case for supporting progression towards low carbon technologies as a route to mitigate the risks associated with dependency on oil reserves (a resource for which the future availability and price are clearly subject to a range of major future uncertainties).

⁴ A number of publications support the role of government in providing subsidies in order to increase the pace of innovation. For example, see Martin & Scott (2000). The nature of innovation market failure and the design of public support for private innovation. Research Policy 29 (2000) 437-447 or Mazzucato (2015). The entrepreneurial state: Debunking public vs. private sector myths. Anthem Press.

⁵ A scoping study for an impact evaluation of the Advanced Propulsion Centre providing more detail on the nature and underpinning evidence for these market failures. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/499865/bis-16-125-apc-scoping-study.pdf

once a technology standard is reached, making investment in R&D projects inherently risky for the sector. While risk may decrease when consensus emerges, there is an incentive for manufacturers to postpone investments to minimise resources spent on developing technology that is not adopted on a widespread basis. However, once such a point has been reached, it is likely that the opportunity for any form of 'first-mover' advantage will be lost (providing a rationale for providing grants for these R&D investments to de-risk pioneering projects).

- **Transactional Frictions:** The development of new forms of propulsion system will likely require OEMs to build relationships with firms outside of traditional automotive supply chains to obtain the required expertise. However, there are a range of market failures that may prevent collaboration emerging, even if the expected returns on investment are sufficiently high. Project success will depend on the commitment of all partners involved, which cannot always be rigorously monitored, creating incentives for partners to 'free-ride' on the activities of others. The outcomes of R&D projects are also uncertain and developing contractual frameworks that cover all eventualities is typically challenging. Additionally, collaborators will rarely be in equivalent positions leading to potential frictions where one partner brings the greater expertise or resources to a project.
- **Knowledge Spill-overs:** Classical knowledge spill-overs might be considered as a factor inhibiting investment in low carbon vehicles. The inability of producers to internalise the full benefits associated with R&D will lead to sub-optimal levels of investment. Knowledge spill-overs may also arise from localised production models resulting from the low inventory processes used in the automotive industry. Initial investments in R&D will create external economies of scale such as labour market pooling and local knowledge exchange, boosting the development of the industry in the UK, including through attracting foreign direct investment⁶. In this case, the presence of these positive externalities provides a rationale for providing public grants to compensate producers and technology developers for those benefits of R&D investment they are unable to capture.
- **International Competition between Governments:** The potential for clusters of expertise has been recognised by several overseas governments which have also developed programmes of support for the development of similar technologies. The availability of analogous support for development of low carbon propulsion technologies in other territories could also lead to an initial concentration of expertise outside of the UK. If these territories build a comparative advantage as a result, investment may be

⁶ For a discussion of these effects, as well as the practical and theoretical limitations of their application see Duranton (2011) California Dreamin': The Feeble Case for Cluster Policies, Review of Economic Analysis.

drawn away from the UK in the long term. Again, publicly funded grants for R&D may help mitigate against these issues.

2.1.3 Theory of Change

This section describes the anticipated processes by which the APC programme will deliver its intended results:

- **Inputs:** The APC involves a ten-year commitment of £1 billion of investment activity into low carbon propulsion technologies (£500m of this capital will be supplied by the public sector, matched by applicants in the form of their own resources, expertise and assets). BEIS and Innovate UK help deliver the APC through providing the staff resources, expertise and platforms employed in co-ordinating competitions for APC funding, assessing applications in terms of their technical quality and value for money (VfM), and monitoring the delivery and performance of projects. Co-ordination of the programme is supported by APC UK. which is funded by a 3.5 percent levy on project costs.
- **Activities:** The activities of the APC can be broken down into two key components:
 - **Competitions for R&D subsidies:** R&D subsidies are allocated through a competitive application process. Applications are appraised for their technical and economic merits, and for value for money. Projects complete a due diligence process and a contracting process and a set of monitoring arrangements are put in place to ensure that spending and project delivery is in line with the initial plans.
 - **Delivery of R&D projects:** The main activities associated with the APC are the implementation of the R&D projects set out in applications. This will largely involve refinement of prototype subsystems and systems of increasing fidelity and in increasingly realistic environments (though some projects may also involve activity at lower TRL levels, such as modelling and simulation activity).
 - **APC UK:** As noted, APC UK. is tasked with coordinating research and development and supply chain activity and provides application support to prospective applicants.
- **Outputs:** APC projects deliver a range of outputs over the course of their delivery (24 to 42 months), including: results of tests of components and systems in increasingly realistic conditions, production prototypes of increasing fidelity, and the development of manufacturing plans and capabilities to produce the systems at low and high volumes.
- **Outcomes:** The APC might be expected to deliver a broad range of outcomes:
 - **R&D expenditure and employment:** The APC may increase R&D expenditure for collaborating partners and create positive short-term employment effects. It may also lead to broader effects in catalysing R&D investment beyond organisations that have received subsidies by demonstrating the technical feasibility of standards.

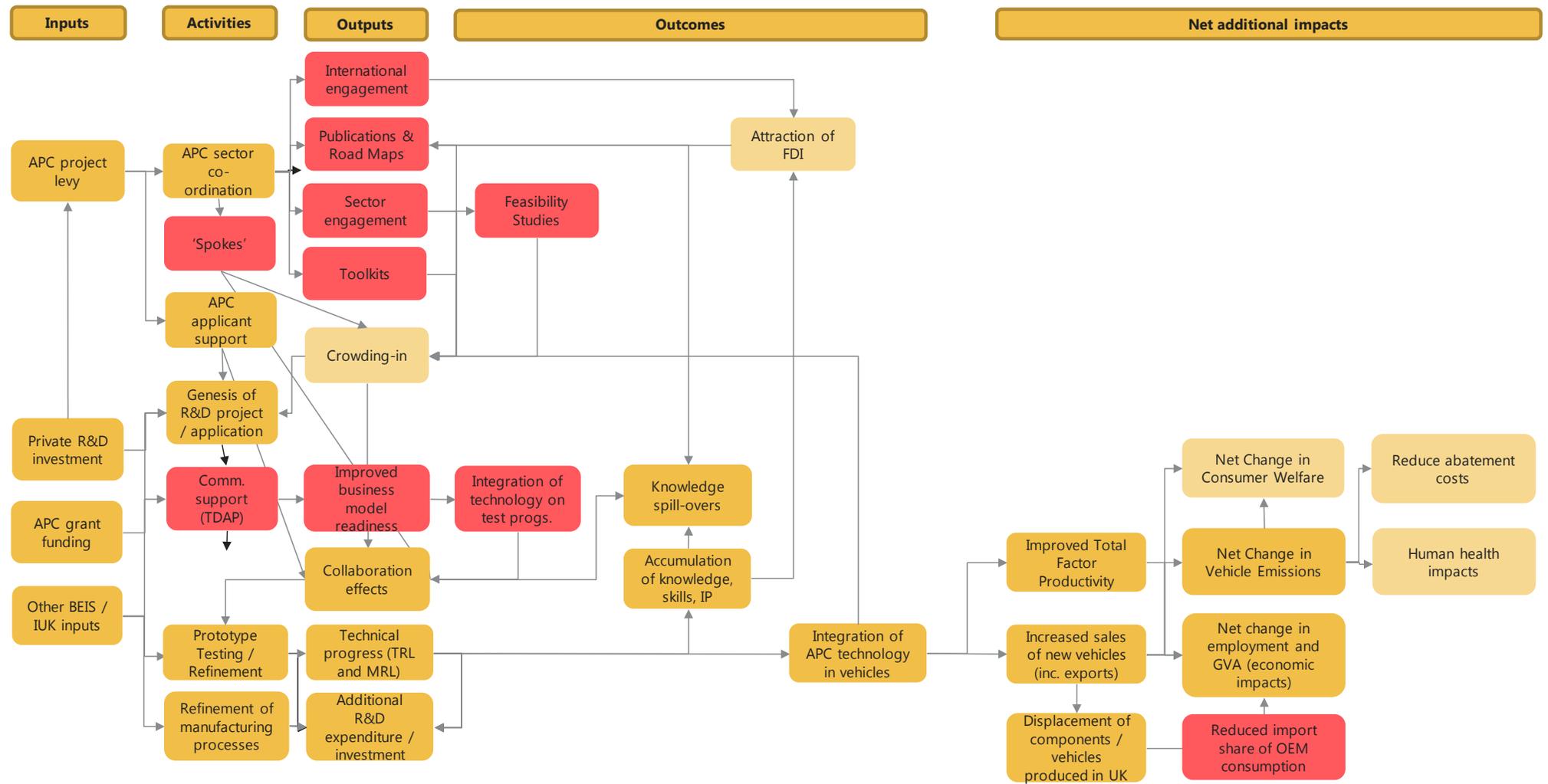
- **Technical Progress:** The APC aims to take R&D projects from TRL5 and MRL 4 to TRL8 and (at least) MRL6, meaning that the propulsion system will have been demonstrated to operate effectively in a working vehicle, and at least to the point at which a manufacturing plan for producing the propulsion system as whole has been prepared. Early stage R&D is an inherently risky activity and a key assumption underpinning the Theory of Change is that APC projects are successful and manage to overcome any arising technical issues. In fact, in the case of innovative R&D in the automotive sector, the associated risk of project failure is commonly thought to be high.
- **Collaboration:** The APC is only open to collaborative applications and the availability of subsidies might be expected to encourage new – potentially enduring - collaborative relationships between firms, or academic institutions (again, potentially involving new entrants to the technology area).
- **Integration of APC funded technology into new vehicle models:** It is anticipated that APC funded technology will be integrated into new vehicle models (contingent on successful completion of the R&D project). This could occur via the integration of the entire propulsion system, or through the integration of individual components developed into an array of new vehicles.
- **Skills Development and Knowledge Transfer:** APC project delivery will likely lead to an accumulation of skills and knowledge amongst the R&D workers involved. In turn, this may lead to feedback effects, either through the genesis of new ideas, building on the technology development, or mediated through knowledge exchange.
- **Attraction of FDI:** The APC may also lead to both direct and indirect effects on foreign investment flows. The grants made available through the programme may be attractive to foreign investors - leading to direct effects on FDI. However, if the APC is effective in supporting an accumulation of knowledge and skills in development of low carbon propulsion technology, it may have knock-on effects in attracting further foreign firms to the UK to locate in proximity to hubs of skills and expertise.
- **Spill-over effects:** The exchange of skills and knowledge between project participants may be applied in other projects, leading to improvements beyond the confines of APC funded projects. Movement of workers between firms may also lead to the application of knowledge or skills acquired elsewhere in the economy. Spill-overs may also arise if competitors can ‘reverse-engineer’ systems in ways that avoids infringement of patent rights.
- **Impacts:** In turn, these outcomes might be expected to produce a range of economic impacts and other improvements in social welfare:

- **Turnover and sales effects:** Where the R&D activity feeds into the production of vehicles with enhanced specifications this should generate sales, resulting in UK manufactured cars securing a greater share of domestic and international automotive markets.
- **Employment and GVA (direct and indirect effects):** OEMs and component suppliers may need to expand employment and output to satisfy additional demand for vehicles integrating APC technologies. To the degree that the systems are manufactured and/or assembled in the UK (or feed into vehicle models assembled in the UK), then these employment and/or output effects will be one of the central economic impacts of the programme.
- **Supply chain effects:** New UK suppliers may develop as new supply chains emerge and this could be observed in reduced reliance of domestically based OEMs on imported components (or increased exports of componentry).
- **Productivity:** The integration of technologies developed may also help firms to raise productivity by increasing the value of output relative to the factor inputs employed in the production of vehicles (presuming that consumers will be willing to pay more for more fuel-efficient vehicles).
- **Emissions, noise and health Impacts:** Positive externalities may arise in the form of improved fuel efficiency, reduced emissions and noise pollution (though these benefits will only be realised by the APC if it displaces the sale of vehicles with inferior technical characteristics).
- **Consumer Welfare:** While improvements in productivity might be captured by firms (through higher profits) or workers (through higher wages), there may also be improvements in consumer welfare driven by reductions in price, or by improvements in quality or fuel economy.

2.1.4 Logic Model

A logic model is presented overleaf, summarising this depiction of the causal process which highlights the range of outputs, outcomes and impacts expected to be associated with the delivery of the APC.

Figure 2.1 APC Logic Model



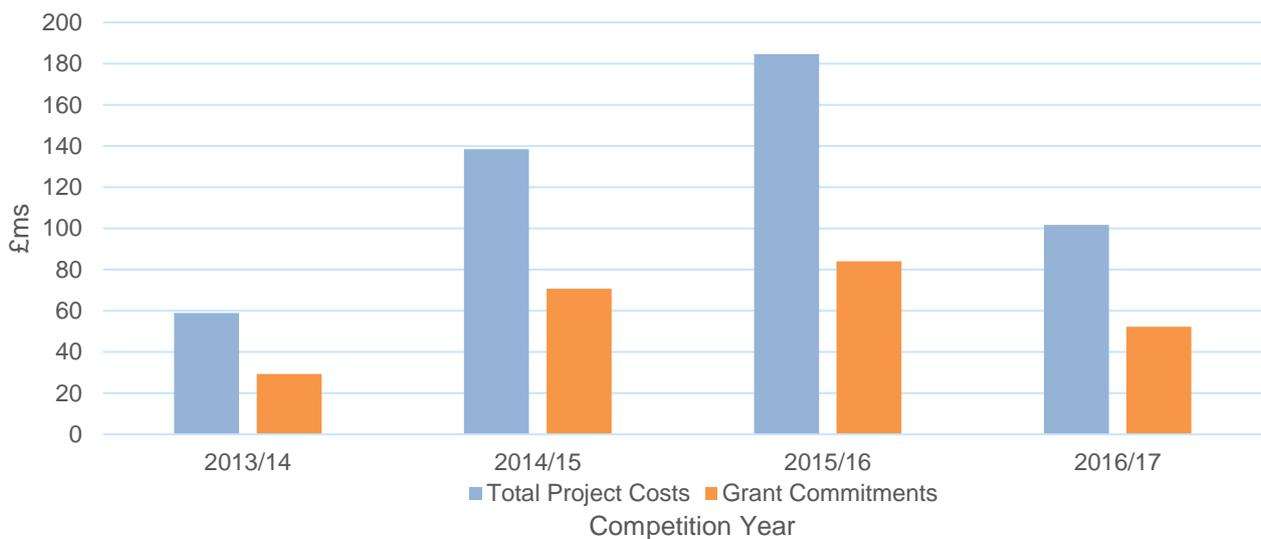
Source: Ipsos MORI (2017).

2.2 Commitment of APC Funds

Forty-seven applications were made to the APC over the first six competition rounds. A further 13 exceptional APC (e-APC) applications were received outside of the normal competition windows. As of July 2017, 31 applications were approved over the first six rounds (an approval rate of 65 percent):⁷

- **Cost and grant commitments:** Grant funding committed to projects totals £245m and matched private sector funding commitments secured also totals £245m. The average grant per project is £8.4m⁸.
- **Yearly distribution of cost and grant commitments:** New public funds committed to projects have risen annually, with the largest number of projects approved in 2016/17 (41 percent). The figure below provides an illustration of commitments over time. Total commitments were highest in 2015/16 (£185m).

Figure 2.2 Total Project Costs and Grant Commitments to APC Projects by Year, Rounds 1 to 6



Source: Innovate UK Monitoring Records: Accessed June 2017 (APC 1 to 6).

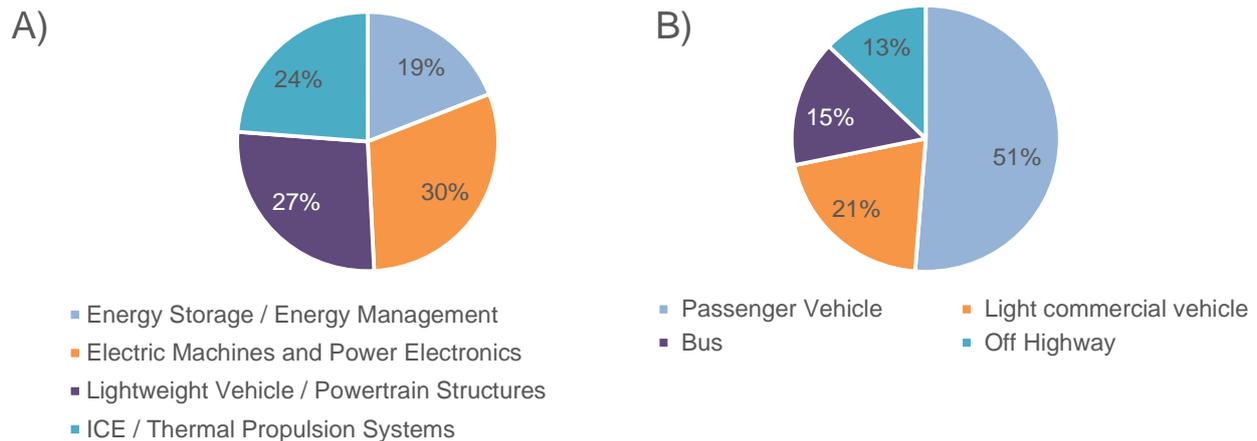
- **Technology focus:** The following figure shows the distribution of work packages associated with APC projects by technological focus (using the APC Technology Road

⁷ Note that while 60 applications were made, the figures presented are based on records of 57 applications that were available for analysis. Two further projects were also approved in 2017 under Round 7 of the APC which are also not included in the following analysis.

⁸ For approved projects where grant amounts set out in the Grant Confirmation Letter (GCL) were unavailable, figures provided in applications were used; average GCL figures are higher grant values by £300k on average.

Map classes for advanced propulsion) and vehicle type.⁹ Projects were evenly distributed between all four core technology areas, though there was an emphasis on passenger vehicles (51 percent). The distribution of grant funding also broadly matched this general distribution.

Figure 2.3 Distribution of Work Packages¹⁰ of APC Projects by Technological Focus (A) and Vehicle Type (B), APC Rounds 1 to 6

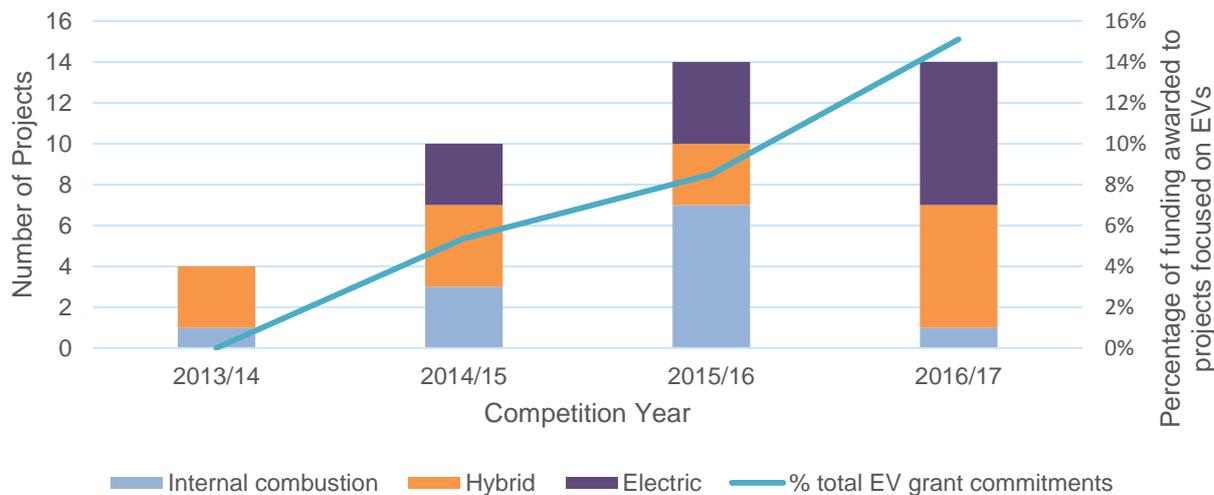


Source: Ipsos MORI analysis of Innovate UK Monitoring Records (2017).

APC projects were also classified in terms of the type of engine into which the technologies under development were intended to be integrated. As the following figure suggests, the portfolio of projects approved has involved an increasing focus on electrification of propulsion systems (a pattern also reflected in grant commitments). However, it should be noted that while electrification projects accounted for a large share of individual projects in 2016, they accounted for a relatively small share of overall funding in Round 6 (14 percent).

⁹ Multicoding has been permitted in these cases.

¹⁰ A single APC project will be made up of a series of 'work packages' that may be delivered in parallel or series. The work packages are defined and agreed at the beginning of the project with the monitoring officer.

Figure 2.4 Distribution of Projects by Engine Type¹¹, APC Rounds 1 to 6

Source: Ipsos MORI analysis of Innovate UK Monitoring Records (2017).

- OEM and Tier One firms:** OEMs and Tier One firms accounted for 32 percent of all partners associated with successful APC applications and 64 percent of total APC funding. Forty-four percent of these firms featured only as a lead on a project; 50 percent featured only as a collaborator; and, eight percent featured as both lead and collaborator on projects. OEMs and Tier One firms were often involved in multiple projects (being involved in 1.4 projects on average).
- Exceptional APC (eAPC):** Five APC projects were approved through the exceptional APC process (an approval rate of 63 percent). Total grant funding committed to exceptional APC projects was £26.4m. eAPC projects scored higher in independent assessments than typical APC projects (80 versus 75) and the categories in which these projects scored highest when compared with APC projects were risk identification, innovation and additionality. On average, APC projects produced just over £8m more in expected benefits than eAPC projects (£28m versus 20m). Overall, the analysis suggests that the eAPC process has not provided any applicant an advantage in securing funding as a result of avoiding a competitive process.

2.3 Expected Benefits

The contractual arrangements for APC projects do not define any expectations relating to technological and/or commercial outcomes associated with project delivery (making it challenging to quantify the anticipated benefits of the project portfolio). However, each

¹¹ In figure 2.4, the blue line provides the share of overall funding awards made to allocated to projects with a primary focus on EVs compared to total funding over time.

application to APC is subject to a value for money assessment as part of the project appraisal and selection process (completed in line with HM Treasury Green Book principles). These assessments quantify the anticipated costs and benefits associated with each project. The values of benefits are estimated using projections of technical performance, vehicle sales, and job creation (or safeguarding) provided by the applicant and adjusted in light of BEIS' assessment of the risks involved and the likelihood the project would proceed without public intervention. These results therefore given some indication of both the applicant's and BEIS' expectations regarding the potential impact of the projects funded:

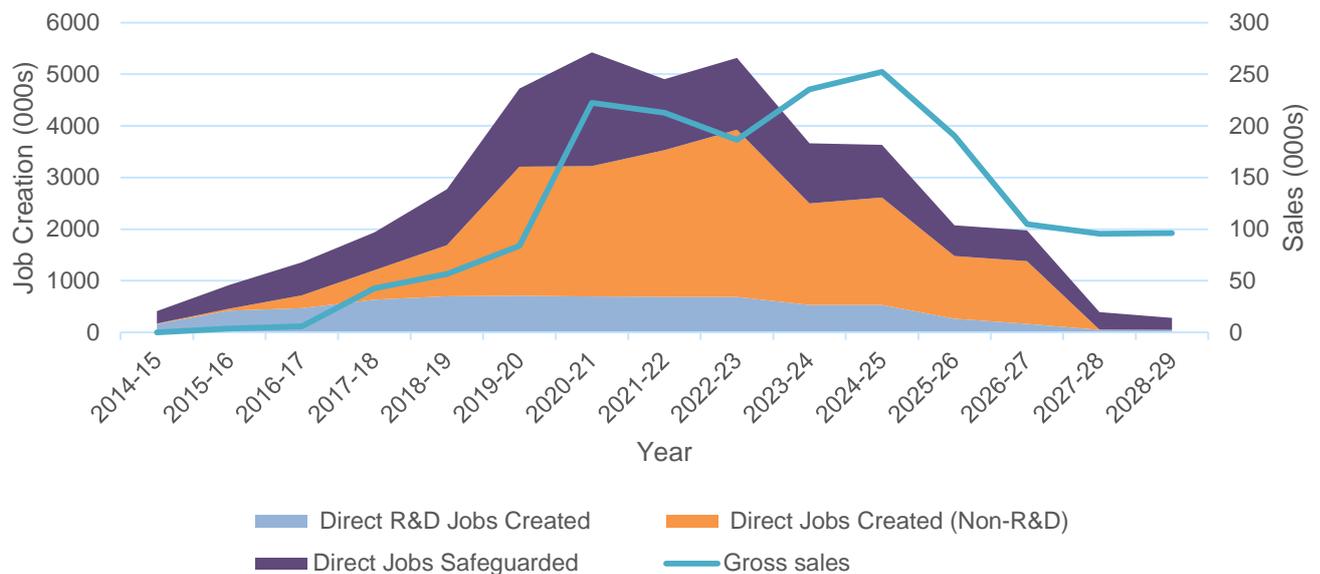
- **Total benefits:** The net benefits expected across the APC portfolio between 2014-15 and 2029-39 total £705m¹², with requests for grant funding made totalling £230m (note that these are the costs upon which the appraisal was based, rather than the level of grant funding ultimately agreed in the Grant Confirmation Letter or subsequent change requests). These estimates are adjusted for deadweight, displacement, substitution, and risk.
- **Distribution of benefits:** These benefits are distributed across a set of different categories: employment, R&D spill-overs, training and other / wider benefits. Other and wider benefits (a category capturing the environmental benefits associated with reduced CO2 and other emissions) account for more than 50 percent of the total net benefits expected (though note that the methodology used to produce these figures changed over time).
- **Vehicle sales:** Applicants also provide projections of sales of vehicles integrating APC funded technology over time. Based on these ex-ante projections, sales were expected to start growing from 2016/17, peaking at an average of 0.7m units from 2023/24 onwards. The implication is that given the timeline for this study, limited exploitation of the technology would expect to be observed (as illustrated in Figure 2.5).
- **Employment:** Applicants also provide projections of the number of direct R&D and non-R&D jobs (largely production jobs) created and safeguarded. As shown in the following figure, gross job creation was expected to peak in around 2020/21 with around 5,200 jobs (employment years) created or safeguarded.¹³ It should be noted that the time horizons over which applicants made these projections differed across proposals (and sometimes across projections for vehicle sales and jobs).

¹² Note that the methodology used to produce these figures has changed over time and basis for these results is not wholly consistent across competition rounds. In addition, analysis conducted by the APC reported that 19,033 jobs had been created or safeguarded. Available at: <http://www.apcuk.co.uk/projects/current-projects/>

¹³ Note that the area under the curve represents the total number gross employment years created or safeguarded.

- Technical performance:** Finally, applicants provided expectations regarding the technical performance of the technologies developed in terms of reductions in emissions. Analysis suggested that CO₂ emissions measured at the tailpipe were expected to fall by just under 40 percent on average (162 CO₂/km).¹⁴ In terms of fuel, the overall net saving is expected to average 0.052 litres per km. Analysis conducted by APC suggests that, in total, 27.4m tonnes of carbon dioxide will be saved as a result of the programme.

Figure 2.5 Time Distribution of Gross Jobs Created or Safeguarded (Employment Years) and Vehicle Sales, APC Rounds 1 to 6



Source: BEIS VfM application forms; Ipsos MORI analysis (2017).

2.4 Project Spending

There is limited quantitative monitoring information available describing the progress of the project portfolio against these expectations beyond data on the defrayment of grant. As of July 2017, data available for 25 projects¹⁵ suggests that £183m in grant funding commitments have been made, with a spend of £72m.¹⁶

¹⁴ The average is unweighted by vehicle sales.

¹⁵ At the time of writing, the Innovate UK grants database only provided data on 25 APC projects – this source was more up-to-date than records provided by the APC, which only recorded up to February 2017. The study team suspects that the Innovate UK source contains incorrect entries.

¹⁶ UK Gov (2017). Innovate UK Online Grants Database. This result is likely to be an underestimate of total spending, given that several projects for later competition rounds had secured funding during the study period and the time-lag associated with the online database. APC data from June 2017 reported, that for 24 projects, £184m in grant funding commitments had been made, with accrued spend of £94m.

The available information does not capture profiled spend. On the assumption of a linear spend profile, £114m should have been drawn down by projects (indicating an underspend of £42m). However, when the analysis is restricted to those projects that have been completed, 97.5 percent of the committed grant was spent. This could be suggestive that projects are more likely to experience delays rather than face severe risks to delivery. It should be noted that many projects will not have linear spend profiles and there may also be delays in the submission of claims and recording spending, and some projects may only decide to make grant claims at the close of projects. As such, the available monitoring information cannot be used to make clear inferences regarding how far projects have been delivered to expected budgets.

2.5 Context

This section provides an overview of the wider context for the programme.

2.5.1 UK Automotive Sector

The UK automotive manufacturing sector¹⁷ contributed £15.9bn to the UK economy and grew by 24 percent in real terms since 2007.¹⁸ The Society of Motor Manufacturers & Traders (SMMT) reported that in 2016, the UK was the 13th largest car and commercial vehicle manufacturer (1.82m) in the world and the fourth largest in Europe (behind Germany (6.1m), Spain (2.9m) and France (2.0m)).¹⁹

The performance of the sector improved substantially between 2010 and 2016 (as illustrated in the following figures). It employed 155,000 in motor vehicle manufacturing in 2015 (an increase from 135,000 in 2009)²⁰. The sector also saw the value of exports rise from £29bn to £40bn over the period (with automotive exports accounting for just under 10 percent of total UK production). Reliance on imports has also fallen with 44 percent of parts used to make cars in the UK produced by UK suppliers in 2017, an increase from 41 percent in 2016.²¹

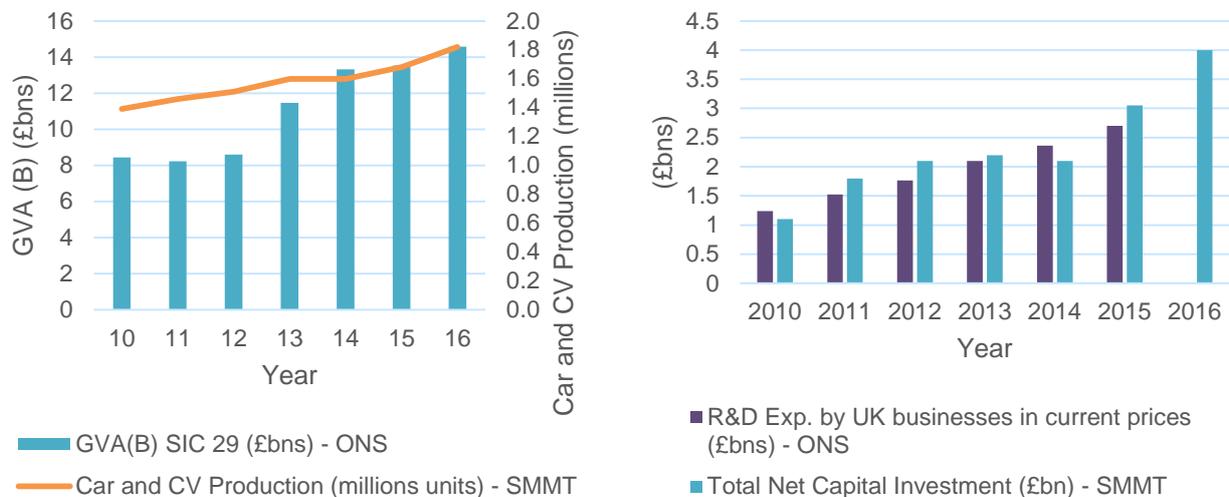
¹⁷ Defined using SIC 29: Manufacture of motor vehicles, trailers and semi-trailers.

¹⁸ ONS. Quarterly National Accounts. Low level aggregates.

¹⁹ SMMT (2017). UK Automotive Sustainability Report.

²⁰ ONS (2016). Business Register of Employment Survey.

²¹ Automotive Council (2017). Growing the Automotive Supply Chain: Local Vehicle Content Analysis.

Figure 2.6 UK Automotive Sector: Output and R&D

Source: SMMT (2017); ONS (2017).

Growing output and productivity has also been accompanied by increasing R&D spending. Office for National Statistics figures indicate expenditure on business R&D in the automotive sector increased from £0.9bn to £2.5bn between 2000 and 2016. The sector has been the second largest (in terms of pounds invested) area of R&D spend in the UK since 2013, after pharmaceuticals (£4.18bn).

2.5.2 Technological Drivers of Change

As a key contributor to emissions, the automotive and transportation sectors are a key area in which transformative low carbon propulsion technologies will be needed. A 2013 horizon scanning exercise by the Automotive Council and Government identified requirements for advances in the key technology areas in the table below.

Table 2.1 Key LCV Technology Areas

Key Technology	Description
Development of Thermal Propulsion Systems (TPS)	Incremental improvements to the efficiency and emissions control capability of combustion engines are a key priority for the UK to support the transition to LCVs (especially true for heavy-duty commercial vehicles).
Energy storage	The UK has expertise in the early stage development of EV batteries. A key focus for R&D is developing an understanding of how to produce at scale both effectively and efficiently. Beyond the Nissan battery plant in Sunderland (largely supplying the Leaf), the capability of the UK to produce at the required scale and unit cost is limited.
Kinetic energy recovery systems	The advancement of hybrid and EV vehicles, coupled with their increased use, has resulted in a set of opportunities related to the development of kinetic energy recovery systems (KERS), whereby a moving vehicle's recovered energy is recaptured and stored (i.e. in a flywheel or battery) to be used at a later point.

Key Technology	Description
Electric machines and power electronics	A range of power electronics, including stop/start functionality, low cost electronics, accessory electrification, and power electronics to drive motion, are all emerging technologies in the automotive sector.
Light weight powertrain structures	Emissions standards and improved efficiency can also be partly achieved through continual lightweighting of the powertrain whilst maintaining the required material strength and flexibility. While lightweighting of vehicle shells through the development of novel alloys is common, miniaturisation and downsizing of all vehicle components (including engines, components packaging, power electronics and other drive train components) has been a key technological trend in recent years.

Source: Low Carbon Automotive Technologies, BEIS and Automotive Council (2017).

In addition, the following key sector trends were identified:

- **Manufacturing:** There is an increasing focus on improving the efficacy and efficiency of UK manufacturing (i.e. the use of real time enterprise management software) and the introduction of advanced manufacturing technologies (i.e. robotics, additive manufacturing, AI, advanced testing and measurement).
- **Alternative fuel infrastructure:** The number of EV charging points increased from just over 1,500 in 2011 to 13,415 in 2016 (across 4,682 unique locations).²² While this represents an increase of 800 percent, a key challenge relates to how far the spatial distribution of the various types of charging point is optimal given local needs. The Government has also committed £23m in investment to support the development of infrastructure to support the use of hydrogen powered vehicles – though there were only nine publicly accessible hydrogen refuelling stations on UK roads in 2016.
- **Recycling:** The introduction of EVs and a growing vehicle repurposing industry creates further issues regarding the lifetime of vehicles, including a rising vehicle age (14.1 years in 2016) which will have implications for the introduction of new technologies to consumers.

2.5.3 Wider Context

A range of wider policy and contextual drivers have influenced the characteristics of demand for lower carbon propulsion systems:

- **The Climate Change Act of 2008:** As highlighted above, this piece of UK legislation places a legal requirement on the UK to reduce its carbon emissions to 80 percent of 1990 levels by 2050. It is estimated that this will require all vehicles in production to be produced to zero emissions by 2040, and was a key driver of the introduction of the APC.

²² Zap-Map (2017). Date accessed: 14/08/17.

- **Diesel Cars:** The introduction of new vehicle tax rates in 2001 created incentives for consumers to adopt diesel vehicles, with the goal of reducing CO2 emissions. However, while this policy was apparently effective in increasing demand for diesel powered vehicles, this came with a trade-off of an increase other pollutants, including a set of nitrogen oxides such as nitrogen dioxide. These pollutants have had an adverse effect on air quality, and in July 2017, the UK Government announced plans to ban the sale of new purely diesel and petrol powered passenger cars from 2040. This policy has led to some concerns over the degree to which the national grid will be able to accommodate a mass shift towards EVs, especially during peak periods. Another issue relates to the ability of the UK automotive supply chain to accommodate this shift at sufficient scale, as discussed in Section 3.

Wider contextual factors

A set of wider contextual factors are also likely to have influenced the outcomes of the APC to date:

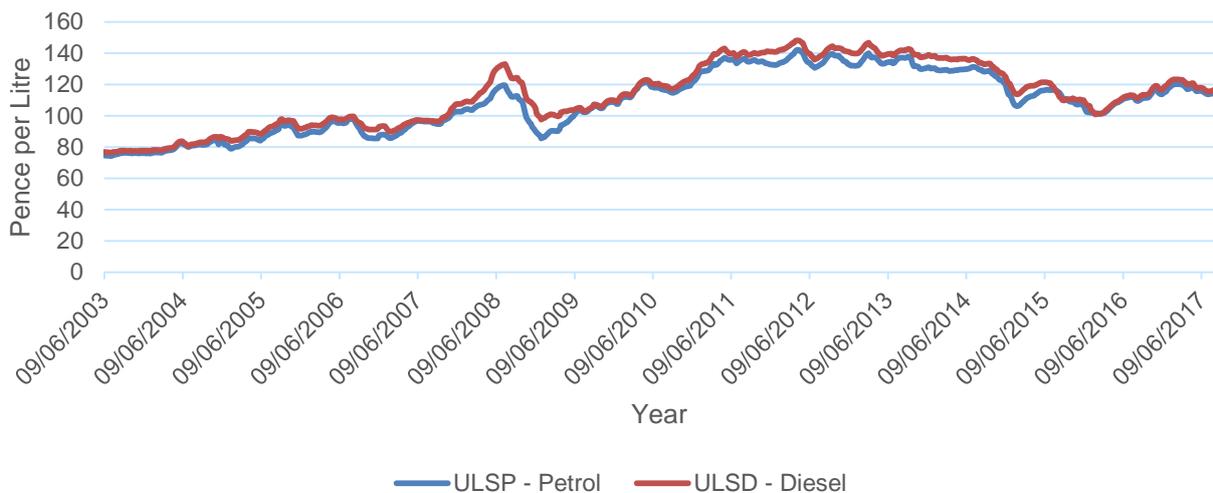
- **Departure from the European Union:** The UK's departure from the European Union creates uncertainties for the sector given the prevalence of foreign owned producers that use the UK as a base to access the EU market. Stakeholders reported concerns that departure from the EU could increase the price of factor inputs as sterling weakens against the euro, resulting in rising production costs, especially for those manufacturers that rely on European imports. In addition, UK automotive firms were expected to revise their business plans to have a more international focus with the view that the barriers to trading with Europe would increase, at least in the short term. However, against this, a weak pound would increase UK exports and could provide more opportunities for mergers and acquisitions and improved international trade agreements²³ - and growth in global demand for low and zero carbon powertrain and vehicle technology is forecast to continue.
- **'Diesel-gate':** In September 2015, the US Environmental Protection Agency issued the car manufacturer Volkswagen with a notice of violation of the Clean Air Act, US law aimed at controlling air pollution at the national level. The German vehicle producer was found to be guilty of introducing emissions controls in vehicles only during lab emissions testing, specifically for nitrogen oxides, and accepted fines totalling \$2.8bn. The scandal was catalytic in raising government and public awareness over emissions produced by the passenger vehicles and led to further inquiries to explore how far other producers may have breached the Clean Air Act, including Volvo, Renault and Jeep. In addition, a new emissions test is expected to be launched at a global level to ensure that results

²³ [Lloyds \(2017\). Automotive Research Report 2017.](#)

reflect real world performance²⁴ which will require significant revalidation testing throughout the industry.

- **Fuel Prices:** In Spring 2015 diesel and petrol prices fell to their lowest levels since 2010, as shown below. Decreases in shale oil prices are a function of overproduction by OPEC countries and low demand from major global economies given slow (or negative) rates of economic growth.

Figure 2.7 Vehicle Fuel Prices - UK



Source: UK Government (2017).

- **Local air quality:** There is evidence that links low air quality with long term health conditions²⁵ and negative environmental impacts.²⁶ Although air quality has improved in recent decades (i.e. UK nitrogen oxides emissions fell 19 percent between 2010 and 2015), there is still unequal access to clear air across the country. For example, 1.9 million people in London in 2013 were exposed to annual average NO₂ concentrations above the EU limit value of 40 µg/m.²⁷ The current government response to this issue is to enable local authorities to tackle local occurrences of bad air quality through the development of a national guiding framework and direct financial support.²⁸

²⁴ [WLTP.EU \(2017\). WLTP Facts.](#)

²⁵ Public Health England (2014). Estimating local mortality burdens associated with particulate air pollution.

²⁶ DEFRA (2016), Provision of Mapping and Modelling of Critical Loads and Critical Levels Exceedance 2016-19.

²⁷ London Data Store (2017). Bespoke borough by borough air quality modelling and data.

²⁸ DEFRA & DfT (2017). UK plan for tackling roadside nitrogen dioxide concentrations. July 2017.

2.6 Summary

- The Advanced Propulsion Centre (APC) was launched by the UK Government and the Automotive Council in 2013 as part of the Coalition Government's Industrial Strategy. The APC had the objective of supporting R&D into low carbon propulsion technologies, anchoring and attracting R&D capability in the UK and leveraging high value manufacturing opportunities that market exploitation may provide. The APC is comprised of two key elements: £1bn in funding commitments from the public and private sector to support R&D and the creation of APC Ltd, an independent body tasked with the coordination of the sector and wider R&D activity. The services offered by APC Ltd now include support for applicants in engaging with the competition process and assistance with the development of consortia bids, a Technology Developer mentoring scheme, development of communities focussed around strategic technologies (spoke network) and co-ordination and management of International Events. A review of those activities is outside of the remit of this study.
- Funding is allocated by the APC through a competitive process. Applications made by industry-led consortia are appraised by independent assessors coordinated by Innovate UK. Successful applicants then complete a contracting and due diligence process which entails a quantitative value for money assessment. While the production of R&D outputs is expected to produce a set of knowledge and R&D employment and training benefits, economic and environmental benefits are only expected to be achieved through the integration of APC funded technology into vehicle production programmes.
- £245m in grant funding has been committed to 29 projects, with approximately £72m spent by February 2017.²⁹ Funding is distributed evenly across APC key technology areas and over 50 percent supports the development of technologies for application in passenger cars. While projects were initially focused on TPS, the proportion of funding allocated to projects developing EV propulsion technologies has increased from 0 to 15 percent as the programme has evolved. The benefits expected across the APC portfolio between 2014-15 and 2029-39 total £705m, with grant funding for these projects totalling £230m.

²⁹ APC data from June 2017 reported, that for 24 projects, £184m in grant funding commitments had been made, with accrued spend of £94m.

3.0 Project Delivery

This section provides an analysis of the delivery of APC funded projects and the range of obstacles and barriers encountered (including the costs and benefits of the collaborative relationships emerging). It also explores the key motivations of applicants and the strength of the case for public funding. The section is based largely on the evidence gathered from the ten case studies.

3.1 Motivations for applying to APC

The evaluation identified three key motivations driving applications for APC funding:

- Commercial objectives to launch new LCV products to market,
- Overcoming the challenges of integrating new technologies into real world applications, and,
- Interest in developing LCV supply chain capabilities.

3.1.1 Launching new Low Carbon Vehicle Products

Most applicants reported they were seeking to integrate low carbon technologies into new product launches to help ensure that firms remain competitive in light of expected changes in carbon emissions legislation, and in some cases, anticipated growth in consumer demand for LCVs. These product launches formed part of both aggressive and defensive commercial strategies:

- **Aggressive commercial strategies:** In these cases, applicants were seeking to acquire a first mover advantage to increase their market share in a key segment(s) or enter a new market in which they had little presence. For example, one applicant hoped to support the launch of a variant of the diesel Euro six engine with electrical systems to support improved fuel economy in its application in buses and light commercial vehicles. In another example, a project hoped to introduce a superior flywheel technology to claim a greater share from dominant overseas producers of off highway equipment by offering customers greater fuel economy.
- **Defensive commercial strategies:** In such cases applicants reported the need to take defensive measures to catch-up with overseas competitors that had already commercialised low carbon propulsion technologies. One OEM reported that they would have been unable to compete on price per performance without developing the technology, given that their chief competition had already hybridised its diesel engines.

However, not all projects involved the development of a new product. For example, one project led by an SME technology developer sought to prove a zero-carbon propulsion system using an alternative fuel to the point at which it could secure a licensing deal with an OEM. Additionally, some projects were focused on technology transfer objectives, building capabilities to produce technologies that had already been materially developed overseas.

3.1.2 Resolution of Technological Challenges

In general, applicants sought funding from the APC to help them resolve key technological challenges associated with the technologies being tested. While applicants had generally developed technology demonstrators that were operational in a relevant setting (TRL5), substantial R&D programmes were required for three key reasons:

- **Overcoming the challenges of integrating new technologies into real world applications:** Many of the technologies under development had not been tested in real world conditions and performance issues were anticipated. In one case, retrofitting a power module onto a diesel engine (required to support start-stop functionality, a novel feature in this market sector) faced the challenge of ensuring the electronics of the system could still function under stressful conditions (high levels of heat and vibration). In another case, a set of issues were identified in attempting to fit batteries to support accessory electrification and hybrid functionality, especially in space constrained small passenger cars and light commercial vehicles. Elsewhere, a project aimed to apply advanced powertrain concepts to a gasoline engine. This application involved the development of single cylinder valve deactivation to achieve significant fuel economies in this class of TPS. The project sought to resolve challenges relating to thermal management, NVH (noise, vibration and harshness) and managing differential torsional vibrations.
- **Reduce manufacturing costs to an acceptable unit price:** In some cases, the systems under development were too expensive to produce given the fuel economy savings they generated (and sometimes could not be produced at scale). Many projects involved objectives to drive down the unit cost of production to a price point that would be acceptable to the consumer. For example, an operational novel zero carbon piston engine developed by one project required considerable additional cost efficiencies for the technology to be economically viable for application in several markets outside the automotive sector. This was because of the weight and bulk of the fuel source used (nitrogen) and the manufacturing cost of key components such as the containment tank (the cost of which needed to be decreased by 90 percent).
- **Technology verification in an operational environment:** While technologies had been tested in operational environments, further R&D was required to validate and evaluate technology performance given the cost increment. For example, one project aimed to deliver a proof of concept fleet of EV vans to test market viability. Part of this work involved the evaluation of build systems in an operational setting through the

collection and analysis of performance data, the results of which were used to refine system configurations before being able to begin commercial roll out. Another project looking to launch a new fleet of hybrid and EV high-end passenger cars needed to evaluate a range of technologies which were under development to assess their readiness for commercial integration, including an advanced electric motor, power control, range extender and a KERS system.

3.1.3 Enhancing UK Supply Chain Capabilities

Several projects had the intention of enhancing UK automotive supply chains, especially with respect to the manufacture of LCV technologies. The case study research highlighted that projects intended to do this by building or upgrading production facilities in the UK and developing the capabilities of SMEs to become large scale suppliers.

3.2 Alignment with Corporate Strategy

The evaluation highlights a set of emerging themes relating to the strategic direction of automotive OEMs and Tier One firms, focussed on the future of passenger cars, buses and off-highway vehicles:

- **Transition to electric vehicles:** Lead applicants and stakeholders reported a view that major OEMs now view electric vehicles as the future technology standard in many vehicle segments. This was thought to have substantially influenced the R&D agendas of major firms (and is visible in the changing nature of APC applications which is illustrated in Figure 2.2). The evidence suggests that external pressures to transition to EVs were most acute for premium vehicle OEMs given greater fuel demands. However, some case study interviewees suggested that the TPS market could still be important in the medium term – particularly for smaller and lower margin vehicles where the economics (and practical issues) of electrification are more difficult. Applicants also suggested that the demand for EVs is not currently sufficient to incentivise a full transition to new propulsion systems. For example, one OEM highlighted that existing EV models sell 50,000 units annually in comparison with a comparable TPS model which sells millions of units annually. Other barriers highlighted included constraints of the capacity and capability of the UK LCV supply chain and the ability of the national grid to support increased electricity demand.
- **Evolution of technology standards for buses:** It was reported that since 2014, the UK bus market has seen a major shift away from improving the efficiency of diesel engines and hybrids to zero carbon solutions. Previously, an array of hybrid solutions were being explored, such as hybridisation of new or retrofitted diesel engines – using KERS (i.e. flywheel development), start-stop functionality and accessory electrification. However, increasing pressures to reduce emissions have resulted in the acceleration of zero carbon solutions such as EV and hydrogen buses. Some applicants engaged suggested that while previous roadmaps had identified that EV buses would enter the market in 2035, these pressures have now brought these expectations forward to 2018.

- **HGVs and off-highway vehicles:** The transition towards EV vehicles has significant challenges for HGVs or off-highway vehicles because of the technical and commercial issues associated with the application of LCV technologies. This is reflected in the APC portfolio monitoring records which indicated off-highway vehicle projects represent the smallest share of total grant funding. The case study research identified that, although some projects are supporting speculative low carbon solutions for these vehicle types, the projects involved have all revised their exploitation plans to reflect the fact that the route to market for some technologies is still unclear or uneconomic. For example, a project developing KERS encountered technical difficulties with associated systems and economic difficulties as a result of decreasing diesel prices in 2015 which would have extended the payback period and made the system less attractive to potential operators.

3.3 Project Origins

As indicated in Section 2, the focus of the APC funding is to support the development of technologies that have already achieved TRL5 (technology validated in an operational setting) for partner vehicle programme adoption. The case study research highlighted that just under half of the case projects had developed the intellectual property underpinning their APC project with public collaborative R&D funding, for example, from EPSRC and Innovate UK:

- **Integrated Delivery Platform (IDP) funding:** The case study research suggested that funding administered through IDP supported the early development of many APC projects. IDP funding was used to support the demonstration of technologies, resolution of ongoing technical issues and the development of prototypes (and collaborative relationships carried forward into APC projects were often formed at this stage). For example, one project that sought to develop a flywheel KERS for retrofitting in buses sought to build on a previous IDP project that demonstrated the performance of a flywheel hybrid bus prototype. In another case, a project was underpinned by three IDP grants that had developed a prototype and tested the efficiency of a zero-carbon piston engine driven by liquid nitrogen.
- **Technology Development Accelerator Programme (TDAP):** At the start of 2017, TDAP was launched to fast track low carbon technology to market. The programme was launched to address increasing concerns that a number of barriers prevent innovative firms from entering the automotive sector. It does this by building the capabilities of innovators to assess market requirements, develop value propositions, provide access to professional networks and provide mentoring and wider funding support. The first pilot is complete, and the second wave was due to open in Autumn 2017. The programme has reportedly engaged one new university spin out, SMEs and sometimes ventures of larger enterprises. At the time of writing, one TDAP project had successfully developed into an APC project.

- **Advanced Manufacturing Supply Chain Initiative (AMSCI):** Some projects receiving APC funding have also had AMSCI funding for capital equipment to produce the technology.

These precursor projects sometimes demonstrated the validity of technologies, helped rule out competing technological solutions, and identified a set of logical progressions for future R&D programmes. For example, the idea for one case project originated in an Innovate UK funded project that allowed the lead applicant to evaluate the available technological options for possible uses of a technology in off-highway vehicles. The applicant was able to show that competing solutions were either not efficient or did not recover a high share of the potential energy generated by the movement of off-highway vehicles. Projects that received previous UK public funding scored higher in the Independent Assessment, particularly in relation to the technical approach to be adopted and how the project would be managed.

The underpinning technology for some projects originated in R&D programmes which had been funded privately and/or developed overseas, such as in the US, Japan or China.

3.3.1 Role of APC Ltd. in the Genesis and Development of Project Ideas

The evaluation provides evidence that APC's LCV strategy is industry-led. The case study evidence highlighted that several OEMs and Tier One firms were consulted during the development of the APC and Technology Road Maps. As such, the APC strategy was thought to reflect existing corporate strategies rather than directly exerting influence on the UK automotive sector with respect to R&D spending. However, as the role of APC Ltd has expanded, stakeholders were of the view that its strategic activity is now beginning to have an influence over the direction of R&D in some areas.

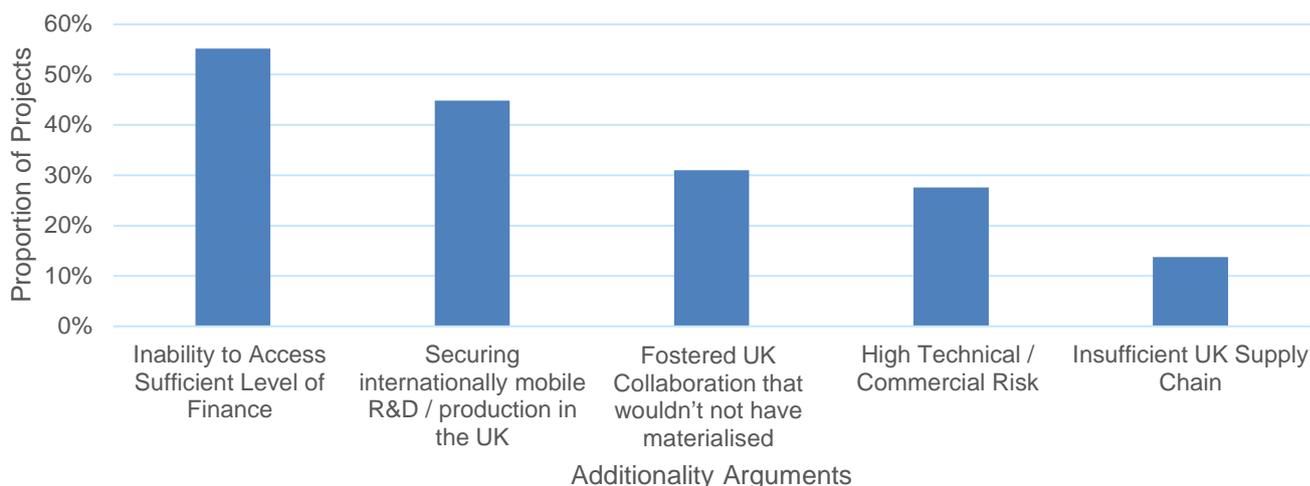
The evaluation found that APC UK has played a minimal role in the formulation and development of project ideas as well as only a limited role in supporting the completion of quarterly monitoring reports.³⁰ Case study interviewees suggested that support for applications has been provided in an ad-hoc manner when needed by applicants rather than supplied uniformly to all, and has mainly taken the form of feedback on the development of applications. For example, APC UK has advised applicants on the inclusion of a proportional number of SMEs in the project consortium and provided guidance on the balance between capital and current expenditure in financial application forms. This feedback was reported to have been provided in a timely manner to applicants who suggested that it aided the successful completion of later stages of the application process (such as the interviews with the Independent Assessors).

³⁰ It should be noted that earlier competition rounds were delivered whilst APC UK was not fully operational.

3.4 Input Additionality

All applicants for APC funding are required to specify the level of funding required to deliver projects and make a case that justifies why public funding is needed (i.e. why the project would not have proceeded anyway). The figure below provides a summary of the key additionality arguments made by approved APC project applicants³¹:

Figure 3.1. Additionality Arguments made in APC Application Forms



Source: Ipsos MORI analysis of APC application forms (2017).

- **Access to a sufficient level of finance:** Access to finance was a common issue reported by those interviewed. Finance raised different challenges for large firms, SMEs and academics:
 - **Large firms:** Large OEMs frequently suggested that, in the absence of APC funding, R&D resources would often have been allocated over a longer period. This may have had commercial implications if projects did not develop at the same pace or scope as those of their (often subsidised) competitors. In one case, it was suggested that the absence of funding would have likely resulted in a delay in the introduction of hybrid engine models by two to three years and diminished sales of the TPS model due to increasing competitive pressures as more hybrid models enter the market. Following the rejection of an APC application, another OEM decided to shelve the proposed programme of development and import the required systems from a competitor because they would have otherwise been unable to mature the technologies over the required timescales.
 - **SMEs:** The research suggested that access to external finance was a particularly acute issue for SMEs that are typically reliant on larger firms to fund multiple large-

³¹ Arguments are multi-coded; the sum of column percentages will be greater than 100.

scale R&D programmes (which in turn, limits the range of R&D programmes that OEMs are able to support). In addition, VC investors were reported to have little appetite to support industrial or advanced manufacturing projects, given preferences for five-year payback cycles and lack of expertise in supporting hardware ventures. For example, one SME supporting the development of a flywheel technology suggested it could not have completed the R&D without funding from the OEM as the maturity of the technology presented a level of technical risk that would not be acceptable to a prospective venture capital investor. It was also reported that SMEs struggled to make use of debt and equity products because of their inability to provide the appropriate levels of collateral to providers.

- **Academics:** In the case of academic collaborators, the cases were unanimous that their project work packages would have been unlikely to go ahead. This was because of the strong complementarities that exist between the academic and industry led work packages and the large funding dependency which academic institutions have on external funding and private support.
- **Securing internationally mobile R&D and/or production in the UK:** Large OEM and Tier One manufacturers identified that they also faced internal competitive pressures from sites in other countries with respect to budget and project allocations:
 - **Global internal competition:** Intense internal competition for resources faced by country divisions was reported by several respondents. The evidence provided some suggestion that internal decisions relating to investment and production are made using strict criteria and a quantitative assessment of the costs and benefits where feasible. To illustrate this point, one UK based production plant had previously failed to compete with an overseas counterpart for the production of a new EV battery and subsequent APC funding has proved insufficient to attract a second battery line to the UK. In the absence of funding, OEMs reported that internal competition may have resulted in the project being delivered overseas. Competing countries highlighted were China, Germany, India, Japan and the US.
 - **Insufficient capability of the UK supply chain:** Reiterating the issue highlighted in 3.1.1, weaknesses in the UK LCV supply chain can disincentivise private investment. The case studies suggested that the strength of the supply chain was often a key determinant in deciding the location of a new vehicle programme. In one case, the UK's supply-chain capability in EV production relative to that overseas was highlighted as a risk at the application stage of a project focused on EV development. A 'gateway review' to examine the technological and production capability of UK suppliers confirmed that resourcing production within the UK would be difficult at the required component volumes given the timeframe of the project. As a result, the project was put on hold.

Difficulties in evaluating the validity of these arguments should be noted. One large OEM made a case for funding on a 'gap funding' argument, based on the relative costs of upgrading facilities in other regions. However, the producer went on to develop additional production facilities in those locations anyway and, given the expected benefits associated with increased security of supply, there are questions regarding the validity of the gap funding argument which was put forward. In another case, the applicant suggested they would take the project forward at an R&D facility elsewhere in the EU. However, a suggestion was made that the competing facility would not have had offered the level of capability needed to deliver the project (again, raising questions regarding the validity of the argument).

- **Transactional frictions preventing collaboration:** Some applicants also suggested that public funding was needed to fund the involvement of collaborators (for which funds could not be secured internally), as a variety of partners, especially SMEs, would not be able to complete R&D at scale without OEM funding. Again, it is difficult to assess the validity of these claims. For example, the use of collaboration agreements supported the safe management of IP ownership issues when working with academics and SMEs.
- **High technical and/or commercial risk:** R&D programmes focused at TRL5 and above often need to resolve residual technical issues. As such, they still exhibit high levels of risk and uncertainty. It was suggested that this may make it difficult to secure funding from internal and external sources. The case study evidence validates this point as OEMs were suggested to have relatively small internal R&D budgets - because R&D is not an immediate profit making activity – as well as a tendency to be risk averse. To illustrate this point, one project aimed to apply advanced power train concepts to the lead applicant's gasoline engine to accelerate the introduction of low carbon engines to the market approximately three years ahead of proposed legislation. The research suggested the OEM would have selected a safer and more expensive route to meet changing emissions legislation if the options pursued had not been de-risked by grant funding.

The additionality arguments made by applicants are reviewed as part of the VfM appraisal discussed in Section 2. The evaluation provides some indication that VfM assessments are internally consistent and appropriately conservative. Analysis of appraisal records suggested that the gross additionality of the APC portfolio was thought to be 38 percent on average, meaning that 62 percent of the project outcomes were expected to have materialised in the absence of grant funding.

3.5 Collaboration

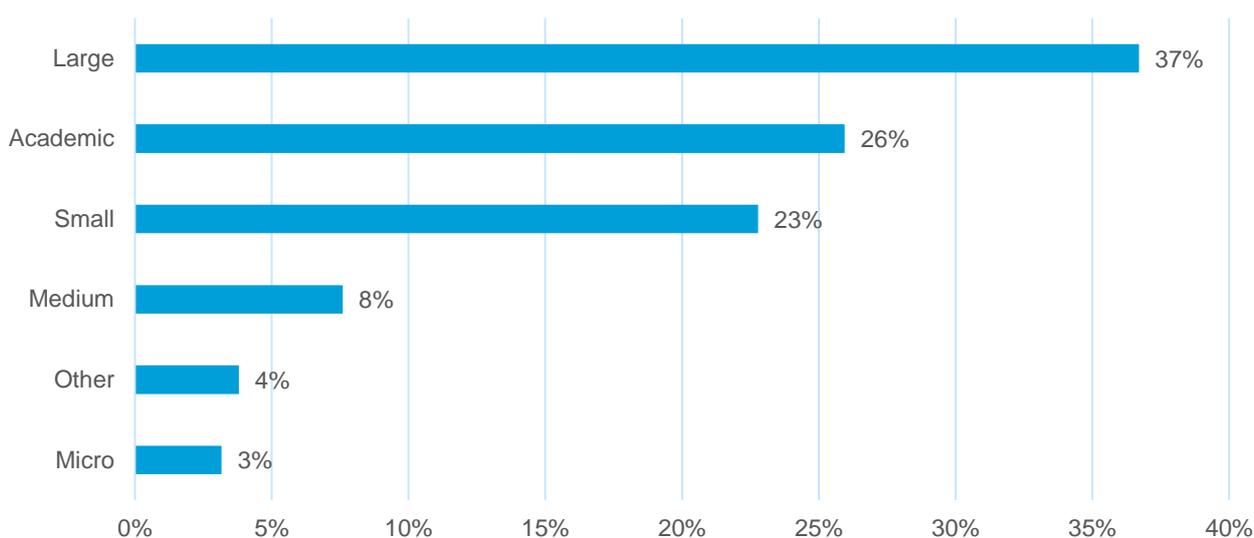
The APC requires that applicants submit collaborative proposals to be eligible for funding (and this requirement also aligns with State Aid requirements under the General Block Exemption Rules). These requirements were introduced in acknowledgement that development of the technologies would require inputs from outside of traditional

automotive supply chains, and that requirements for collaborative activity could help anchor R&D activity within the UK (potentially helping to reverse the ‘hollowing out’ of the UK automotive supply chain observed since the 1980s). This sub-section provides an analysis of patterns of collaboration within the APC project portfolio, the roles of partners, and the costs and benefits associated with working in collaboration.

3.5.1 Distribution of Collaborators

The total number of partners (excluding lead partners) involved in the delivery of APC projects is 155 (five per project on average, though ranging from two to ten). While over 80 percent of project leads were large firms, there was more variability in the composition of partners. Large firms still make up the highest proportion of collaborators (37 percent), SMEs account for around 33 percent of partners and around 26 percent of partners were academic institutions. The distribution of grant funding among collaborators follows an almost identical similar pattern.

Figure 3.2 Distribution of Partners



Source: Innovate UK Monitoring Information (2016).

A key question for the evaluation is to what degree APC has been effective in facilitating relationships with SMEs outside traditional automotive supply chains? The evidence suggested that the APC portfolio is primarily comprised of firms already in the traditional automotive supply chain, either in an R&D or manufacturing capacity. This judgement was developed through an analysis of primary SIC codes and analysis of case study

evidence.³² The SIC code analysis suggested that the SMEs involved broke down into three groups:

- **Manufacturers:** Around 57 percent of SMEs are classed as manufacturers. A review of the SMEs indicated that all were already active in the UK automotive supply chain (predominantly in the manufacture of electrical and electrical equipment for motor vehicles or manufacture of other special-purpose machinery). Of these, 14 percent had a direct involvement in the manufacture of motor vehicles, trailers and semi-trailers³³. The evaluation identified few instances where manufacturing collaborators had not previously worked in the automotive sector. However, the case study research did identify an instance where a large semiconductor firm, previously unengaged in the automotive sector, was a collaborator on a project supporting the development of a power module for a hybrid engine.
- **Professional, scientific, and technical services:** SMEs in these sectors accounted for 22 percent of collaborating partners and typically supported projects through research and consultancy activities, particularly specialist design and engineering³⁴ services and experimental development. For example, a large OEM delivering a project that developed a range extended hybrid electric light commercial vehicle drew on the expertise of specialist cross-sector engineering firm to develop the prototype and a set of monitoring and evaluation tools. There was some indication that this group did not have relationships with the conventional automotive supply chain prior to working on APC projects, especially in the case of experimental R&D (i.e. biotechnology, nanotechnology).
- **IT sector:** SME collaborators in the IT sector accounted for 14 percent of partners and generally provided software solutions to projects, particularly for modelling, testing and enterprise management activities.³⁵ A review of this category of collaborators indicated that these firms had all worked in the automotive sector previously.

3.5.2 Development of Collaborative Links

Project collaborations were typically based upon existing direct and indirect collaborator relationships though were sometimes encouraged by APC UK and/or Innovate UK. Novel links were often formed to meet the requirements of APC funding in relation to consortium composition and to enhance the expertise available to the project.

³² SIC codes recorded in Companies House data were used to identify the sectors in which applicants operated. Sectors identified included: manufacturing, professional, scientific and technical activities, information and communication, wholesale and retail trade; repair of motor vehicles and motorcycles, and administrative and support service activities.

³³ SIC code 29.

³⁴ Covering mechanical and electrical engineering

³⁵ In this instance, the IT sector is used to refer to firms that are coded with the following SIC codes: 62090 - Other information technology service activities, 62020 - Information technology consultancy activities and 62012 - Business and domestic software development.

In most cases, there was at least one instance where collaborative relationships had been involved in the delivery of previous collaborative R&D projects or through the personal networks of employees. In the case of academic and industry links, OEMs and Tier One firms were often reported to hold a formal relationship with a university research group prior to their successful APC funding application. This was either through previous collaborative R&D delivery, joint investment into a university based technology centre or through the delivery of student development programmes. Projects also identified potential collaborators through the networks of existing partners at the application stage. Mediation activities such as networking events organised by the APC also enabled the development of collaboration links. In one case, a UK SME joined a project consortium after meeting the lead applicant at an APC networking event. In addition, applicants made reference to the Road Maps developed by the APC in guiding application development and consortium formation.

The evaluation highlighted that collaboration patterns partly reflected the need to adhere to the objectives of the business case established by the APC which encourages OEM-SME collaboration. The case study research highlighted examples where OEMs partnered with UK SMEs to secure APC funding despite showing a preference for overseas suppliers. For example, one project reported that it included a UK SME to lead on the development of control systems. The lead applicant indicated that the link was novel and would not have been formed in the absence of APC funding.

However, one stakeholder challenged the need to include SMEs in consortia, reporting that consortia were better placed if they could prioritise including Tier One firms so as to support production rather than SMEs, who were thought to be able to add more value during the early stages of R&D projects. Nevertheless, there was unanimous agreement across the case studies research that SMEs have added value to the delivery of projects.

3.5.3 Benefits of Collaboration

The case study research identified a set of benefits that arise from collaboration, the most prevalent of which were: the ability to deliver R&D at scale, the generation of new technical knowledge and the generation of new commercial knowledge:

- **Deliver R&D at scale:** The development of consortia was reported to have catalysed the R&D process by providing significant capacity with the required range of skills and expertise to progress work packages at a faster rate that would have been achieved in an internal R&D programme. In addition, the case study research identified that collaborative R&D reduced the risk of free-riding or the distribution of unequitable rewards from collaboration. SMEs benefitted especially from working with OEMs, particularly in relation to developing an understanding of how OEMs deliver and coordinate R&D programmes and what their particular needs are when seeking R&D collaborators. This is useful given that the case study research highlighted instances where UK based OEMs concluded that no suitable UK SMEs existed to support an aspect of a project.

- **New technical knowledge:** The creation of new knowledge was reported to have helped resolve residual technical issues relating to technologies, as identified in section 4. The resolution of issues was reported to have been supported by the ability to collaborate. This was because existing knowledge was shared across organisations and access to capital equipment and specialist tools owned by partners was available for project activities.
- **New commercial knowledge:** Collaborations enabled firms to better understand the commercial aspects of the technology that they were developing. This ranged from resolving a set of outstanding business model issues, increasing a firm's ability to engage in component markets in a more informed manner, and increasing internal understanding of the UK automotive sector and supply chain. For example, in one project, a large auto Tier One firm, which had limited experience in purchasing semiconductors from suppliers, reported an increased ability to engage with semiconductor suppliers effectively after having worked with one directly on an APC project. In addition, SMEs were reported to have benefitted in this regard, particularly from generating an understanding of how to interact and work with OEMs from both an R&D and manufacturing perspective.

3.5.4 Costs of Collaboration

The evaluation also identified a number of costs of collaboration for APC projects, particularly in relation to delays caused by ineffective consortia management. Major costs identified in the research relate to issues working with academics, and managing organisational relationships:

- **Issues working with academics:** The evaluation suggested that timing of processes relating to APC funding are not entirely compatible with the way in which academics engage in funded research. Delays of up to several months at the inception of projects occurred because academics were unable to commence delivery 'at risk' until financial arrangements have been confirmed. This also delays the recruitment of required staff and creates problems and costs for other partners.³⁶ To illustrate this point, the university partners on a project developing EV battery production facilities were unable to work at their own risk. When the project did start the universities also found sourcing talent problematic, and entered into a lengthy international recruitment process. To mitigate for the slow start to this aspect of the project, an additional member of the academic staff was hired, and a capital expenditure item was brought forward to ensure that the spending profile for the whole project was not affected.
- **Managing organisational relationships:** The case study research highlighted instances where the management of internal consortia relationships introduced project

³⁶ This was suggested to be an acute issue given the high search costs typically associated with global highly skilled automotive engineering labour markets.

delays and constrained the ability of firms to make decisions in an effective and timely manner:

- **Misaligned technology readiness expectations:** One case reported the requirement for an additional set of consortia meetings to build internal consensus on the readiness (with respect to TRL) of subsystems to be integrated into an overall system at the outset of a project. This misunderstanding resulted in a delayed understanding that certain project technologies were not mature enough to progress.
- **Changes in project scope:** Significant changes in scope were reported to cause delays such as the decision to alter the vehicle type to which a technology would be applied (i.e. from buses to HGVs) or to pause development in favour of an 'off-the-shelf' solution. In one case, despite a significant change in project scope which resulted in a project technology not going into production, a project collaborator faced uncertainty (given a lack of clarity relating to the terms of non-disclosure) relating to their ability to exploit research outputs they had developed. The partner indicated that this management issue introduced delays in their ability to identify alternative routes to market.

3.5.5 Subcontracting

Stakeholders raised concerns relating to the geographical profile of subcontractors in APC projects. These related to how far the processes for delivering the programme were maximising R&D spend in the UK (critical given the underlying objective of anchoring UK automotive supply chains in the UK). The evaluation evidence suggests that, in most cases, applicants attempted to source UK based subcontractors and overseas subcontractors were generally only used where no UK based supplier could be contracted. The case studies provided an illustration of specific capabilities that are lacking in the UK. Key examples included: clutch testing facilities, software to control hydraulic systems and the ability to supply electrical control systems. The case study evidence also highlighted that OEM and Tier One firms subcontracted overseas counterparts to provide advisory services to project teams.

3.6 Project Delivery

This section provides an overview of the evaluation results that relate to project delivery. It draws on all evidence sources to provide an overview of the key activities undertaken, provide an analysis of the extent and nature of the problems encountered in practice, and identify the extent of any major changes in project scope.

3.6.1 Activities Completed

The evaluation highlighted the following set of key activities that were completed as part of APC funded projects:

- **Market research:** Projects completed market research studies to gain a better understanding of the determinants and characteristics of demand and supply in certain market segments. For example, one project completed a supply chain readiness review which identified potential suppliers and assembly line specifications, whilst another completed a study of the specification requirements of large bus OEMs to understand what hybrid engine functionality is most desirable.
- **Virtual design and validation:** Projects completed initial design activity virtually to enable a high degree of flexibility early in the R&D process and minimise costs. These designs were typically validated through the use of computational simulation software.
- **Design and development of prototypes:** Most of the projects involved prototyping activities to develop proof of concepts in relevant and/or operational settings. This typically culminated in the production and evaluation of a demonstrator at a particular TRL or MRL - for example, a demonstrator of power electronic components to be integrated into hybrid engines.
- **Monitoring and evaluation:** Projects regularly completed monitoring and evaluation activity to assess the performance of technologies both during and after the APC project was completed. Evaluation was completed over the course of projects to identify residual performance issues and determine whether and when projects were sufficiently developed to achieve pre-set milestones. For example, one project needed to evaluate the performance of TPS engine and electrical components to assess their viability in a light commercial vehicle and another sought to evaluate performance of electrical components in high stress environments. After the completion of projects, the focus of monitoring and evaluation was on providing real-time analysis of the performance of integrated technologies in a fleet and/or to provide insight into the production operations.
- **Design and development of assembly processes:** Given the nature of the APC, most projects had work packages that related to the design and development of production processes and assembly lines. For example, projects cited deliverables relating to the development of quality parameters defined for production, the production of assembly designs and specifications and the completion of manufacturing trials based on performance.

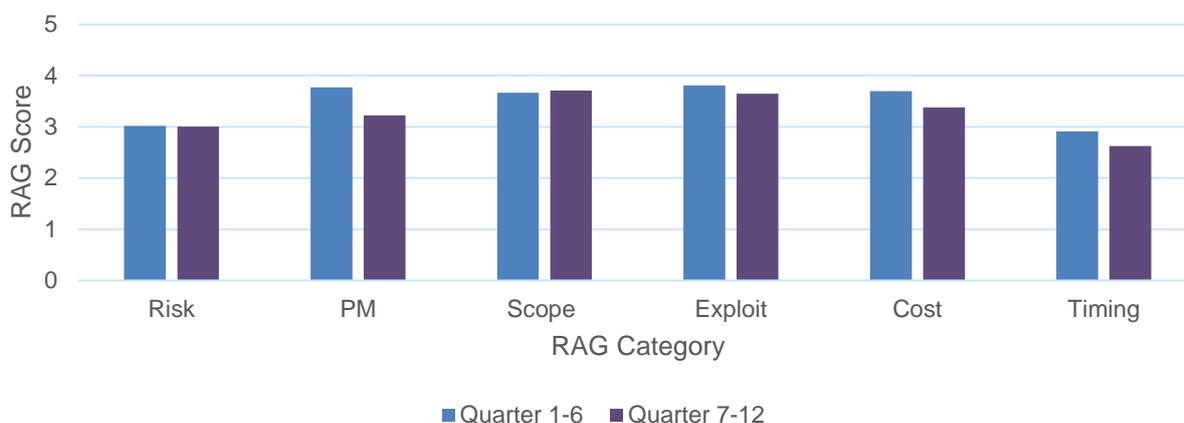
3.6.2 Project Delivery Issues

The evaluation suggested several projects encountered delivery issues. These had a range of consequences including: delays, financial virements and changes in project scope and exploitation strategies. While a small number of projects were substantially re-scoped or put on hold, most cases were not the result of issues associated with the delivery of research outputs.

An assessment of RAG records from quarterly monitoring reviews undertaken by Innovate UK provides a quantitative indication of these issues. Project progress is assessed by

Monitoring Officers using the six RAG rating categories used by Innovate UK for all grant funded projects: cost, exploitation, project management, risk, scope and timing. The results of the reviews are developed further in formal reports with a numerical score for each RAG category assigned to projects within a one to five range. Five represents the best score possible and one is the lowest. Analysis of records between April 2014 and December 2016 indicates that none of the projects in the APC portfolio have been terminated or put on hold.³⁷ The figures below depict changing RAG scores since April 2014. Worsening RAG scores were much more prevalent than improving scores across all categories with issues in relation to cost and exploitation. However, at least 50 percent of all projects experienced no change in their RAG score for risk, scope and timing categories.

Figure 3.3 Change in RAG Scores between April 2014 and Dec 2016



Source: Innovate UK Monitoring Information (2016).

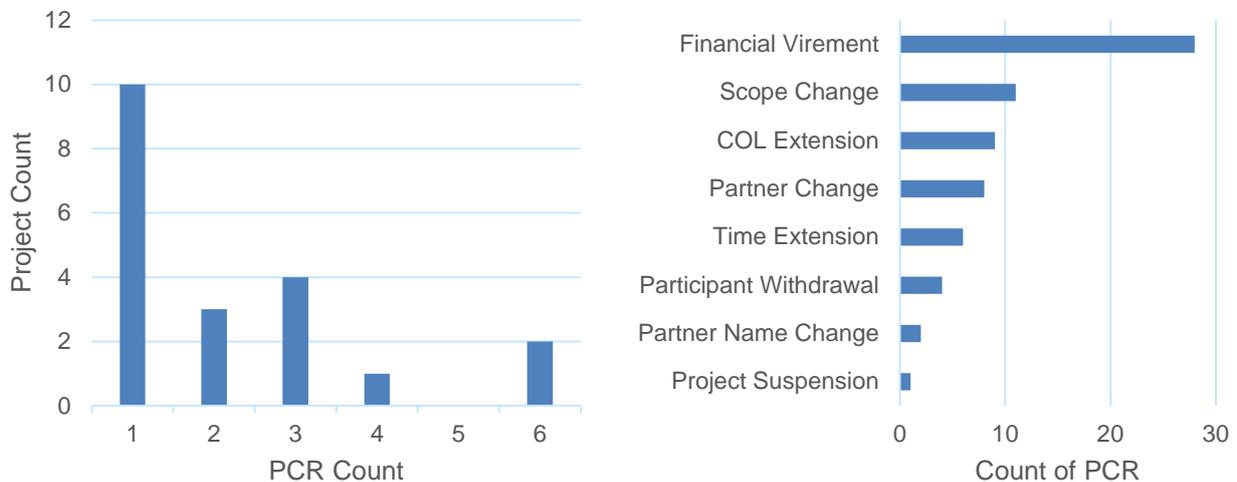
3.6.3 Project Change Requests

A Project Change Request (PCR) is a formal process by which project leads can negotiate and confirm changes to the delivery of their grant funded projects. The process is mediated by the project's Innovate UK external Monitoring Officer and reviewed and approved by Innovate UK. Analysis indicates that a total of 44 PCRs have been made and approved in the case of the APC portfolio. The figure below suggests that 50 percent of projects have filed for one PCR, with 35 percent filing for at least three. As noted in the introduction to this report, R&D projects carry a high degree of risk and changes in direction are not unexpected. The most common PCRs are for financial virements, scope changes and Conditional Offer Letter extensions. The average value of a financial

³⁷ RAG data provided by Innovate UK only covers 16 APC projects, as many were still at GCL confirmation or had not been in delivered long enough to attend a RAG review. The evaluation is aware that at least one project is on hold.

virement PCR is £488k and the average month extension requested for time and COL extensions are 9 and 2 months respectively.

Figure 3.4 Project Change Requests: Frequency and Type



Source: Innovate UK Monitoring Information for 20 APC projects (2017).

3.6.4 Factors Driving Delivery Issues

The evidence highlighted a range of possible project delivery issues that resulted in difficulties for APC projects (again, as stressed elsewhere, R&D projects are by their nature risky and these types of issues can be expected). These have been categorised into those resulting from technical, management or dependency issues. The research highlighted that these issues were the most likely to result in delays to project delivery or changes in scope of expected exploitations plans:

- Contextual:** Changes in the external environment were reported to have caused issues for projects, particularly with respect to scope and exploitation. The research suggested that shocks to the automotive market whether on the demand (i.e. negative publicity for diesel engines) or supply side (i.e. decrease in fuel prices) challenged the existing business case for the technologies under development, especially with respect to the validity of the predicted routes to market. For example, negative media attention on diesel engines was reported to have led to declining demand for diesel hybrid engines in preference for EV models. In one project that was developing an integrated diesel hybrid engine with electronic components, these external factors resulted in a significant re-scoping, a decision not to go into production and the exit of an SME partner. This introduced a delay of three months to the project and reduced expectations of sales of vehicles with the engine.
- Technical:** The case study research highlighted a set of technical issues that were experienced by projects, relating to both performance and commercial factors.

Technical issues experienced by applicants are discussed in more detail in subsection 4.1.2.

- **Management:** The case study research highlighted several delivery issues associated with the management of projects which were suggested to have caused delays to delivery. Key areas of concern that were highlighted included:
 - **Inclusion of academics:** As noted, university policy sometimes prohibits academics from starting project delivery or hiring personnel for a project until a grant confirmation letter (GCL) has been approved to minimise financial risks. In addition, hiring staff for R&D positions with a sufficient level of experience of working in industrial collaborative projects was reported to be a challenge given that universities had often recruited from global labour markets, suggesting an insufficient supply of suitably skilled researchers in the UK.
 - **Monitoring reports:** Monitoring arrangements were thought by some to require a relatively large amount of project resource in relation to total project costs. In addition, the research uncovered instances where challenges arose in educating collaborators on the benefits and requirements of providing timely monitoring information to monitoring officers.
 - **Lack of consensus on technology readiness:** As previously discussed, tensions arose between collaborators when consensus of the readiness of technologies could not be reached. This introduced delays in progressing through milestones and increased costs through the requirement for additional testing and validation activities. In one case, a lack of mutual understanding arose between the OEM and collaborators on the technological and engineering issues involved in integrating the electrification of the power train. The collaborators appeared to have different understandings of the extent of the readiness of the technologies for integration at the outset of the project.
 - **Lack of project management:** A minor theme raised in the research was delays through projects not correctly specifying a project management lead. Conversely, the research highlighted that project management was of a high quality when projects had two managers: one technical lead and one administration lead.
 - **Dependencies:** A set of coordination issues arose through the inter-dependencies within consortia. Dependencies were reported to be both internal and external to the APC project (e.g. the commencement of some work packages was sometimes dependent on completion of precursor work packages). Dependencies on parallel activity sometimes contributed to project delays. For example, a delay in prototype engines becoming available for a project was reported to have resulted in “more modelling and less testing”, which introduced delays. In another case, slow technological progress was caused by machining faults in the production of prototype components. In this case, this was outside the control of the project

team as the component was developed as part of a different engine development programme. Several time extensions were introduced to accommodate delays in the main engine development programme on which the project progress was dependent.

3.6.5 Changes in Project Scope

Changes in scope reflect any changes in project deliverables that are specified in a project's level 2 plan. Of the PCRs analysed, over 80 percent of scope changes were also accompanied with financial virements, 36 percent with time extensions and 36 percent with alterations in project consortia. The case study research highlighted the types of scope change that occurred in practice:

- **Production decision:** A prerequisite for APC funding is that the technologies developed are intended for integration into a vehicle development programme. Significant re-scoping of projects was required where decisions were made not to go into production. The case study research suggested that these decisions were linked to insurmountable technical issues or unexpected changes in the market context (e.g. changes in fuel prices or the approach of local and national authorities to air quality issues). In cases where a decision was made not to go into production, funding was halted and/or completion of sub-systems and demonstration of technologies at lower TRL / MRL levels was pursued instead.
- **Altered work package specification:** The introduction of new work packages or the alteration of existing ones often occurred where unexpected technical issues were identified in the process of delivering the project. For example, case studies highlighted situations where projects highlighted a need to introduce market studies to complete exploratory research to better understand market conditions and inform specification requirements. In some cases, applicants sought to develop their technology for applications in different vehicle types (i.e. from buses to light commercial vehicles) or made use of existing technologies from abroad in light of residual technical issues faced with the technology under development.
- **Reallocation of work packages:** The research highlighted cases where the delivery of work packages transferred from one collaborator to another. On these occasions, the planned lead was unable to make use of specialist equipment given time delays and capacity constraints or was dependent on the delivery of prototypes that were behind schedule.

In no case was the original value for money assessment reviewed by BEIS at the time of project's appraisal undertaken, even where major changes were under consideration that would fundamentally alter the business case for public funding (and positive or negative changes in BCRs were likely).

Recommendation: Introduce a trigger for VfM reassessment

- (9) APC, BEIS and Innovate UK should consider whether there may be value in repeating the VFM assessment in cases where projects are subject to major re-scoping and fundamental changes to the basis on which public funding was awarded (to provide assurance that the new proposal offers sufficient value for money). A clear definition of what is understood by 'major rescoping' will need to be introduced.

3.7 Summary

- The evaluation identified three key applicant motivations for applying for APC funding: new low carbon vehicle product developments (either to pursue or maintain a competitive advantage amid expected changes to emissions legislation); the resolution of residual technical challenges; and, enhancing the capability of the UK supply chain. APC portfolio OEMs were seen to be focused on the development and manufacture of EV and hybrid technologies, inter alia, addressing the transition of bus engines from diesel to zero carbon. The portfolio was less focused on the development of low carbon technologies for light commercial and heavy goods vehicles, reflecting the speculative and nascent state of low carbon technologies for applications in these vehicle types.
- The evaluation highlighted that APC projects were commonly underpinned by technologies developed in previous publicly funded R&D efforts. However, the research also identified cases where initial technology development had been supported by overseas initiatives. The APC strategy was viewed to be strongly industry-led, with no evidence that APC Ltd. had greatly influenced corporate R&D agendas. APC Ltd. was suggested to have played a role in coordinating potential collaborators and providing support to applicants during the application stage (though the case studies often involved engagement with R&D staff rather than those responsible for developing proposals, and respondents could not always offer a clear view of the role of APC Ltd).
- Five key additionality claims were made by APC funding applicants, which largely reflected the market failures and barriers identified in the business case. An inability to access a sufficient level of finance was the most commonly cited additionality claim made by applicants, followed by the presence of funding gaps and weaknesses in the UK low carbon vehicle supply chain which would have prevented the allocation of R&D spending in the UK by globally mobile OEMs in the absence of APC funding. A set of transactional frictions with respect to collaboration and outstanding technical and commercial risks were also claimed to prevent private investment in the absence of public support.
- Most projects were led by large firms (80 percent). With respect to collaborators, SMEs account for around 33 percent of partners and around 26 percent of partners were academic institutions. The evaluation suggests that most firms involved in APC projects

had already worked in the automotive sector and resided in manufacturing, professional scientific and technical and IT sectors. Collaboration links were typically forged through previous working relationships, often on previously funded R&D programmes. Collaboration supported the ability of partners to deliver R&D at scale and develop new technical and commercial knowledge. However, the evaluation provided some indication that collaboration benefits came at the cost of increased project management requirements and consensus building activities, resulting in project delays and change requests.

- The risks associated with projects were shown – on average - to increase over time, especially in the case of costs, exploitation and timing. Key factors driving this reflected an evolving external context, challenging residual technical issues and a set of management issues. Projects responded to these factors through change requests, which largely consisted of financial virements and scope changes.
- The evaluation recommends that the APC develop a set of criteria that identify when a VfM assessment completed during the appraisal stage of the application process should be revisited for a project. Substantial changes in scope are likely to have consequences for calculated benefit-cost ratios. Updating assumptions about the expected benefits to be produced by projects has the potential to improve decision making with respect to current funding commitments and future funding allocations.

4.0 Outcomes

This section provides an overview of the technological and economic outcomes associated with the projects funded by the APC portfolio to date and emerging lessons for programme delivery. This section draws primarily on the evidence gathered from the ten case study projects (qualified by evidence provided by stakeholder consultations). It should be stressed that, while there are proposals to gather monitoring information that quantifies the outcomes associated with APC funded projects, these have not yet been implemented and as such, programme wide measures of the outcomes achieved are unavailable at this stage.

Recommendation: Technological and economic monitoring

- (2) APC, BEIS and Innovate UK should consider accelerating the implementation of arrangements to monitor the technological and economic outcomes associated with the projects which have received funding. This will provide benefits in terms of assessing performance management (by enabling a clear assessment of how projects have performed against expectations), as well as in facilitating communication of the results of the programme to wider stakeholders and informing the assessment of bids for further public funding.

4.1 Technological Progress

The APC provides funding to support R&D activities aiming to accelerate the commercialisation and exploitation of low carbon propulsion technologies. These activities tend to focus on identifying and resolving the engineering issues involved in ensuring the technology functions effectively in real-life environments, or addressing the issues involved in producing the technology at a price that would be acceptable to consumers.

This section provides an analysis of the technical objectives and outcomes that have been achieved by APC projects to date. It is important to bear in mind the following:

- All R&D projects will involve a level of technical risk, and there is an expectation that some projects will inevitably not deliver the anticipated improvements in vehicle performance.
- APC projects are complex, often involving the development of several technologies with the potential to be exploited independently. For example, while the system under development may fail overall, projects may result in the development of components or sub-systems that can be successfully integrated into other vehicle or engine platforms.

- Success in achieving technological objectives does not necessarily imply that the technology will eventually be commercialised. For example, changes in the external environment may mean that it is no longer economic to exploit a technology. Equally, firms may also face other barriers in commercialising technologies (such as difficulties in securing the capital to produce the technology at scale).

4.1.1 Technology and Manufacturing Readiness Levels

The technical progress of R&D projects in terms of mechanical and electrical engineering can be quantified using the Technological and Manufacturing Readiness Level scales (TRL and MRL).³⁸ These scales describe the progression of technologies through a sequence of tests of increasingly high fidelity prototypes in increasingly realistic environments. APC funding was available to projects where the core system under development was at TRL5³⁹ and MRL4⁴⁰, and applicants often provided an assessment of both baseline levels of technical development and expectations with respect to where they expected to finish at the end of the APC project⁴¹. This provides a framework against which the progress of projects can potentially be assessed.

The case studies were used to collect evidence on the progress made by projects against the TRL and MRL scales and assess progress against expectations. This suggested:

- **Technology Readiness Levels:** Focusing only on the development of the core integrated systems at heart of the APC projects funded, the ten projects progressed from an average of 5.0 to 7.1 on the TRL scale against an average expectation of 8.0 (implying that projects had largely developed operational systems). This analysis includes incomplete projects, though similar patterns were observed amongst the four completed projects which were subject to review.
- **Manufacturing Readiness Levels:** In terms of MRL levels, projects progressed from 4.1 to 5.5 (against an expectation of 6.3) implying that projects were at the point of producing prototype components and systems but were still some way off the requirements for low volume production (MRL8).
- **Meeting technical objectives:** Two of the ten projects reviewed met their broad technical objectives for the core integrated system under development at the time of the review – and a further three were expected to do so on completion.

³⁸ [APC \(2014\). Automotive Technology and Manufacturing Readiness Levels.](#)

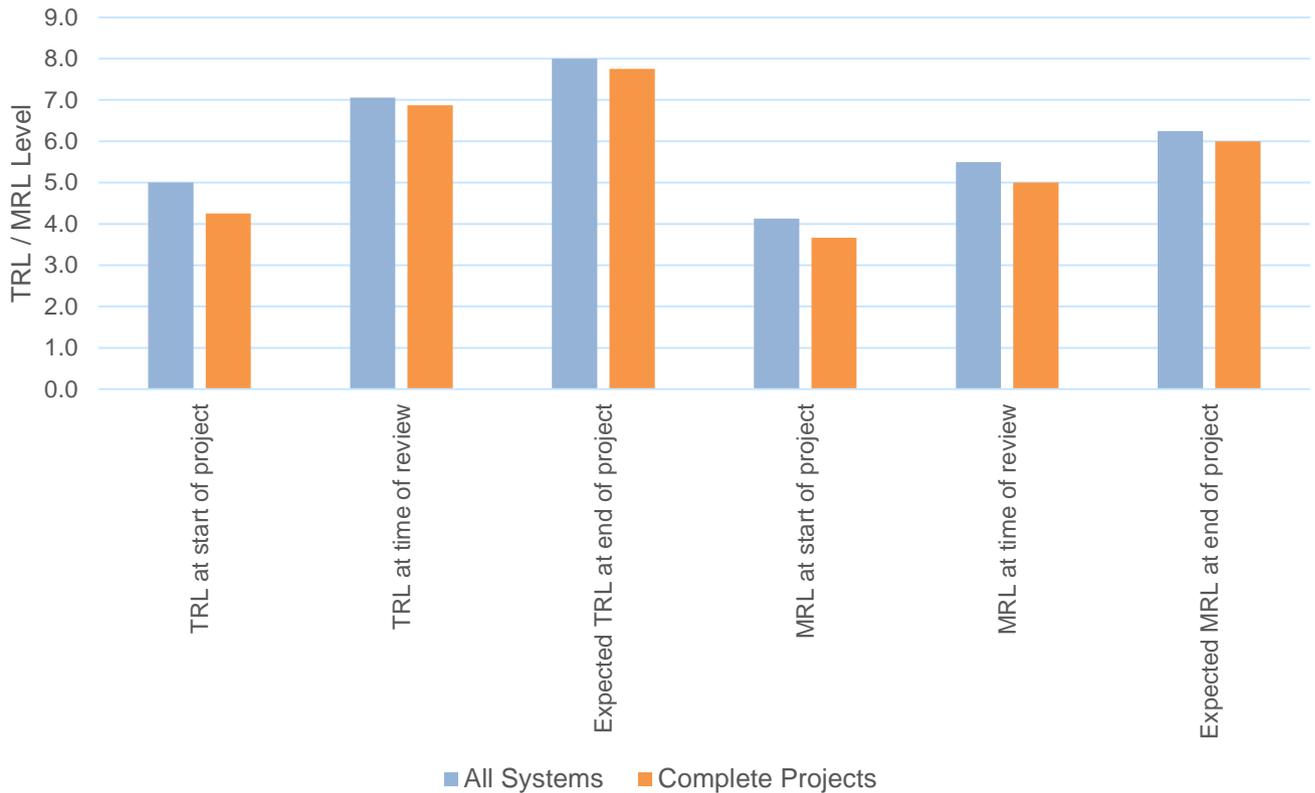
³⁹ Implying that TRL4 had been completed - successful tests of a low-fidelity technology (i.e. ad-hoc components) had been completed in a laboratory environment (e.g. on a testing rig).

⁴⁰ Implying that MRL3 had been completed – indicating that experimental hardware or manufacturing processes had been created but were not integrated or representative.

⁴¹ Under State Aid regulations, the APC cannot fund projects to reach the end-point of technical development (TRL9).

The results suggest that on average around 50 percent of projects have reached their technical objectives but that the core systems at the heart of APC projects have tended to fall around one TRL and MRL stage short of expectations. It should be noted that this masks the progress made in the development of important subcomponents which sometimes underwent more rapid development than the integrated system of technologies being developed overall.

Figure 4.1 Technology and Manufacturing Readiness Levels: Case Study Projects



Source: APC applications forms and case study results.

4.1.2 Technical Challenges Encountered

The case studies suggested a range of explanations for the patterns observed:

- Engineering issues:** Many of the projects encountered unexpected challenges in addressing engineering issues associated with integrating laboratory tested technologies into vehicle prototypes. The most frequently reported challenge was ensuring the technology offered a satisfactory user experience (e.g. addressing unacceptable vibrations and noise or ensuring the reliability of hydraulic systems). However, applicants tended to find solutions to these types of problem (though at the expense of fuel economy savings) and technical challenges were rarely the underlying cause of failure to meet the expectations defined at the application stage.

- **Overstatement of capabilities:** More common was a tendency of applicants to overstate internal or external capabilities (or the maturity of the technologies or subsystems involved in the project) which often had more significant effects on progress. One applicant suggested that, while they brought a strong understanding of the properties of the individual systems required to produce efficiency improvements in diesel engines, weaknesses in internal capabilities in the integration of systems led to an understatement of the technical challenges in bringing the components together, causing delays in delivery. Another suggested that initial testing indicated that the subsystems themselves were not at the required level of maturity, leading to a major re-scoping of the project. A third project involving developing a UK supply chain capability to produce lightweight zero-emission capable vehicles has been put on hold because initial feasibility work suggested that that required capabilities were not available in the UK (and could not be developed without significant investment).
- **Prevalence:** The types of issue described above tended to be more prevalent where projects were led by smaller or niche vehicle producers. Projects led by larger producers typically met their technical objectives, though it should be acknowledged that in two of the five cases reviewed the project involved a transfer of technology that had already undergone significant development and de-risking overseas. In one case, challenges were encountered because of an attempt to integrate the technologies under development into a new (rather than an existing) engine architecture, creating dependencies on parallel project, though this did not prevent the project meeting its technical objectives.
- **Changes in the external environment:** Changes in the external environment outside of the direct control of applicants also affected technical progress by requiring changes of course. For example, declining diesel prices placed pressure on the commercial viability of one project seeking to use flywheel technology to improve the fuel economy of off-road vehicles (resulting in the termination of the project before technical development was completed). Rising concerns regarding diesel emissions also led to pressures on applicants (particularly those producing technology for buses). One applicant encountered pressures to retrofit the flywheel technology under development to a wider range of vehicles than originally planned. Additionally, applying the technology on Euro 6 vehicles resulted in fuel penalties as the decoupling of the engine resulted in cooling of the exhaust system and a requirement to burn fuel to restore temperatures and control emissions. More generally, bus operators are moving very quickly away from hybrid diesel to zero emissions solutions, causing the abandonment of the core concept of two APC projects and leading to the refocussing of technological development on alternative applications in one case.

Technical risks of the nature described above were sometimes recognised in the project selection and approval process. For example, recognition of weaknesses in the UK supply chain capabilities at the appraisal stage prompted the introduction of a 'gateway review' process that required the applicant to complete an initial feasibility study before the project

could proceed. However, in most other cases, the key risks that emerged were not identified as concerns by Independent Assessors (based on the comments provided in the independent assessment and following interview).

Questions could be raised regarding whether the volume of technical material required from applicants is sufficient to support a thorough evaluation of risk at the assessment stage. The applications and supplementary annexes provided to Ipsos MORI often provided an overview of the technology and claims regarding its performance, though little evidence to validate these claims in the form of results and scope of precursor tests that enabled the project to reach TRL5.

Recommendation: Technical review

- (4) APC, BEIS and Innovate UK should consider whether it would be feasible to require applicants to provide additional documentation at the due diligence stage describing the extent and results associated with the tests completed to take the development of the core systems to TRL5. This could potentially help validate the technical claims made by applicants and identify any risks that could form the focus of any 'gateway reviews' introduced to support risk management, the increased use of which is suggested in recommendation 7.
- (7) APC, BEIS and Innovate UK should consider making greater use of 'gateway review' processes (or staged grant awards linked to the achievement of technical milestones) to more effectively manage the risks associated with committing funding to large programmes of technical development. The implementation of any such processes should involve rapid timescales for decision making to provide certainty and avoid unnecessary delays in project delivery.

4.1.3 Technical Performance

Applicants are also asked to define expectations regarding the expected technical performance of the systems under development in terms of reductions in tailpipe emissions. These projections are used in the VFM assessment to estimate the environmental benefits associated with the programme. The case studies were used to collect evidence on actual performance of the technology in any tests completed by applicants to gauge how far results aligned with initial expectations⁴².

- **Performance against expectations:** While in three cases the expected fuel economy improvements were realised, in three others performance fell short (by an average of 33 percent). These differences were in some cases materially significant in that had the

⁴² Relevant tests had only been completed in six of the ten case studies.

VFM case been prepared based on actual performance, the project would have failed to meet the minimum threshold for funding.

- **Drivers of divergence:** Only in one case was the divergence driven by technical issues (i.e. the case where the technology resulted in fuel penalties owing to the need to heat the exhaust system when the engine was decoupled). In another case, estimates of the potential carbon savings were made based on secondary technical literature (and a misreading of this literature caused the applicant to overstate the potential fuel economy benefits of the project). This raises wider questions regarding the baseline level of technical development in this instance (as it might be reasonable to have expected the applicant to have demonstrated the concept in a laboratory environment and to have possessed some test results upon which to base an estimate of the fuel economy savings).
- **Holding back technologies for future engine models:** In the final case, the argument was made that, while the technology was proven through the project, it was not matured quickly enough to make it onto an upcoming vehicle launch. This resulted in a mild hybrid system that delivered a reduction in fuel consumption of 13 percent as opposed to the 20 percent expected at the application stage. However, these savings were sufficient to meet emissions standards, and it may be reasonable to speculate that some technologies are being ‘held back’ for the future engine development cycles. There was also evidence from the other case studies that other OEMs were displaying similar behaviour.

Recommendation: Optimism bias and benchmarking

- (5) The separate presentation of BCRs with and without environmental benefits following the VFM assessment is appropriate given the uncertainties involved. However, BEIS should consider whether it may be appropriately conservative to also apply an optimism bias adjustment in the VFM assessment given the evidence that the technologies developed did not always deliver their anticipated fuel economy savings.
- (6) BEIS should also consider whether it may be desirable for the VFM analysis to assign higher weight to expected fuel economy gains produced in excess of emissions legislation targets, given that these targets need to be met in any case. The VFM analysis could potentially be refined by discounting any emissions savings below regulatory requirements (or exploring this through sensitivity analysis). Additionally, a timing adjustment for any emissions savings above those targeted or required by the lead applicant may be desirable to allow for possibility of technologies for future product launches.

4.2 Exploitation

The economic benefits of the APC to the UK will be primarily linked to whether and how lead applicants and collaborating partners exploit the technology under development. Applicants to the APC are required to define their exploitation plans in several documents, including in the application and in the Exploitation Plan that form part of the monitoring framework agreed with Innovate UK monitoring officers. Applicants are also required to provide quantitative projections of the number of vehicles sold integrating APC technology and the number of (direct jobs) that will be associated with their production. This section examines how far the projects funded are on course to deliver against these plans based on the case study evidence gathered.

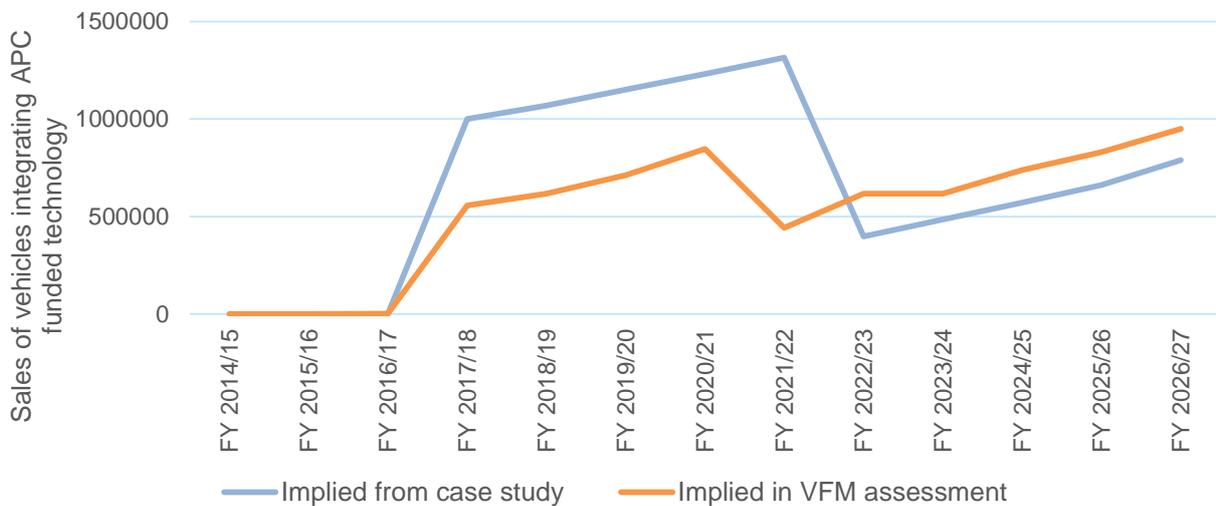
4.2.1 Expected Vehicle Sales

Applicants are expected to provide a projection of future vehicle sales integrating APC funded technology at the application stage (which partly drives the VFM analysis). These were compared to current expectations (as determined through the case study research) to provide a quantitative assessment of the extent to which commercialisation plans aligned with prior expectations.

Projections have been adjusted to account for applicant's current expectations both in terms of production volumes and the timescales over which the technology will enter production. The following analysis focused on the six projects where commercialisation plans were comparatively clear (projects undergoing major re-scoping and those that had just started were excluded from this analysis). Additionally, the analysis focuses only on the sales of the core systems at the heart of the projects and excludes the sales of collaborators (as associated ex-ante projections were not available). Additionally, it is important to note that applicants provided projections over different time horizons and comparisons are made over equivalent periods, creating the apparent volatility in the chart below. Finally, the forecasts provided are in terms of production volumes and do not necessarily reflect the value of sales.

Although no applicant had entered commercial production at the time of the case study, sales of vehicles were expected to exceed the expectations defined in application forms (and to grow to 1.2m units in 2021/22). This would represent a significant share of the overall volumes of vehicles and engines currently produced in the UK and some questions could be raised regarding the plausibility of these projections, though the projections do capture the expectations of three of the largest manufacturers of passenger cars in the UK.

Figure 4.2 Expectations of future annual sales of vehicles integrating APC technology, at appraisal and in mid-2017 (Case Study Projects)



Source: VFM assessments and case study findings.

4.2.2 Divergence Against Original Plans

The case studies suggested that exploitation plans had departed from original expectations for several reasons:

- Higher than expected demand:** The main driver of higher than expected sales forecasts stems from changes in the plans of three large OEMs that were seeking to increase production volumes for a variety of reasons. One producer intended to integrate a mild hybrid system for diesel engines into a wider range of vehicle models than originally intended. A similar result was reported by a large OEM exploring significant fuel economies in small engines, in which the technology was to be integrated in larger engines than originally envisaged. Finally, another producer reported higher than expected demand for its electric passenger car and suggested it was now planning to increase planned production by 85 percent (resulting in two additional shifts on the production line and creating approximately 200 further jobs). At peak production, these projects were expected to create around 430 direct production jobs in the UK, and it is likely that this number will increase given changes in plans (though quantitative estimates were not provided in all cases).
- Re-scoping:** The re-scoping of one project resulted in a shift in focus from both buses and HGVs to the latter alone (due to challenges both in getting manufacturing costs down to an acceptable level and in enabling the technology to function effectively). This change in strategy has resulted in an overall reduction in anticipated sales volumes (by approximately 20 percent) as well as delays of around four years in getting the product to market. Additionally, the new technology concept being explored was thought to be at TRL4, and clearly there remain major risks as to whether these sales will ultimately be realised.

- **Abandonment:** The abandonment of one project aiming to integrate energy recovery technology to improve the fuel economy of off-highway vehicles also had the effect of reducing anticipated sales volumes by around 2,200 (though it might be expected that these would have been high value items). It might be inferred that the 30-35 direct jobs expected to be created in producing the technology will also fail to emerge. Equally, the abandonment of the stop-start technology designed to improve fuel economy in hybrid diesel buses would have reduced the sales projections above by almost 20,000 units at peak production (and, again, the failure to create around 40-45 production jobs).
- **Sales by collaborating parties:** The figure above does not capture sales expectations of collaborating parties outside of vehicle models produced by the lead applicant. In both cases in which the core project was abandoned, IP was developed by collaborating SMEs was subsequently exploited. The SME developing energy recovery technology for off-highway vehicles has subsequently integrated the technology into the vehicles produced by several other OEMs and is projecting production volumes of 6,500 by 2024 and associated revenues of £25-30m. Another SME that developed a bespoke power module for the discontinued diesel hybrid engine project has secured an NDA with another OEM to develop the technology for a different application (though it is too early to provide sales projections at this stage).

The evidence above suggests that while APC projects have faced delays and in some cases, major technical difficulties, based on this sample of ten projects, the commercial upsides have generally outweighed the downsides. It is expected that gross vehicle sales and direct job creation will outstrip the expectations set out at the application stage. As highlighted above, even where OEMs ultimately abandoned the projects, some collaborating parties appear to have been able to exploit the technologies under development.

Recommendation: Staged funding

- (8) If APC, BEIS, and Innovate UK seek to make greater use of staged payments or 'gateway reviews' as means of improving risk management, consideration should also be given to the potential exploitation of sub-systems being developed by collaborating parties. In cases where there is a compelling reason to withdraw funding from the core project, there may be a case for continuing the funding of the development programmes led by collaborating parties. This may require downsized (rather than cancelled) contributions to the OEM to maintain the benefits of their involvement in terms of both expertise and preserving a route to market.

4.2.3 Organisation of Production

The economic impacts of APC projects will be linked to how far production of the associated systems and subsystems will be completed in the UK. This section examines evidence from the case studies regarding the evolution in production plans since the

commencement of projects (focusing largely on those projects where the exploitation route has been largely determined):

- **Projects led by large OEMs:** In all but one case, OEMs expected to produce the final system in the UK at the time of the application for funding. There was little evidence from the case studies that for those technologies expected to enter production there had been any deviation from these plans. In the one case where assembly and production was initially expected to go forward in the European Union, the exploitation of the technology on a wider range of engine types has resulted in the firm expanding its production plans to include a UK facility. However, one OEM suggested that, while production of components would take place in the UK, assembly would be taken forward in the EU (though the application in this instance provided a strong implication that the relevant engine would be produced in full in the UK).

Recommendation: Outcomes monitoring

- (1) APC, BEIS and Innovate UK should consider the implementation of monitoring of post-completion exploitation outcomes to determine how far OEMs and Tier One suppliers go on to produce the technology in the manner claimed at the application stage. On the expectation that the APC will involve a long-term relationship - with OEMs submitting repeat applications - this type of evidence could be helpful in informing expected leakage corrections in the VFM appraisal. Excessive administrative burdens could be avoided by ensuring any follow-up is periodic and light touch.
- **Supply chain effects:** The large OEMs operate complex global supply chains and it was generally anticipated at the application stage that firms based both in the UK and EU would provide inputs to projects (though it has not proven possible to quantify the spatial distribution of inputs). Again, there was no material evidence of significant deviation from original plans and there were some indications that the APC may have helped (at the margin) to reverse the ‘hollowing out’ of the UK automotive supply chain observed since the 1980s:
 - **Anchoring of SMEs in the supply chain:** One of the key effects of APC funding noted in the preceding chapter was that the collaboration requirements forced OEMs to work with UK based partners where they may have otherwise preferred to work with overseas suppliers. The expectations set out in application forms were that these partners would be effectively ‘anchored’ in the supply chain should the technology be taken into production. This has proven to be the case, including in instances where core production activities will take place outside the UK.
 - **Exports:** As noted above, some SMEs could exploit the technologies developed outside of their relationships with the lead OEM. This has also produced additional

export sales for the firms involved, with one SME reportedly developing relationships with OEMs in US and in Asia.

- **Other benefits for SMEs:** SMEs also reported other major benefits of their involvement in the APC. Formal collaborative relationships with OEMs were reported to have enabled them to de-risk technologies under development, enabling them to be both clearer on the performance traits of the technology and its unit costs in further engagement with OEMs. Less tangibly, some SMEs also reported that involvement in projects enabled them to resolve aspects of their business model (e.g. which vehicle segments represented the greatest potential for the technologies under development).
- **Manufacturing capabilities of SMEs:** A specific issue arose across multiple case studies regarding the ability of SMEs to manufacture at the required scale, particularly – though not limited to - technologies focusing on the electrification of vehicles. The limited presence of large Tier One suppliers in the UK was acknowledged in the business case for APC, and it was hoped that funding provided through the programme could support the growth of SMEs in the supply chain of large automotive producers. In practice, these types of issue caused the failure of one of the ten projects examined in the case studies, and there was wider evidence that SMEs had to navigate scale problems. For example, one SME that initially entered the project with the aspiration of bringing production of energy recovery systems ultimately elected to pursue a virtual manufacturing model, reportedly due to financial market constraints (using a contract manufacturer to produce the components). Other SMEs were seeking to license the technologies under development, and one OEM indicated that, while the supply chain was equipped to produce components of electric vehicles at relatively low production volumes, domestic suppliers would be ill-equipped to respond to large increases in demand. It is conceivable that these factors will lead to an elevated risk that the technologies under development will eventually be exploited overseas (where producers were reportedly better able to accommodate larger production volumes).

Recommendation: Financial market constraints research

- (10) BEIS and Innovate UK should undertake specific research exploring the extent to which SMEs in the automotive manufacturing sector face specific financial market constraints that prevent them building their manufacturing capabilities, and whether there may be a need and demand for complementary instruments to help SMEs upscale production (i.e. capital investment rather than R&D subsidies) – or how far the apparent challenges are driven primarily by challenges in producing at an acceptable unit cost. There may also be comparable issues in other advanced manufacturing industries to which these instruments may well be relevant.

- **Collaboration agreements:** Collaborating parties are required to sign a collaboration agreement before Innovate UK can issue a Grant Confirmation Letter that enables the project to proceed (Innovate UK operates a policy of non-intervention regarding the specification of these agreement). In two cases, collaborating parties indicated that their efforts to exploit the technology were inhibited or delayed by the clauses they agreed to in the collaboration agreement (both in projects where the core technology was abandoned by the lead OEM). While both have been able to overcome these barriers, given the relative bargaining power of OEMs and SMEs, there is a risk that the clauses defined prevent the exploitation of knowledge that has been subsidised by the public sector (working against the public interest).

Recommendation: Collaboration agreements

- (3) The APC should work with applicants to help resolve any issues that may arise in situations where collaboration agreements may inhibit the exploitation of the technology developed with public funding.

4.3 Knowledge Spill-overs

The evaluation sought to make an assessment of the extent to which new skills, knowledge or intellectual property developed through APC projects might have been adapted and/or applied in other projects, shaped new R&D projects or made use of in other business and commercial activities. For the purposes of this evaluation, spill-overs have been grouped into those that accrue within one collaborating organisation, across collaborating organisations, to project subcontractors and externally to those outside a project consortium. These effects can then be categorised further by whether the spillover relates to technical, economic or managerial knowledge replicated or imitated in another application, as shown in the table overleaf.

The case study evidence suggested that at this stage in the APC portfolio, spill-over effects of most potential types can be observed. The only case where spill-overs were not observed was in the application of knowledge for commercial benefit outside of project consortia. This is probably because vehicles with APC technology are not expected to have reached the market until at least 2018, so the opportunity to replicate or imitate technologies is limited. The cases also highlighted instances where technologies were protected through the registration of intellectual property rights. No evidence suggested that the research outputs of APC projects have been used to inform the development of new R&D projects.

Table 4.1 Examples of spill-overs accrued from the case study research

Spillover type	Within a collaborating organisation	Across project collaborators	External to the project consortia
Technical	<p>Example 1: Existing TPS OEM software has now been incrementally improved to support electrification. The software has since been used on other internal projects.</p> <p>Example 2: Results of experimentation with new materials that operate in extreme environments used in other projects outside the automotive sector by semiconductor design SME.</p>	<p>Example 1: Shared resolution of technical issues across a number of cases, i.e. mounting electronics, identification of appropriate power sources, powertrain electrification, material processing</p>	<p>Example 1: Academic publication of fundamental science by universities without commercial designs reported to have informed new basic science research avenues, i.e. power electronics, systems integration.</p> <p>Example 2: Technical knowledge shared with and from overseas OEMs and subcontractors, i.e. onboarding of systems within off-highway vehicles, engine valve control system.</p>
Managerial	<p>Example 1: Increased internal niche vehicle OEM capability and capacity to delivery internal R&D programmes.</p>	<p>Example 1: Academic experience of working with an OEM helped them to think about how technology will be commercial exploited – supported future R&D scoping.</p>	<p>Example 1: An OEM decided to begin MO reviews with a systematic update of the project aims and objectives. This increased the efficiency of reviews and was reported to have been adopted in other projects the MO supported.</p>
Economic	<p>Example 1: Applications of energy storage system in agricultural and military vehicle markets.</p> <p>Example 2: expertise in UK LCV supply chain to be used in other projects and wider strategic planning.</p>	<p>Example 1: An OEM worked with an electronic components SME. As a result, the OEM is a more knowledgeable consumer and able to better specify its requirements to suppliers the future projects that require power electronics.</p> <p>Example 2: Development of training materials to be commercially exploited in order to train other organisations in battery plant manufacturing processes.</p>	

Source: Ipsos MORI analysis (2017).

4.4 Leakage Risks

While there were numerous examples of APC anchoring R&D and manufacturing capabilities in the UK, there were also several unavoidable instances in which there were risks that the benefits of the programme leaked overseas:

- **Subcontractors:** The delivery of many APC projects involved the use of overseas subcontractors (or in one case, collaborators with a small UK presence where the relevant expertise was supplied from overseas offices). As noted in the preceding chapter, the use of these subcontractors was routinely justified by applicants on the basis that it was not possible to obtain equivalent capabilities in the UK. In some cases, these may lead to overseas firms building competitive advantage (though based on the case studies, it is unlikely that this will have a detrimental effect on the UK). For example, one firm engaged a German producer of hydraulic control systems that had no prior presence in a vehicle segment dominated by Korean, Japanese, and Chinese producers, and the knowledge acquired through the project may later allow them to obtain a foothold in this market.
- **Improvements to technology produced overseas:** In a similar manner, one niche vehicle producer was dependent on a diesel engine platform produced by a large European OEM. The project revolved around hybridising the engine and involved the OEM as a partner. This involvement has the potential to allow the OEM to 'free-ride' on the knowledge accumulated through the project and cement any competitive advantage.
- **Virtual manufacturing models:** The evidence suggested some SMEs which went into projects with the aspiration to produce the technology found it difficult to raise the capital needed to develop a production line. One solution to this challenge is to adopt a 'virtual' manufacturing model in which contract manufacturers are engaged to produce the designs developed. The one SME adopting this model across the case study projects elected to establish a wholly UK based supply chain, but clearly there are risks that other SMEs seek to offshore manufacturing activities overseas (working against the objective to reverse the 'hollowing out' of the UK automotive supply chain). Similar risks are also present in cases where SMEs are seeking to license designs rather than engage in production activities. The extent to which this issue is addressable will be partly dependent on how far the central issues relate to barriers preventing SMEs scaling up their production model or fundamental challenges in producing new technologies at an acceptable unit cost. This again reinforces the need for further research into these challenges.
- **Exports:** As mentioned previously, an SME developing a flywheel system for use in off-highway vehicles could find a market for the technology, despite the lead OEM on the project withdrawing their involvement. In this case, the technology has been integrated into off-highway vehicles produced by OEMs based overseas, potentially giving them a competitive advantage over domestic producers.

4.5 Impact of Contextual Factors

Applicants were asked to identify the impact of contextual factors on the technical and commercial outcomes of their projects. The evaluation provides evidence to suggest that APC projects are sensitive to changes in the market and political contexts, especially with respect to project scope and the exploitation strategy. The programme of qualitative research explored the influence of these factors:

- **Departure from the EU:** The UK's departure from the EU is expected to have several consequences and has introduced a degree of uncertainty. However, views gathered suggested that applicants had no intention of reallocating funding or terminating funded projects due to the UK's departure from the EU. Currently, the exchange rate changes in recent months are the only effect of the EU Referendum Result to have had practical implications for projects. For example, weak sterling has involved significant unit cost increases for a collaborator on a project developing both hybrid and EV technologies (particularly for battery cells, that comprise 40 percent of vehicle costs and were purchased from abroad in US dollars). In this case, the impact of Brexit enforced a strategic change in the role the SME took in the project to focus on low-volume high-tech R&D rather than EV battery production, which clearly has knock-on implications for the UK supply chain.
- **Fuel prices:** Falling fuel prices were suggested to have affected (at least in the short term) APC projects. This is because the size of value of fuel economy savings expected are critical to the economic viability of some projects. The decrease in the value of expected project benefits (in the form of the value of net fuel savings) will have an impact on project payback periods. One applicant reported that, in addition to facing challenges in reducing production costs of a KERS technology, the fall in fuel prices greatly challenged the economic viability of the project through increasing the payback period.
- **Supporting infrastructure:** The Business Case for APC identified a lack of infrastructure to catalyse both the production and use of LCV as a key market barrier. This view was repeated by respondents in the case study research. For example, applicants who pursued EV solutions commonly reported the need for physical infrastructure (i.e. enough correctly located charge points) coupled with increases in consumer demand for the EVs to make a significant impact on the environment and large scale automotive production.
- **'Diesel Gate':** The review identified that more industry (and increasingly public) attention was being paid to the issues caused by the production of nitrogen oxides by diesel engine powered vehicles. Applicants highlighted that, in the aftermath of 'Diesel Gate', they came under pressure (and official inspection in some cases) to ensure that their product fleets meet global emissions standards. 'Diesel Gate' was also reported to have accelerated demand for EV or zero carbon solutions, ruling out some technologies

under development altogether for fear of not meeting stricter incoming emissions regulation at local or national levels. In two cases, the business case for a hybrid bus engine deteriorated as bus purchasers were reported to increasingly demand ZEV models for their fleets.

4.6 Summary

- **Technological outcomes:** The case studies suggested that around half of the projects funded have encountered difficulties in meeting their technical objectives (which given the high level of risk associated with the projects funded is to be expected). While engineering challenges arose frequently in the delivery of projects, they were rarely the cause of failures to progress technical development to the intended levels. Difficulties arose more frequently where applicants had overestimated either their internal capabilities or those of suppliers (or the maturity of the technologies under development). Nevertheless, the case studies suggested that, on average, projects progressed to around TRL7 and MRL4-5, though there appeared to be some optimism bias associated with applicants' prior expectations regarding the potential technical performance of the technologies under development.
- **Exploitation:** Only one of the projects reviewed was at the stage where it was ready to launch a new product to market, though in many cases there was greater clarity regarding future commercial plans. Despite the technical challenges encountered in the delivery of many projects, on balance, current expectations in relation to future sales of vehicles integrating APC technology exceed those formed at the point of the application. Much of the anticipated production activity is expected to be undertaken in the UK, with few examples of unplanned offshoring. The evidence also suggested that the programme has been particularly beneficial for SMEs involved in projects, where participation has often helped anchor them in the supply chain of large OEMs (even where the core system is being produced overseas).
- **Manufacturing capabilities of SMEs:** Weaknesses in the capability of SMEs to produce the componentry and subsystems needed for electric vehicles was highlighted as a challenge in many projects (and caused one project to be put on hold). Given the wider direction of travel in the industry, this remains a potential threat and alternative instruments may be needed to help build the required capabilities to take advantage of the technologies supported through APC.
- **Risk management:** While the findings offer encouraging results, the level of risk associated with APC projects appears to be higher than assessed at the appraisal stage (with VFM assessments implying a 27 percent risk of failure). Consideration to introducing additional measures to manage risk both at the appraisal stage and while the project is in delivery may be helpful in maximising the value for money associated with the programme.

5.0 Conclusions

5.1 Progress against Objectives

The evidence from the evaluation suggests that the APC is broadly on course to meet its dual objectives of accelerating the progress of low carbon propulsion technologies and securing the long-term competitiveness of the UK automotive sector. While many of the projects have encountered technical challenges and suffered from delays, the underlying technical challenges have frequently been overcome (and the failure of some projects is to be expected in programmes of this nature). Although most projects reviewed as part of this evaluation were not at the stage of a commercial launch, current expectations in terms of future sales of vehicles integrating APC funded technology often exceed those formed at the outset of the project.

Much of the planned production activity is expected to go forward in the UK and there are numerous examples of APC projects anchoring production activities in the UK and in some cases contributing to the development of significant capabilities (such as in kinetic energy recovery systems). Generally, there was little evidence that applicants have sought to offshore production activity (except where it was declared as the intention at the point of application), though one large OEM did report an intention to assemble componentry elsewhere in the EU while implying this activity would take place in the UK at the application stage (suggesting there may be some risks that the benefits of the programme leak overseas, though this may be beneficial provided the R&D is anchored in the UK). However, it will also be important to understand the potential net benefits of leakage as making use of overseas contractors may enable the future exploitation of opportunities that draw on this initial development of UK capacity.

Recommendation: Progress against objectives

- (1) APC, BEIS and Innovate UK should consider the implementation of monitoring of post-completion exploitation outcomes to determine how far OEMs and Tier One suppliers go on to produce the technology in the manner claimed at the application stage. On the expectation that the APC will involve a long-term relationship - with OEMs submitting repeat applications - this type of evidence could be helpful in informing expected leakage corrections in the VFM appraisal. Excessive administrative burdens could be avoided by ensuring any follow-up is periodic and light touch.
- (2) APC, BEIS and Innovate UK should consider accelerating the implementation of arrangements to monitor the technological and economic outcomes associated with the projects which have received funding. This will provide benefits in terms of assessing performance management (by enabling a clear assessment of how projects have

Recommendation: Progress against objectives

performed against expectations), as well as in facilitating communication of the results of the programme to wider stakeholders and informing the assessment of bids for further public funding.

It is clearly challenging to attribute these results to the funding provided through programme without undertaking a quantitative impact evaluation, particularly amongst large OEMs where the general indications are that subsidies have helped to accelerate planned R&D programmes rather than to support projects that were genuinely marginal. As such, the conservative approach taken by BEIS in assessing the likelihood that projects would proceed without public support appears to be broadly appropriate.

The collaboration requirements of the programme have forced OEMs to work with many domestic suppliers where they may have otherwise preferred to have worked with firms overseas. This has produced numerous benefits for SMEs which may have otherwise struggled to fund further development and been unable to de-risk their technologies. Some have become anchored in the automotive supply chain and, in some cases, generated export sales. More generally, APC funding has given momentum to collaborative endeavours by formalising roles and responsibilities and has stimulated the commitment of resources. However, there was some evidence that the collaboration agreements signed at the outset of projects inhibited the ability of SMEs to exploit the technologies under development.

Recommendation: Progress against objectives

- (3) The APC should work with applicants to help resolve any issues that may arise in situations where collaboration agreements may inhibit the exploitation of the technology developed with public funding.

5.2 Risk Management

While the progress of the portfolio of projects is encouraging, technical and commercial risks appear to be more significant than anticipated at the appraisal stage by stakeholders (with average level of risk judged at 27 percent in the VFM assessments completed by BEIS). There appears to be a level of optimism bias associated with applicant's expectations regarding the likely level of performance of the technologies under investigation (which informs funding allocation decisions). Unforeseen changes in the external environment have also had major effects on the objectives or commercial viability of some of the projects funded.

As suggested above, it is natural to expect some projects to fail given the nature of the programme, though it may be beneficial to consider possible strategies for improving the management of risks. The case study evidence suggested that the technical hazards that arose in the delivery of projects were rarely identified at the Independent Assessment stage. Additionally, projects involving major changes in scope that would materially alter the basis on which public funding was awarded are not given the same level of scrutiny as at the initial award stage. The use of 'gateway reviews' appeared to prove effective in ensuring public funds were not expended on pursuing projects that would ultimately not deliver, and wider use of this mechanism could be potentially beneficial.

Recommendation: Risk Management

- (4) APC, BEIS and Innovate UK should consider whether it would be feasible to require applicants to provide additional documentation at the due diligence stage describing the extent and results associated with the tests completed to take the development of the core systems to TRL5. This could potentially help validate the technical claims made by applicants and identify any risks that could form the focus of any 'gateway reviews' introduced to support risk management, the increased use of which is suggested in recommendation 7.
- (5) The separate presentation of BCRs with and without environmental benefits following the VFM assessment is appropriate given the uncertainties involved. However, BEIS should consider whether it may be appropriately conservative to also apply an optimism bias adjustment in the VFM assessment given the evidence that the technologies developed did not always deliver their anticipated fuel economy savings.
- (6) BEIS should also consider whether it may be desirable for the VFM analysis to assign higher weight to expected fuel economy gains produced in excess of emissions legislation targets, given that these targets need to be met in any case. The VFM analysis could potentially be refined by discounting any emissions savings below regulatory requirements (or exploring this through sensitivity analysis). Additionally, a timing adjustment for any emissions savings above those targeted or required by the lead applicant may be desirable to allow for possibility of technologies for future product launches.
- (7) APC, BEIS and Innovate UK should consider making greater use of 'gateway review' processes (or staged grant awards linked to the achievement of technical milestones) to more effectively manage the risks associated with committing funding to large programmes of technical development. The implementation of any such processes should involve rapid timescales for decision making to provide certainty and avoid unnecessary delays in project delivery.
- (8) If APC, BEIS, and Innovate UK seek to make greater use of staged payments or 'gateway reviews' as means of improving risk management, consideration should also

Recommendation: Risk Management

be given to the potential exploitation of sub-systems being developed by collaborating parties. In cases where there is a compelling reason to withdraw funding from the core project, there may be a case for continuing funding the development programmes led by collaborating parties. This may require downsized (rather than cancelled) contributions to the OEM to maintain the benefits of their involvement in terms of both expertise and preserving a route to market.

- (9) APC, BEIS and Innovate UK should consider whether there may be value in repeating the VFM assessment in cases where projects are subject to major re-scoping and fundamental changes to the basis on which public funding was awarded (to provide assurance that the new proposal offers sufficient value for money). A clear definition of what is understood by 'major rescoping' will need to be introduced.

5.3 Contextual Factors

The R&D agenda of large OEMs has evolved substantially since the programme was conceived in 2013, with many now seeing electric vehicles as the likely future standard that will enable the requirements of emissions legislation to be met. In some sectors, growing concerns regarding air quality (as well as the publicity associated with 'diesel-gate') have accelerated the need for zero carbon propulsion technologies ahead of prior expectations. The rapid speed of change led to the abortion or major re-scoping of some projects, and it may be likely that the technologies developed through earlier rounds of APC will become redundant more rapidly than expected. Some stakeholders and vehicle producers also saw the move toward electric vehicles as precipitating a form of technological 'lock-in' in which OEMs had stopped seeking to explore alternative technologies that could offer similar emissions reductions.

These trends potentially pose major challenges for the APC in meeting its overall policy objectives. A major issue that arose in the research was a concern relating to the capabilities of suppliers to respond to a large-scale increase in demand for electric vehicles. While there is evidence that the programme has helped SMEs build their capabilities, they were insufficiently developed to enable them to produce at the scales that may be needed in the future. These types of issue caused the failure of one of the ten projects examined in the case studies, and there is evidence that SMEs are seeking alternative exploitation models (such as 'virtual' manufacturing models or licensing deals). It is conceivable that these factors will lead to an elevated risk that the technologies under development will eventually be exploited overseas (where producers were reportedly better able to accommodate larger production volumes).

Recommendation: Context

Recommendation: Context

- (10) BEIS and Innovate UK should undertake specific research exploring the extent to which SMEs in the automotive manufacturing sector face specific financial market constraints that prevent them building their manufacturing capabilities, and whether there may be a need and demand for complementary instruments to help SMEs upscale production (i.e. capital investment rather than R&D subsidies) – or how far the apparent challenges are driven primarily by challenges in producing at an acceptable unit cost. There may also be comparable issues in other advanced manufacturing industries to which these instruments may well be relevant.



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