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Advanced Propulsion Centre: Impact and Economic Evaluation Scoping

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Contents

Executive Summary

Ipsos MORI, Ecorys and George Barrett were commissioned by the Department for Business, Innovation, and Skills in November 2014 to undertake a programme of evaluation activities in support of the Advanced Propulsion Centre (APC). This report sets out the results of an evaluation scoping study designed to establish an evaluation framework and methodology for assessing the causal effects of the APC. The framework has been designed to assess the APCs net effects on social welfare through an economic evaluation delivered in alignment with the principles of the HM Treasury Green Book.

The Advanced Propulsion Centre

The APC is a joint commitment by industry and government to invest £1bn over the next ten years into research, development and commercialisation of low carbon propulsion technologies. The APC also involves the creation of the APC Ltd to support co-ordination of R&D relating to low carbon propulsion technologies. At the time of writing, eleven applications had been received over two rounds of the programme, and an exceptional process, with £60m committed to seven projects from a total public sector budget of £500m.

Objectives of this Report

This report builds an impact evaluation framework and scopes out the delivery of a future evaluation of the Advanced Propulsion Centre. It details the APC’s objectives, its rationale and economic case, and the mechanisms by which it is expected that these objectives are to be achieved. It also develops the key performance indicators required for a robust evaluation as well as considering how they should be used. The report has been prepared to sit alongside a process evaluation report focusing on the implementation of the APC programme.

Rationale for Intervention

Climate change legislation is likely to transform the nature of automotive propulsion systems, requiring that the stock of registered vehicles emit no greenhouse gases by 2050 (and by extension, that all vehicles in production meet these standards some 10 years beforehand). The change threatens to de-stabilise existing supply chains posing both an opportunity and a threat for existing supply chains which are predominantly organised around the production of internal combustion engines. There are several arguments put forward that anticipate that the private sector will not capitalise on these opportunities without intervention. Chief amongst these is the likelihood that any widely adopted propulsion system will require a network of supporting infrastructure leading to the 'lock-in' of a particular technology. The nature of this technology is unclear, and any large scale R&D efforts to develop new propulsion systems carry a significant risk that the resources expended would be wasted (creating incentives for firms to free-ride on competitors R&D activities until there is more certainty over this future standard). As such, public support will likely be required to stimulate the R&D activity needed to take advantage of the strategic opportunities presented by these broader policy drivers.

Key Outcomes

The table below defines the key outcomes that an impact evaluation of the APC might need to establish (and an indication of their importance in demonstrating the potential effects involved). This covers the direct of the large scale grants offered through the programme on R&D activity, technological progress, and the downstream economic impacts associated with launching new low carbon propulsion systems to market. The broader activities of APC Ltd might also be expected to lead to a range of indirect effects (such as crowding-in of investment). The APC is a long-term programme of support to the automotive sector, and the projects funded may only deliver their full impacts over long time horizons. As such, it should be acknowledged that some of these effects may also only be visible over long timescales (potentially up to 2030 or beyond).

Table 1: Key Outcomes for an Impact Evaluation of APC

Outcome Area	Outcome Measure	Direct or Indirect	Priority	Timescale
R&D activity	• Low carbon propulsion R&D projects initiated	Indirect	Low-medium	**2013-2023**
	• % of R&D targeted at low carbon propulsion technologies	Indirect	Low-medium	
	• New entrants to the low carbon propulsion technology area	Indirect	Low-medium	
	• R&D expenditure	Direct	Highest	
	• R&D employment	Direct	Highest	
Technical progress	• Technology Readiness Levels	Direct	Highest	
	• Manufacturing Readiness Levels	Direct	Highest	
Collaboration	• Inter-firm collaborations	Both	Medium	
	• Industry-academic collaborations	Both	Medium	
Technology Transfer	• Number and value of licensing agreements	Direct	Medium	
	• Value of sale of IP from academia to industry	Direct	Medium	
Intellectual Property	• New IP registered	Direct	Medium	
	• Value of IP	Direct	Medium	
Skills Development	• Number of R&D workers employed in automotive sector	Indirect	Low-Medium	
	• Wages of R&D workers employed in automotive sector	Indirect	Low-Medium	
	• Knowledge spill-overs	Indirect	Medium	
FDI	• Levels of FDI in automotive sector	Indirect	Medium	
Economic Impacts	• Sales of vehicles integrating APC technology	Direct	Medium-High	**2020-2030 (and beyond)**
	• Turnover	Direct	Medium-High	
	• Employment	Direct	Medium-High	
	• GVA	Direct	Medium-High	
	• Average Labour Productivity	Direct	Medium-High	
	• Total Factor Productivity	Direct	Medium-High	
	• Imports as % of total inputs	Direct	Medium-High	
	• Export sales	Direct	Medium-High	
Environmental impacts	• CO_2 emissions profile of vehicles sold	Indirect	Medium-High	
	• Particulate matter associated with vehicles sold	Indirect	Lowest	

Measurement of key outcomes

An evaluation of the APC will require longitudinal data (ideally annual) on a wide range of outcomes of interest measuring aspects spanning from R&D activity and investment, technological development, through to sales of vehicles integrating low propulsion technologies and their technical specifications. In many cases, these measures can be established either directly, or via proxy measures, through appropriate use of secondary datasets. These datasets include:

- **APC monitoring:** Monitoring data will provide a range of information on the technical progress of projects alongside longitudinal data relating to the activity of the firms involved in APC supported collaborations.
- **Patent data:** Patent data provide a useful window on the technological development process that may throw light on a range of questions of interest including illustrating overall resources committed to the R&D process, changing research priorities, and offer signals of knowledge spill-overs.
- **Monitoring associated with other programmes:** Monitoring data associated with other programmes might offer some insight into the pipeline of low carbon propulsion technologies which are at early stages of development as well provide control variables to allow the effects of APC to be separated from other projects.
- **Vehicle production and sales data:** Records of vehicle registration and their technical specifications are available at a model level through trade organisations such as the SMMT and the ACEA. This data could be exploited to explore the impacts of APC funded technology in product markets, provided it is feasible to trace the technology developed through to the particular vehicle models.
- **Government datasets:** Finally, ONS held micro-data available through the Virtual Microdata Laboratory will provide longitudinal observations on some of the key firm level observations needed to examine the economic impacts of the APC.

A **data-linking feasibility** exercise was completed as part of this study. This demonstrated that linking records of APC applicants to computerised patent records, the datasets within the VML, and monitoring data collected as part of other programmes would achieve high success rates. However, there may be issues with disclosure owing to the small samples sizes (preventing retrieval of analysis from the VML).

Primary research in the form of surveys of applicants is recommended to measure the full breadth of outcomes of interest (particularly in obtaining measures of technical progress amongst potential comparison groups). This will also offer a contingency option in the event that it is not feasible to retrieve results from the VML.

Monitoring Recommendations

Some enhancements to monitoring might be implemented to improve the potential range of evaluation options available. The most critical improvements are set out below (others of possibly less importance are noted in Section 3 and Section 7).

Recommendation	Priority	Cost
Technological monitoring: Technological monitoring should be adjusted to capture the MVRIS code associated with any vehicle models into which APC technology has been integrated to aid linking to SMMT and other product market data.	**High:** It is anticipated that the main opportunity for rigorous analysis will be to explore the product market effects of the introduction of vehicles integrating APC funded technologies. However, this will only be feasible if it these technologies can be traced into the product market (and at, present, this will not be feasible).	**Low:** Again, this would require an additional column to be added to the technological monitoring frameworks. The burden on applicants should in principle be low, as they would only be required to report this information where the technology has been integrated into new vehicles.
Post-project monitoring: On-going monitoring of APC projects should continue for a minimum of three years following the completion of the project (perhaps on an annual basis), to more completely capture the technical and commercial effects of APC projects (including MVRIS codes as highlighted above).	**High:** The commercialisation of APC projects will not occur until after they have come to an end: it is expected that many applicants will need to resolve outstanding engineering challenges before propulsion systems can be integrated into new vehicles. As such, many of the important commercial or economic impacts may be missed if monitoring concludes following project completion.	**Medium:** Clearly, on-going project monitoring will place an additional burden on Innovate UK monitoring officers as well as on the applicants themselves (though the additional resource burden may be minimal if Project Associates can support this process).
Company monitoring: The scope of company monitoring could be usefully extended to a range of additional measures, including: • Employment • Turnover • Exports • GVA • Consumption of finished goods and services	**Medium:** To some extent, information on economic monitoring, while critical in the long term for an economic evaluation, can be gathered through alternative means including primary surveys of applicants or through data-linking. However, these approaches may be more costly than extending monitoring, may not offer data that is neither as robust nor timely as might be gathered through monitoring.	**Low:** Regular monitoring of these variables will likely mainly place additional burdens on applicants in the collation of these measures (though finance officers should routinely be able to compile these measures from accounting data). This burden could be minimised by completing the process annually (for example) and utilising light touch and user friendly tools. Additionally, the changes required represent an incremental change on existing Innovate UK monitoring processes.

Impact and Economic Evaluation Options

In terms of an impact and economic evaluation, a mixed methods evaluation strategy is recommended as follows:

- **Uncertainties:** There are substantial uncertainties over the sample sizes associated with any future analysis, which may limit the application of quantitative methods. This should be kept under review before commissioning a main-stage evaluation.

- **Direct impacts of APC:** Contingent on sufficient sample being available, it should be in principle feasible to quantify the causal effects to varying degrees of robustness using the following strategy.

  - **Choice of counterfactual:** Unsuccessful applicants would be the preferred comparison group for an econometric analysis. However, if resources permit, the inclusion of other groups might be integrated into a main-stage evaluation (such as applicants to LCV-IP that did not apply to APC) to check on the sensitivity of results to the selection of controls.

- **Econometric methods:** It is advised that the main-stage evaluation involves the application of a combination of econometric methods. This would include longitudinal panel methods, alongside potentially more robust pipeline (if appropriate) and Regression Discontinuity Design methods. Matching techniques could potentially be applied to refine samples in terms improving their balance with regard to the observable characteristics of the projects and applicants involved.

- **Displacement:** The availability of detailed product market data will mean that quantitatively rigorous approaches to estimating displacement effects can be plausibly explored and should be pursued as part of an evaluation strategy. This would involve modelling the negative effects on the market share of competing vehicles following the introduction of vehicles integrating APC funded technology). However, these strategies can only be feasibly implemented if it possible to trace APC funded technology into specific vehicle models (as described in Chapter 3).

- **Spill-over effects:** The architecture of the APC creates the possibility of broadening the definition of the treatment and comparison groups to include organisations that potentially might receive a spill-over benefit (including spatially adjacent firms, networks of collaborators beyond those named in APC applications, or those citing patents registered by APC applicants). It is difficult to predict the potential value of such analyses, but as they will exploit similar sets of secondary data, an exploratory analysis is recommended as part of a main-stage study.

- **Contingency:** In the event that insufficient sample sizes are available, a before and after approach is recommended examining the gross outcomes of APC projects.

- **Indirect impacts of APC:** The APC has been designed to have broader impacts in terms of stimulating investment in low carbon propulsion technologies in the UK, effects that may be visible in a broader population of firms and academic institutions than grant applicants. To explore these effects, it may be feasible to both develop a 'reference' technology area as a comparator, and implement an international comparative study relating the availability of subsidies for R&D to the performance of the automotive sector. Such studies are likely to fall short of providing a true counterfactual, and will likely conflate the impacts of APC with the wide array of Government investment in this technology area. As such, while results may provide useful context for an evaluation (and framing the results of quantitative and qualitative research), a quantitatively rigorous separation of the impacts of APC from other policies is likely to be infeasible. As such, a before and after analysis drawing on the available secondary data is recommended, supplemented by qualitative research forming the case studies below).

- **Case studies:** Given the challenges involved in establishing robust quantitative estimates of the impacts involved, a programme of case study research is advised to examine the impact of APC on grant applicants, the emergence of new low carbon propulsion technologies, and the attraction of FDI projects. Case studies could be grounded in realist, process tracing, or contribution analysis methods depending on the focus, and would take the forms specified in the table overleaf.

Effects of APC on grant applicants	Broader Impacts of APC
Synthetic control groups: statistical tools known as synthetic control groups can be used to provide a quantitative structure for the case study analysis. This technique can be used to build an artificial, tailored comparison for a particular firm, or consortia to be investigated through the case studies, Drawing on the metrics discussed above, this approach will offer an initial hypothesis about the relative performance of the firms in question to test through the qualitative research. **Documentary evidence:** existing materials will provide a starting point for the in-depth investigation of case-study applicants. This analysis will draw on application forms, monitoring reports, technical papers, patent submissions and their citations, as well as secondary statistics such as vehicle sales. **Depth interviews with lead applicants and collaborators:** the most critical activity for the preparation of these case-studies will be to make contact with project participants to test and validate the hypotheses made about the projects from the data and documentary evidence. This would explore the history of the projects, the financial model used to bring it forwards, the activities undertaken, the relationship between project partners and their relative roles, the role of the financial and soft support received from the APC as well as other public bodies as well as the wider context of the project (such as related initiatives from the partners and their competitors)	**Emergence of new propulsion technologies:** Reflecting the scale and significance of APC funding, it is realistic to expect the programme to have some impact on a large proportion of the new low carbon propulsion technologies emerging from the UK up to 2030. Case studies can therefore be prepared around specific future advances in low carbon propulsion technologies. Each would focus on a new technology, product or business model, and the objective would be to investigate the role the APC played in bringing this forwards. These case studies would draw on soft systems methodologies to map the contribution of different actors in the innovation process. This would rely on a snowball sampling approach – starting with interviews with individuals understood to be linked to the innovation, and broadening out across the network of actors identified as responsible by them or any supporting material. **Foreign direct investment:** A similar case study approach could be pursued to investigate the role of the APC in attracting foreign direct investment. Here the unit of analysis would be a major investment in the UK from a foreign automotive manufacturer in the area of low carbon propulsion systems. An equivalent methodology could then be used to explore the role of the APC in their decision to invest in the UK.

Main Stage Specification

Revisit Scoping

The proposed research programme set out below should be revisited by BIS in 2017 or 2018 once the overall volume of applicants to the APC is known or can be predicted with more clarity. This exercise should focus on examining how far sample sizes are sufficiently large to support a detailed quantitative analysis of impact. If not, the proposed work programme might be adjusted to focus on a quantitative demonstration of the gross outcomes (i.e. a before and after study). This may also be a useful opportunity to take stock of technological and other developments in the industry as the first set of projects reach completion, as means of identifying potential case studies for the programme of qualitative research proposed.

Main Stage Evaluation

A long term evaluation programme would be required to examine the impacts of the APC. It is suggested that the evaluation takes place over three waves (2018/19, 2022/23, and 2029/30). Initial waves would primarily focus on issues regarding the effects of APC on accelerating technological developing and leveraging private R&D spending, while later waves would increasingly focus on examining the downstream economic impacts of the programme. An overview of the recommended data collection strategies and methods are set out in the table overleaf.

An interim *process* evaluation in 2016/17 may also be beneficial to examine early activities and outputs from projects that have started, how far the projects have progressed to plans, and technical or commercial issues that have been encountered in development of the technologies forming the focus of projects.

Aspect	Interim Evaluation (2018)	Interim Evaluation 2 (2022)	Final Evaluation (2030)
Central focus	Effects on R&D spending and technical development and broader investment patterns.	Effects on R&D spending and technical development and early economic impacts.	Downstream economic impacts of the APC.
Direct Impacts of APC			
Analysis of Monitoring Information	Covering the progress of projects funded between 2013 and 2018, covering technological and R&D expenditure and employment outcomes. Initial assessment of post-completion outcomes.	Full statement of progress achieved by APC projects between 2013 and 2023, including post-completion outcomes achieved by those projects that were completed prior to 2022.	Full assessment of post-completion outcomes associated with all APC funded projects.
Survey of APC applicants	First survey wave of applicants capturing retrospective baseline measures and follow-up measures. Coverage of successful applicants, and if sample sizes are likely to permit application of econometric methods, unsuccessful applicants.	Second survey wave of applicants capturing follow-up measures of key outcomes. Coverage of successful applicants, and if sample sizes are likely to permit application of econometric methods (even only in the longer term), unsuccessful applicants.	*Further surveys unlikely to be deliverable at this stage, owing to loss of institutional memory and time elapsed since grant funding provided.*
Datalinking	Linking of applicant records to patent records, bibliometric data, and ONS VML datasets. Coverage of successful, unsuccessful and non-applicants to the APC.	Linking of applicant records to patent records, bibliometric data, and ONS datasets and VML. Linking to MRVIS if vehicles integrating APC funded technology have been launched at this stage.	Linking of applicant records to patent records, bibliometric data, ONS VML datasets, and MVRIS.
Econometric analysis (contingent on sample sizes)	Application of difference-in-differences, pipeline methods and RDD (where appropriate), focusing on questions relating to input additionality and technical progress.	Application of difference-in-differences, pipeline methods and RDD (where appropriate), focusing on questions relating to input additionality, technical progress, and economic impacts.	Application of difference-in-differences, pipeline methods and RDD (where appropriate), focusing on questions relating to economic impact.
Assessment of displacement	Not at this stage.	If vehicles integrating APC funded technology have been launched by this point in time.	Yes
Assessment of spill-overs	Not at this stage.	Exploratory analysis suggested as a possible option.	Exploratory analysis suggested as a possible option.
Project level case studies	Consultation with key project personnel and synthesis of available documentary evidence.	Consultation with key project personnel and synthesis of available documentary evidence. Application of synthetic control methods.	Unlikely to be feasible at this stage.
Indirect Impacts of APC			
Analysis of secondary data	Focusing largely on crowding-in effects, relevant levels of R&D activity (including pipeline projects visible in LCV-IP, EPSRC applications), FDI projects and technological change.	Focusing on crowding-in effects, relevant levels of R&D activity (including pipeline projects visible in LCV-IP, EPSRC applications), FDI projects and technological change. Analysis extended to employment, productivity, and output in the automotive sector, and technical properties of vehicles for commercial sale.	Analysis focused on long term changes in performance of the automotive sector in the UK (including sales in non-domestic markets), and the technical properties of vehicles for commercial sale.
Technology case studies	Where it is possible to identify commercialisation of low carbon propulsion technologies.	Where it is possible to identify commercialisation of low carbon propulsion technologies.	Where it is possible to identify commercialisation of low carbon propulsion technologies.
FDI	If possible to identify specific FDI projects of relevance.	If possible to identify specific FDI projects of relevance.	If possible to identify specific FDI projects of relevance.

1.0 Introduction

Ipsos MORI, Ecorys and George Barrett were commissioned by the Department for Business, Innovation, and Skills in November 2014 to undertake a process evaluation, a KPI review, and a scoping study exploring and testing impact and economic evaluation options for the Advanced Propulsion Centre (APC).

1.1 The Advanced Propulsion Centre

Forming a key element of the UK Automotive Strategy[1], the APC is a joint commitment by industry and government to invest £1 billion over the next ten years into research, development and commercialisation of low carbon propulsion technologies.

Advanced Propulsion Centre: Overview
The points below summarise the portfolio of applications received and supported by the APC. A full analysis is included in Appendix C. • 11 full applications were received through two full rounds and a supplementary exceptional process (Note that at the time of reporting, Rounds 3 and 4 were out of scope). • These applications came from eight different lead partners. Two of these applications were re-submissions, and one was a second application from a lead partner that was funded under a prior round. • On average applications involve a consortium of six partners. All but one application has been led by a large firm and seven different academic institutions have featured within the applications. • Eight of the 11 applications relate to adjustments to an internal combustion engine. Five cover energy storage and energy management, and three relate to electric machines. • Seven projects have received funding. To date £60m has been committed to projects from the total £500m APC budget.

1.2 Objectives of this report

This paper builds an impact evaluation framework and scopes out the delivery of a future evaluation of the Advanced Propulsion Centre. It details the APC's objectives, its rationale and economic case, and the mechanisms by which it is expected that these objectives are to be achieved. It also develops the key performance indicators required for a robust evaluation as well as considering how they should be used. The report has been prepared to sit alongside a process evaluation report focusing on the setting up and implementation

[1] https://www.gov.uk/government/publications/driving-success-uk-automotive-strategy-for-growth-and-sustainability

of the APC programme, and a data testing report which tests the data-linking methodology proposed below.

1.3 Methodology

This output draws from research conducted across the evaluation programme. The wider evaluation programme has involved a familiarisation phase consisting of a programme document review, interviews with policy stakeholders, a literature review and analysis of all application and appraisal data. Further to this, case studies have been prepared on applicants – both successful and unsuccessful – and discussions have been held with non-applicants to the programme.

1.4 Structure of the report

This paper is structured as follows:

- Section 2 sets out the proposed framework for the evaluation.
- Section 3 outlines how the key outcomes might be established.
- Section 4 explores the range of possible impact evaluation options (quantitative and qualitative).
- Section 5 details the required elements for an economic evaluation.
- Section 6 concludes the paper by summarising the required evaluation tasks and the proposed timings for the main-stage specification.

2.0 Evaluation framework

This section sets out an overarching framework for undertaking an impact and economic evaluation of the Advanced Propulsion Centre (APC). This framework articulates the overall policy objectives of the APC, the strategic and economic rationale for intervention and the anticipated causal process by which the programme is expected to lead to its anticipated outputs, outcomes and impacts. Consideration is also given to the broader policy context within which the APC is delivered, highlighting implications for the evaluation.

2.1 Aims and objectives of the APC

The core objectives of the Advanced Propulsion Centre are to[2]:

- achieve significant progress in developing low carbon propulsion technologies; and,
- secure the future of the UK automotive manufacturing sector.

The Advanced Propulsion Centre involves two main elements. Firstly, the UK Government and the Automotive Council have made a commitment to invest £1bn (including £0.5bn in public subsidies) in research and development projects aimed at commercialising low carbon propulsion technologies. Subsidies are targeted at projects where a minimum level of technological development has been reached (i.e. prototypes have been developed at laboratory scale), but significant challenges remain in terms of optimising performance and developing assembly line manufacturing processes. Competition rounds to date have been aimed at collaborative projects (reflecting the modular nature of propulsion systems) that involve an Original Equipment Manufacturer (OEM) or Tier One supplier (to provide some assurance that there is a realistic route to market).

The second element of the APC is the creation of an independent body (APC UK Ltd), tasked with co-ordinating research and development activity in the technology area. The function of APC UK Ltd envisaged in the Business Case included maintaining technology roadmaps for the sector, matching products to customers, catalysing new collaboration, as well as a commercial function in securing provisional orders and securing finance for low volume production. In the future, it was anticipated that the APC UK Ltd would involve the co-location of senior engineers from industry working on the development of technology that could be shared across OEMs (though any future evaluation programme will need to consider how the role of APC UK Ltd evolves over time and whether this will introduce any additional research priorities).

2.2 Strategic rationale

The Climate Change Act of 2008 places a legal requirement on the UK to reduce its emissions to 80% of 1990 levels by 2050. This is driven by an aim of reducing the negative externalities (in the form of future abatement costs) associated with carbon dioxide

[2] Advanced Propulsion Centre: Business Case, Department for Business, Innovation and Skills, 2013 (unpublished).

emissions. 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 will be needed[3].

The implication is that supply chains centred on the production of internal combustion engines will, at some point in the future, 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 specialisation in propulsion technologies. At present the UK is the 14th largest producer of vehicles in the world and the 4th largest in the EU, producing 1.6 million finished vehicles in 2014[4]. The UK also produces a further million internal combustion engines (ICEs) for cars each year (the propulsion systems of cars account for approximately 40 per cent of the value of a vehicle[5]). The automotive sector is also export intensive: the UK exports almost 80 percent of the vehicles it produces, many of which are classed as premium vehicles, resulting in a current account surplus of finished motor vehicles of £104m for the industry in 2013[6]. In total, the automotive industry accounts for four percent of UK GDP, supporting 200,000 direct jobs in the UK automotive sector[7] and a large number of jobs in other supporting industries. Productivity in the sector is high (with GVA per worker at £115,400 in 2014 almost double the UK manufacturing sector average) and continues to grow. SMMT analysis in April 2015 suggests that the industry produced 11.5 vehicles per worker employed between 2010 and 2014, 23 percent higher than between 2005 to 2009, and 75 percent than during the early 1990s.

As such, changing regulation and demand have the potential to threaten the economically significant automotive sector. SMMT data shows that while ICE vehicle sales have been relatively stable across Europe between, sales of LCVs were rising (though accounting for a small share of overall vehicle sales). The Automotive Council and Government undertook a horizon scanning exercise in 2013, mapping out the anticipated path of technological development in the automotive industry. The resulting ‘roadmap’ set out what they described as 5 ‘sticky technologies’[8] that are central to the UK’s future competitive advantage in the automotive sector. These were:

- Internal combustion engines;
- Energy storage and energy management;
- Electric machines and power electronics;
- Light weight vehicle and powertrain structures; and
- Intelligent mobility.

Of these, the following have been identified in the original business case for the APC to the Treasury as key components of a low emissions vehicle: internal combustion engines,

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[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 is subject to a range of major future uncertainties).
[4] International Organisation of Motor Vehicle Manufacturers, Production Statistics. Available at: http://www.oica.net/category/production-statistics/ (accessed March 2015).
[5] The APC business case highlights the high value of propulsion systems as part of their rationale.
6 The Pink Book, Trade in Goods, Office for National Statistics, 2014. Available at: http://www.ons.gov.uk/ons/rel/bop/united-kingdom-balance-of-payments/2014/index.html (accessed March 2014).
[7] http://www.smmt.co.uk/2014/02/motor-industry-facts-2014/
[8] These technologies are described as sticky due to the likely network effects and external economies of scale that can be realised from developing a depth of expertise in these areas. Source: Automotive Council, Technology Group website content available at: http://www.automotivecouncil.co.uk/technology-group-2/

energy storage and energy management; power electronics; and light weight powertrain structures. Recent research across global automotive executives suggests that the key area of technological effort in propulsion technologies (to 2025) will be the optimisation or downsizing of the Internal Combustion Engine[9], rather than the development of battery, electric or fuel cell propulsion systems. This may be reflective of broader slow rates of technical development in these forms of technology: the underlying principles have been known for some time, but have not received much attention since the first serious attempts at zero emissions vehicles in the 1960s[10].

As such, there is a window of opportunity for the UK to build on its existing strengths and capacities to safeguard automotive manufacturing, and potentially reverse the 'hollowing out' of the automotive supply chain observed since the 1980s if a form of 'first mover advantage' can be developed in which the relevant skills and expertise in the UK automotive supply chain can be developed ahead of global competitors (leading to the attraction of foreign direct investment, greater exports of UK manufactured components and systems, and lower import dependency). Such a transition will involve radical innovation (though in the short-term, progress is likely to be seen in terms of improvements to the internal combustion engine), fundamental design re-thinks, transformations in how products are specified and new underpinning architectures (and will likely depend on the ability of the sector to act in collaboration, including co-ordinated inputs from across the supply chain). However, other States are also recognising these opportunities: for example, the Chinese Government has announced a £10bn programme of investment in these technologies over five years as a means of putting the country at the forefront of global automotive manufacturing. Given these threats, this window of opportunity may only remain open for a comparatively short period of time.

2.3 Economic rationale

There is a range of plausible arguments put forward outlining why the private sector may not respond to these challenges and opportunities in an optimal and timely way. In particular, there are market failures relating to the network externalities associated with the complementary infrastructure that will be likely be required to support a fleet of low carbon vehicles (which will magnify the risk associated with large scale R&D investments). Additionally, the collaboration required to develop new propulsion systems may be subject to a range of transactional frictions that prevent its emergence even where it is in the best interests of the parties involved to co-operate. Relatedly, the vertically dis-integrated nature of automotive supply chains also creates the risk of classical knowledge spill-overs that may also prevent OEMs internalising the full benefits of their R&D investments.

Network externalities

It is anticipated that the widespread adoption of low carbon vehicles will require a network of complementary infrastructure (which could range from new investments in power generation and fuelling stations through to a new workforce competent in the maintenance of the technologies of relevance). A form of technical 'lock-in' will likely emerge once it becomes clear which standard is technologically superior (e.g. as was the case in the

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[9] Global Automotive Executive Survey, KMPG, 2015. Available at: http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/global-automotive-executive-survey/Pages/default.aspx (Accessed March 2015).

[10] Eisler, (2012)

1970s and 80s as dual and three-way catalytic converters were being explored as optimal solutions to regulatory requirements to reduce hydrocarbon, nitrous oxide, and carbon monoxide pollutants in vehicle emissions[11]). Even if two technically comparable standards emerge from R&D activities, 'lock-in' will likely occur owing to the positive network externalities associated with the adoption of a single standard on an EU wide or global basis.

This makes investment in specific R&D projects highly risky for OEMs, particularly given the high costs associated with moving from a laboratory developed prototype to assembly line production (e.g. development of efficient manufacturing processes or investment in machine tools for suppliers). These risks are likely to fall once there is more clarity over the future direction of technological development, creating an incentive for manufacturers to postpone their investment to avoid the possibility of the losses that might be incurred as a consequence of expending large amount of resources on a 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 subsidising these R&D investments to de-risk pioneering projects).

Transactional Frictions

Vertical dis-integration within the automotive sector has been an on-going trend as OEMs seek to maximise the efficiency of their core operations (assembly of finished vehicles or propulsion systems) giving space to suppliers to optimise the manufacturing of componentry (often requiring close relationships between the Prime and suppliers). While this long-term trend has possibly contributed to the 'hollowing-out' of the automotive supply chain (as Primes seek to source componentry from overseas suppliers that can offer a lower price point), it will also mean that the development of new propulsion technology will require collaboration across the supply chain that would provide the mechanical or electrical components that would form the system. Given, the disruptive nature of the technology, relationships may need to be built with new types of firm not traditionally associated with automotive manufacturing.

However, there are a range of market failures (that might loosely be grouped under the heading 'transactional frictions') that may prevent a collaborative R&D projects from being taken forwards even if the expected returns on investment are sufficiently high:

- **Free-riding:** The success of collaborative projects will rely on all partners involved committing resources. However, such commitment cannot always be rigorously monitored. This creates incentives for partners to under deliver against their commitments (i.e. allowing them to free ride on partners' investments). As a consequence, collaborative projects can be inherently unstable and may break down before project goals are realised.
- **Incomplete contracts:** The outcomes of R&D projects are to some extent uncertain by definition. This can make it difficult to agree a contractual framework to cover collaboration, and particular issues can arise over the ownership of any IP generated by the work. As such, some projects may not proceed owing to difficulties in agreeing these contractual issues.

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[11] Lee, J. and Berente, N. 2013. The Era of Incremental Change in the Technology Innovation Life Cycle: An Analysis of the Automotive Emission Control Industry. *Research Policy*.

- **Uneven distribution of returns:** Collaborators are rarely equal, and there will typically be one partner who brings the greatest expertise and resources to a project. The transactional challenge here is to find a structure which proves attractive for all partners.
- **Classical spill-over effects:** Collaborations can also be inhibited by the perceived or actual risk of knowledge spill-overs whereby co-operating partners are able to gain an understanding of (and exploit or leak) their collaborators' competitive advantages where they would have otherwise remained secret (again, creating disincentives to work co-operatively). These issues are less prominent in vertically oriented collaborations (where incentives are closely aligned) and more significant for horizontal collaborations (and as the APC Business Case highlights, there has been historically close to no collaboration between OEMs on R&D projects). These types of issue are illustrated in the parallel process evaluation of APC, which obtained evidence to suggest project leads would often require the signature of non-disclosure agreements before novel partners could be engaged.

These market failures may lead to the failure of R&D projects either to emerge, or to progress beyond earlier stages of technical development where resource commitments tend to be smaller. At a minimum, this would justify public subsidies to minimise the transactional frictions involved, as well as for the R&D activities involved if the collaborating partners see substantial risks of spill-overs within collaborations. However, the failure of horizontal collaboration to emerge can also lead onto negative social welfare effects in the form of inefficiently *high* levels of R&D investment where competing firms engage in R&D 'arms-races' to develop similar technologies that might have been more efficiently developed through co-operation (in part, providing a rationale for APC UK Ltd.'s anticipated role in developing 'shared' technology for the sector).

Furthermore, the development of low carbon propulsion technologies may also benefit from the both the expertise and facilities offered by academic institutions. Again, there may a wide range of reasons why such collaborations may not emerge without public support, as described in a recent evaluation of UK collaborative R&D schemes[12]. These include mismatches between the missions of the university and the business, mismatches in the timescale over which the inputs are required and the capacity available to produce those inputs is available, and differences in the price the at which university the university is willing to provide the inputs needed and what the business is willing to pay.

Knowledge Spill-overs

Finally, classical knowledge spill-overs of a broader nature might be considered as a factor inhibiting investment in low carbon propulsion technologies. An OEM will typically need to contract a Tier One supplier to produce the componentry associated with the product being tested. A large Tier One firm may work with many OEMs, allowing them to observe the relative advantages of the different systems, as well as develop 'vanilla' technologies to more efficiently produce the components required (thus allowing them to free-ride on the investments being made by OEMs). This inability to internalise the full benefits involved will lead to sub-optimal levels of investment, providing a rationale for public subsidies (and from a strategic perspective, restrictions on the geographical profile of firms involved in

[12] The Impact and Effectiveness of Policies to Support Collaboration for R&D and Innovation, Cunningham and Gok, NESTA Working Paper No. 12/06.

subsidised projects may help prevent or reduce the speed with which spill-overs 'leak' over national boundaries).

Knowledge spill-overs may also have benefits owing to high levels of localised production, resulting from the low inventory production models used in the automotive industry. More generally, localised production networks are often closely associated with areas of rapid innovation. Geographic proximity supports the repeated face-to-face contact that is often required for the transmission of tacit and un-codified knowledge that is of prime value for innovation[13]. The importance of this close geographic proximity has been studied in detail by Smith and Florida looking at the automotive sector in Japan[14], and in the UK by Pinch and Henry in looking at the rise of a supply network for motorsport in the fifty miles around Silverstone[15]. The aspiration is that early intervention to support the emergence of UK strengths in these areas will result in a self-reinforcing process of 'Myrdal circular cumulative causation[16]'. The principle is that the positive externalities arising from additional automotive R&D activities will be focused locally. 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 investment[17].

International Competition between Governments

The potential for such clusters of expertise to emerge also relates strongly to the strategic case for Government investment set out above, in that a number of overseas governments have also developed programmes of support for the development of similar technologies. The availability of similar programmes of support for development of low carbon propulsion technologies in other territories may lead to an initial concentration of expertise outside of the UK. As such, if these territories are able to build a comparative advantage as a consequence of this public support (including attracting FDI away from the UK), the process of agglomeration may act to draw investment away from the UK in the longer term (with corresponding implications for levels of output, R&D expenditure, and employment).

2.4 Theory of change

This section articulates the expected causal processes by which the APC programme will deliver its intended results.

Inputs

The APC involves a commitment of £1 billion of investment activity into low carbon propulsion technologies over the next 10 years (£500m of this capital will be supplied by the public sector). The activities of the APC Ltd will be funded by a 3 to 5 percent levy that is charged on the total value of funded projects supported via the APC, paid directly to the organisation from the grant award. In addition to these inputs, BIS and Innovate UK are providing secretariat support to the APC (including the staff resources, expertise and

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[13] For a discussion of the increasing importance of this relationship see Sonn, J. and Storper, M. (2003) The increasing importance of geographic proximity in technological innovation: an analysis of US patent citations, 1975-1997.
[14] Smith, D. and Florida, R. (1994) Agglomeration and industrial location: An econometric analysis of Japanese-Affiliated Manufacturing Establishments in Automotive-Related industries, Journal of Urban Economics, 36, 23-41
[15] Henry, N. and Pinch, S. (2000) Spatialising knowledge: placing the knowledge community of Motor Sport Valley, Geoforum, Volume 31, Issue 2, May 2000, pp 191-208
[16] Myrdal, G. (1957) Economic Theory and Underdeveloped Regions, Harper and Row
[17] 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 3 (2011) 3-45

platforms employed in co-ordinating competitions for APC funding, assess applications in terms of their technical quality and value for money (VfM), and monitor the delivery and performance of projects.

The delivery of APC will also indirectly benefit from the resources expended in the delivery of other related programmes. For example, initial R&D activities may have been supported by subsidies through the Low Carbon Vehicle Innovation Platform (and in the future, projects may also emerge from the additional subsidies for early stage research and development to support the development of ULEVs by the Office for Low Emissions Vehicles). These upstream subsidies for technological development should be accounted for in any evaluation of the APC (and while it will be close to impossible to separate the causal effects of the APC and any subsidies provided by prior programmes, any outputs or outcomes delivered might potentially be apportioned to the programme based upon its overall share of the public costs involved). Additionally, demand for APC funding may also rise if the Automotive Investment Organisation is effective in bringing new OEMs to the UK that may later seek APC funding to take forward R&D projects focused on the development of new propulsion technologies).

Activities

The activities of the APC can be broken down into two key components: a competitive fund providing subsidies for R&D projects aimed at low carbon technologies midway through their course of development, and the broader activities of APC Ltd. These activities are described in more detail below:

Competitions for R&D subsidies

R&D subsidies are being allocated over a sequence of funding rounds through a competitive application process. The eligibility criteria for the scheme are such that applicants must produce proposals where the technology is at a minimum level of technical development (i.e. they must be at least at the point at which a prototype can be tested in a realistic environment (TRL5), and where the prototype can be produced in a laboratory environment (MRL4)). Applications must also involve collaboration with other firms, including an Original Equipment Manufacturer (OEM) or Tier 1 Supplier, to demonstrate that the project has a clear route to market. The competition process involves the following aspects:

- **Application process:** Applicants must complete an application form describing the technical details of the project (typically divided into separate work packages) and commercial potential of the R&D project as well providing a case for public sector investment (including elaborating on the reasons why the project would not be funded without public intervention). Applicants are also required to provide quantitative projections describing the anticipated impact of the R&D project, including forecasts of the sales of vehicles integrating the technology under development, the anticipated technical impact of the R&D project (in terms of improvements in the emissions profile of vehicles produced), and the number of jobs that would be created by the project (either in the delivery of the R&D project or in downstream vehicle production).
- **Project selection –** Applications are judged through a dual appraisal process involving a technical and an economic appraisal. The technical appraisal focuses on the strength of the scientific, engineering and commercial rationale for the project, while the economic appraisal (undertaken in line with HM Green Book principles) focuses on estimating the potential value for money associated with the project (allowing for factors

such as deadweight, displacement, multiplier effects, potential spill-over benefits from R&D spending and risk). Applications must reach minimum scores under both appraisals in order to be approved for funding. The objective of this process is to optimise the value for money associated with public sector investment (and to avoid as far as practicable any inefficient crowding out of private investment).

- **Due diligence and contracting –** Successful projects must complete a due diligence process in which the solvency of the applicants is determined by Innovate UK's finance team, and a contracting process defining a set of milestones that will be achieved over the course of the project (that will form the basis of monitoring). This process requires the collaborating applicants to sign a collaboration agreement defining the roles and responsibilities of partners and how the any intellectual property generated through the project will be shared across partners (thereby potentially addressing some of the potential transactional frictions holding back collaborative activity).
- **Monitoring –** A set of monitoring arrangements are implemented to ensure that spending on projects is in line with the plans set out at the point of application. Projects are monitored against the results they plan to deliver in terms of technological development and their potential to generate emission reductions. The purpose of monitoring is primarily to avoid any potential moral hazard issues in which the applicant may have an incentive to deliver a less risky investment projects (or de-risk the project in other ways, by delaying investment or recruitment).

APC Ltd

As noted, APC Ltd. has been created and will be sustained by a levy on the total value of the projects. At the point at which this study was prepared, the role of APC Ltd in the delivery of the APC only beginning to emerge, though consultations suggested that this role would be primarily in terms in providing a co-ordination function for R&D in this technology area. Examples of the types of activity APC Ltd might complete include:

- **Marketing and communications:** The development and distribution of marketing materials with the objective of promoting the grant competition forming the main locus of expenditure of the APC.
- **Catalysing collaboration:** Encouragement of links between manufacturing firms of varying types and sizes (as well as academic institutions) with the objective of generating new collaborations, knowledge and skills exchange, and technology transfer. At a later stage, this may involve the co-location of engineers to develop shared technologies or platforms for the industry
- **Strategic role:** Act as a channel for the implementation and communication of the Automotive Council's broader strategy and road-map for developing the low propulsion technologies forming the focus of the APC.

The broader strategic remit of APC Ltd raises the possibility that the impacts of the APC may be visible beyond applicants to the programme, particularly where it has facilitated the development of new collaborations and the transfer of new technologies (though it is possible that the firms or academic institutions involved may make applications for subsidies through the APC).

Outputs

The main outputs of the APC will be the implementation of the research and development programmes set out in the application forms. On the basis of a review of the application forms received over Rounds 1 and 2 of the APC, these R&D programmes typically relate to the development of an entire propulsion system, integrating a set of individual components that form the focus of separate 'work packages.' For example, a project may involve the integration of flywheel technology into internal combustion engines to improve efficiency by storing the power generated through braking (projects have largely involved improvements to ICEs rather than more transformative technologies). The R&D project itself may span projects relating to technical development of the flywheel itself, as well as others focusing on the development of complementary mechanical parts (such as valves) and electronic systems. In many cases, the production of these components may be led by different manufacturers or academic institutions, and the modular nature of the propulsion technologies may mean that it may often be better to understand each APC project as a collection of smaller of R&D projects than a singular project (particularly as components may find application in other systems).

The R&D projects themselves will typically deliver a range of immediate outputs over the course of project delivery (which as described in section 2.7, might be expected to be delivered over the course of 28 to 36 months following project commencement):

- **Testing results:** R&D programmes typically involve testing of individual components in increasingly realistic conditions for durability and other characteristics in order to understand any specific issues that might be encountered once integrated with other componentry, in production, or highlight areas in which performance might be optimised.
- **Prototype development:** Results will also be used to refine the prototypes developed in laboratory conditions and enhance their characteristics.
- **Manufacturing plans:** Many of the prototype components forming the focus of the R&D projects will have only been produced in the laboratory, and project proposals also describe plans for developing strategies for manufacturing the components at scale. This could include development of manufacturing processes, identification of manufacturing risks, specification and manufacture of the machine tools required to produce the components and assemble the propulsion systems at scale (though it is not expected that applicants will be ready to enter into low rate production by the end of the majority of APC projects (MRL8/9)).

Clearly, the diverse range of the potential outputs involved creates some challenges in monitoring the outputs of the APC in a systematic and standardised way (an issue explored in more detail in Section 3).

APC Ltd. might be expected to deliver a range of additional outputs, such as the initiation of new collaborative R&D projects within the relevant technology areas (potentially involving partners that have not worked together in the past), as well as new applications for APC funding (driven by its activities in marketing and promoting the programme).

Outcomes

The APC might be expected to deliver a broad range of outcomes that will need to be examined in detail through an impact or economic evaluation.

R&D expenditure and employment

The APC may produce a number of effects on both the volume of R&D expenditure and the nature of R&D efforts. Firstly, provided that R&D subsidies are targeted at infra-marginal projects (i.e. those that would not have been delivered anyway), it might be a reasonable expectation that the subsidies would produce a rise in R&D expenditure across the collaborating partners (a number of academic studies[18] have shown that R&D subsidy programmes have the potential to produce these effects, though the evidence is less strong where these subsidies are directed towards large firms). Increases in R&D expenditure might also be associated with short-term employment effects amongst applicants, mediated through the recruitment of new R&D workers.

However, the failure of an evaluation to find a causal effect on R&D expenditure or employment would not necessarily be indicative that public investment had crowded out private sector in this case, owing to a number of ambiguities:

- **Efficiency of the R&D process:** The APC requires organisations to work in collaboration which may produce efficiencies in the R&D process through supporting transfer of knowledge and skills between collaborating parties. In such cases, some types of marginal projects (where the project, but not the collaboration, would not have been taken forward without APC subsidies) may lead to reductions in overall levels of resources required to commercialise the technologies being targeted (producing positive welfare improvements through reducing costs rather than producing economic, social and environmental benefits).
- **Effects on the nature of R&D:** The APC may also lead to changes in the focus of R&D activities. The technology agnostic design of the APC means that it is unlikely to produce an effect by which it focuses funding on particular engine designs such electric vehicles (though is not to say that APC may not demonstrate the technical feasibility of particular standards, thereby influence the path of infrastructure development, reducing uncertainty, and encouraging further investment). However, APC funding may encourage firms to prioritise propulsion technologies over other areas of technical development (such as safety systems), crowding out other projects because of limits on 'organisational bandwidth' and a reluctance of individual companies to pursue an expanded portfolio of potentially risky and costly R&D projects simultaneously. An assessment of the impact of APC on the nature of R&D activities will be of interest in testing how far it has been effective in meeting its strategic objectives[19].

Given the broader strategic goals of the APC (and the function of APC Ltd) there may also be reasonable expectations that it leads to broader effects in catalysing R&D investment beyond those that have received subsidies through the programme (i.e. crowding-in effects). For example, the ten year duration of funding may offer confidence to industry and academic researchers that long term public support for activity in this area will be available, leading the genesis of new ideas, new entrants to the sector, and greater levels of R&D investment (possibly diverted from other areas). The availability of substantial subsidies through the APC may also have broader effects mediated through FDI (as explained below), though such effects would be visible in a similar set of outcomes.

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[18] See for example: Are Incentives for R&D Effective? Evidence from A Regression Discontinuity Approach, Raffaelo Bronzini and Eleonora Iachini, 2009,

[19] However, from the perspective of an economic evaluation, it will be important to test how far any such changes in the focus of R&D have produced a higher NPV than the projects shelved as a consequence.

Finally, if APC is effective in delivering the anticipated effects in accelerating technical progress, this may deliver important effects by demonstrating the technical feasibility of particular standards, which may in turn influence the course of infrastructure development, reducing uncertainties and stimulating further investment (through de-risking particular R&D areas, for example).

However, while APC may lead to additional investment in R&D, there are also indications that the UK supply of workers with the technical expertise required to deliver R&D projects is severely constrained[20]. Any additional demand for workers to deliver R&D activities funded through APC may to some extent place pressure on wages, crowding out other ‘marginal’ R&D activity. While such wage effects may create incentives for individuals to take up STEM subjects at school and university, or encourage a greater proportion of those who have STEM qualifications to seek employment in technical occupations, such effects might take decades to be felt, and research has identified very real issues with the operation of such markets[21].

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 (with only minor engineering refinements required), and at least to the point at which a manufacturing plan for producing the propulsion system as whole has been prepared. To the extent that resources have been targeted at infra-marginal projects, the expectation is that the impacts of the APC will be visible in progress to these milestones and beyond (i.e. they would have otherwise stalled or progress less rapidly). Given the broader potential of the APC to stimulate R&D activity targeted at propulsion technologies beyond the immediate applicants for R&D subsidies, an evaluation would also ideally track the progress of any other relevant R&D projects initiated. Such projects would likely be starting from at lower points on the TRL and MRL scales, except in cases where initial development work had been carried out overseas.

Collaboration

The APC is only open to collaborative applications (and given the modular nature of the systems involved, successful development will likely require specialist inputs in a range of areas of both design and manufacturing), and the availability of subsidies, efforts to address transactional frictions, as well as the broader activities of APC Ltd might be expected to encourage new collaborative relationships between firms, or with academic institutions (again, potentially involving new entrants to the technology area).

At the point of an application to APC funding, such effects on new collaborations might be expected to be relatively small (as the partners involved will typically have had a history of joint working to develop the systems concerned to the technological levels required). However, the funding may prove critical in preventing existing collaborative relationships breaking down as the cost (and therefore the commitment and risk borne by partners) of moving to higher stages of technical development increases exponentially. It has also

[20] See for example: Winterbotham, M. et al. (2014) UK Commission’s Employer Skills Survey 2013: UK Results, Evidence Report 81, UKCES or Perkins, J. (2013) Professor John Perkins’ Review of Engineering Skills, Department for Business, Innovation & Skills

[21] For a review of the evidence see Levy, C. and Hopkins, L. (2011) Shaping up for innovation, The Work Foundation

been found in studies of other schemes (e.g. the Advanced Manufacturing Supply Chain Initiative) that being a successful applicant can create a 'halo-effect' in which the beneficiary of high profile Government schemes can attract new partners.

Additionally, a data-linking exercise (linking records of those applying to APC to those applying to the Low Carbon Vehicles Innovation Platform and the Advanced Manufacturing Supply Chain Initiative) suggest that the profile of collaborating partners can change substantially in the process of move from early to late stage R&D activities. In particular, while not all partners involved in the early stage of projects are necessarily retained for late stage development, the total number of collaborators involved often expands. While these findings are largely indicative (only two LCV-IP projects could be directly linked to APC or AMSCI applications), they suggest the possibility that the availability of APC subsidies may encourage some firms to form novel collaborative relationships.

Additionally, a key goal of the APC Ltd is to stimulate the genesis of new collaborations, though effects of this nature may not be immediately visible in applications to the programme (particularly if any new collaborations involve the initiation of genuinely new R&D projects, rather than filling gaps in technical expertise or knowledge). As such, an examination of frequency and strength of collaborative relationships across those active in this technological area (as well as the resources committed to collaborative projects) will be critical in understanding the nature of the 'innovation systems' effects that might be induced by this broader catalytic and co-ordinating activity. Such effects may also be illustrated in changes in the patterns of collaboration in applications put forward to the APC over time.

Technology Transfer

The APC may also lead to important effects (mediated by collaboration) in terms of technology transfer by which new manufacturing processes or products developed at lab scale in academic institutions are taken to an industrial scale through the projects funded. Effects of this nature might be primarily visible in any licensing agreements between the academic institutions and private firms involved (or the sale of intellectual property). The analysis of application forms suggests that there is some potential for such effects to occur (though in some cases, HEIs are involved as contract research organisations to test the properties of the componentry involved). Participation in APC funded collaborations may also induce behavioural changes in mechanical and electrical engineering departments within the UK, through encouraging them to adopt more entrepreneurial behaviours, seeking out opportunities to find commercial applications for fundamental research in this technology area (which may feed back into the collaborative outcomes described above)

Intellectual Property

A likely outcome associated with any technical progress would be the development of intellectual property (IP) around low carbon propulsion systems; new insights, knowledge, technical processes, products or business models (though it is likely the relevant patents will have already been registered at the point of application, based on a review of the applications submitted). The registration of patents is not necessarily a useful indicator of the importance of innovative activity: in some cases, technical advances will be protected by secrecy rather than through patenting, in others 'marginal' advances with no commercial application may be patenting (for example, as a blocking mechanism to prevent competitors pursuing similar routes of technical development). Additionally, some applicants may have generated and registered IP in advance of their application to the

APC. As such, some care will need to be taken in interpreting any analysis of patenting activity.

Integration of APC funded technology into new vehicle models

Once the R&D process is completed, it is anticipated that the technology receiving funding from the APC will be integrated into new vehicle models (contingent on successful completion of the R&D project). This could potentially occur via the integration of the entire propulsion system into a new vehicle model, or (given the modular nature of the systems) through the integration of individual components developed into an array of new vehicles (as the manufacturers of such components may be able serve a range of OEMs, for example). Provided the APC addresses the technical priorities of the scheme, these effects should be visible in various measures of vehicle performance (particularly in fuel economy measures, as well as potentially other improvements, such as reduced noise).

Skills Development and Knowledge Transfer

Delivery of low carbon propulsion R&D projects 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 (mediated for example, through turnover in the labour market). Such effects may lead to improvements (or maintenance) of the productivity of R&D investments made in the technology area, as well as generating spill-over by which competing firms are able to build on the advances made by those benefitting from the APC (such spill-over effects might also arise where competitors are able to ‘reverse-engineer’ any componentry once vehicle models have entered production and are sold to market.

Attraction of FDI

The APC may also lead to both direct and indirect effect on foreign investment flows. Firstly, the subsidies available through the APC may be attractive to foreign investors in themselves (leading to direct impacts on FDI). Secondly, if the APC is effective in supporting an accumulation of knowledge and skills with regard to low carbon propulsion technologies, it may have knock-on effects in terms of attracting further foreign firms into the UK to locate in proximity to a European hub of skills and expertise. Such attraction of FDI would potentially lead to further feedback effects in terms of raising investment in R&D in this technology area (another systems level effect that will be of key interest for any evaluation of the programme).

Spill-over effects

It is possible that the APC may lead to a wide range of possible spill-over effects (which could be positive or negative). Firstly, the exchange of skills and knowledge between project participants may find application in related or unrelated projects, leading to product or process improvements beyond the immediate confines of specific APC funded projects. The labour market may also act as transmission mechanism for knowledge exchange, by which the movement of workers leads to the application of knowledge or skills acquired through APC in competing firms. APC UK Ltd also may take an active role in disseminating broader learning from the portfolio of R&D projects funded through the APC (as well as other insights that might be generated in academia or through other public or private institutions, such as the Transport Systems or High Value Added Manufacturing Catapult Centres). However, spill-overs will also be likely once APC funded technology enters the market place: competitors will potentially be able 'reverse-engineer' the systems in ways that avoid infringement on patent rights. Such effects may be positive if UK based firms are able to build on the technology developed, though there is a risk that overseas competitors will also do the same.

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 (provided the vehicles or componentry are being offered to the market at a competitive price point). This could be expected to result in UK manufactured cars securing a greater share of both domestic and international automotive markets than would otherwise have been the case. Applications to the APC include sales projections, the scale and time profile of anticipated results, as well as describing the types of vehicles into which the technology will be integrated. The numbers of vehicles integrating these technologies expected to be sold by applicants are included as part of the application process. For projects funded through Rounds 1 and 2 sales of passenger vehicles are forecast to rise to 600,000 in 2021/22 – which compares to a total UK production forecast of 2.1m in 2017. As noted above, it is anticipated a high proportion of these vehicles will be destined for export markets.

Employment and GVA (direct and indirect effects)

In order to satisfy any additional demand for vehicles integrating APC funded technologies, OEMs and component suppliers may need to expand employment and output (though equally, if the effect of APC is to protect market share, then this might be observed in stable employment or output). To the extent that the components and propulsion 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.

One of effects of particular interest, given the anticipated de-stabilising effect of climate change legislation, will be how far the APC has addressed the 'hollowing' out of automotive supply chains in the UK observed since the 1980s. In particular, if new UK suppliers develop as a consequence of the emergence of new supply chains, this may be observed in reduced reliance of domestically based OEMs on imported components (as well as potentially increased exports of components for assembly overseas).

Productivity

The integration of technologies developed as a consequence of APC in new vehicles may also help firms to raise productivity by increasing the value of output relative to the factor inputs employed in the production of vehicles (on the presumption that consumers will be willing to pay more for more fuel efficient vehicles). Such effects would be visible in GVA per worker (as well as Total Factor Productivity), though it is somewhat unclear how far these productivity gains would be distributed across individual units of the supply chain, and how far they would be captured by firms and workers in the form of higher wages or profits. Additionally, owing to highly competitive nature of the automotive industry, productivity gains driven by APC may not be visible in improvements in profitability amongst those launching new vehicles, but in losses of profitability amongst those slow to respond to the challenges posed by climate change legislation.

Displacement

The scale of the overall GVA effects involved (which will be driven by a combination in the expansion of demand for vehicles produced by relevant firms, and the productivity effects highlighted above) will be offset by displacement effects in the markets for both componentry and final vehicles (by which technologies emerging as a consequence of APC or vehicles integrating that technology, reduce the market share of competing technologies or vehicles produced in the UK). It is important to note that these effects may occur in product markets on a global scale as 80 percent of UK automotive is produced for export (though it is anticipated that the majority of these effects would be confined within Europe). Additionally, while such displacement effects may reduce the sales volumes and employment of domestically based manufacturers, if they occur by displacing output from less to more productive firms then there will still be an improvement in overall social welfare arising from the more efficient use of factor inputs in the production process.

Emissions, Noise and Health Impacts

The APC has the potential to deliver a range of positive externalities through the improved fuel efficiency, reduced emissions and noise pollution, and improvements in human health mediated by reduced levels of particulate matter in the air. However, the APC will only deliver these types of benefit if it displaces the sale of vehicles with inferior technical characteristics. If the APC merely displaces vehicles with similar (but foreign produced) technological characteristics, then there may be no net effect on these variables (and the impacts of the APC would be purely economic in character). Additionally, the extent of environmental impacts will also be contingent on broader de-carbonisation of the facilities used to produce the fuels powering the new propulsion systems (if such de-carbonisation is not achieved, then there is a risk that carbon emissions are merely displaced).

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 directly driven by reductions in price or improvements in quality. Consumer welfare may also be enhanced indirectly through reductions in fuel costs (though clearly this may be offset if there are higher maintenance costs associated with the vehicles of interest). Again, any net changes in consumer welfare will be dependent on the nature of displacement effects (i.e. if consumers would have otherwise bought domestically or non-domestically produced vehicles with comparable technical specifications and at similar price point, then there will be no net gains in consumer welfare).

2.5 Logic Model

A logic model is presented in Figure 2.1 overleaf, summarising this depiction of the causal process, and highlighting the range of outputs, outcomes and impacts that may need to be considered.

2.6 Key Outcomes and Time horizons

Table 2.1 below shows the anticipated completion dates of currently supported APC projects. Across all the funded projects the average duration is two and a half years. Analysis of applications to the APC (detailed in Annex C) indicates that applicants expect that by 2019/20 a reasonable proportion of the sales benefits will have been realised. For commercial vehicles integrating APC funded technology, applicants anticipate having reached annual sales figures of 25,000 in 2019/20 and 50,000 by 2022/23. For passenger vehicles integrating APC technology, gross sales of 400,000 units are expected by 2019/20 and 650,000 by 2026/27. It should be noted these sales expectations are significant relative to overall vehicle production in the UK (i.e. 2m passenger vehicles were produced in the UK in 2014), and if they are attained, then the effects of APC may be sufficiently large to be visible in product market data.

Table 2.1: Length of supported projects

Funding round	Ave. project duration	Estimated completion date of projects
APC round 1	30 months	August 2017
APC round 2*	36 months	April 2018
eAPC*	28 months	July 2019

*Source: APC application forms (*round 2 and the exceptional projects have yet to begin)*

However, the APC is a ten year commitment between industry and government to invest in low carbon propulsion systems. Only approximately ten percent of APC funding has been committed to date. As applications are received for future rounds and new projects come online this will significantly extend the time horizon for the realisation of benefits from the programme. Even if parts, processes or systems are immediately ready for use at the end of the project it may take some time before they are brought to market at scale. The implication is that new technologies supported by APC grants could be entering the market as late as 2030.

It is anticipated that in the short term, an evaluation would need to focus primarily on intermediate outcomes, with technical progress through the development pathway, input additionality (i.e. how far R&D investment would not have taken place in the absence of APC), registration of IP, and collaboration patterns likely to be particularly important in the near term. For example, analysis of the patenting activity of LCV-IP applicants suggests that near term technical impacts could potential be visible in patent data two years following the start of projects. Economic impacts are unlikely to be visible until 2020 and their full value observed until some point after 2030.

Figure 2.1: Logic Model

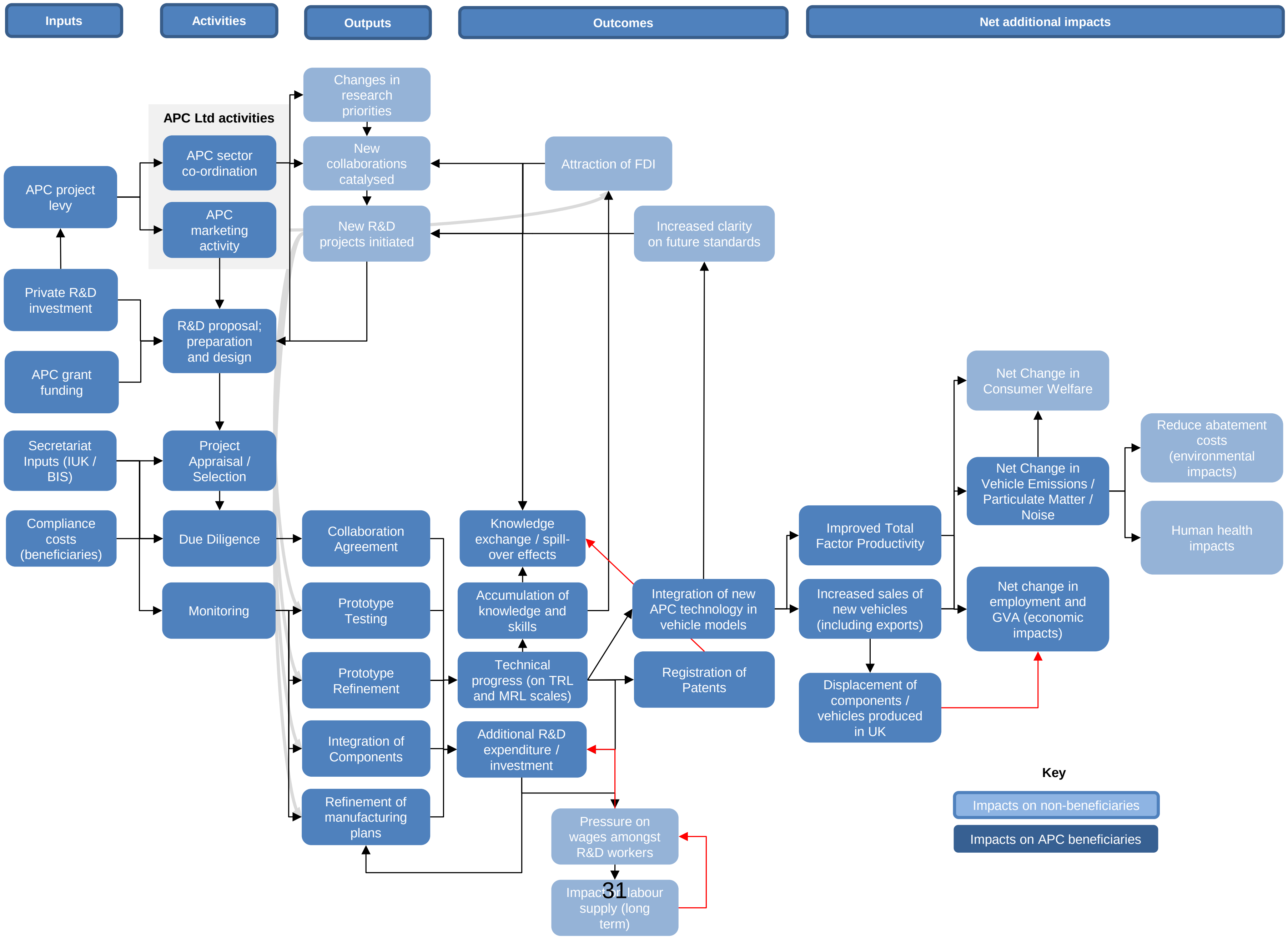

Table 2.2 below summarises the key outcomes expected, and the timescale over which they might be realised and observed. It should be noted that there will be a difference between when outcomes are realised (and gross outcomes visible in monitoring information), and the point in time at which causal effects can be estimated with statistical rigour. The latter depends on a sufficiently large number of projects being funded, and depending on the rate at which new projects are funded, it may not be possible until 2018 to generate statistically significant results.

Table 2.2: Timescales for Observation Key Outcomes for an Impact Evaluation of APC

Outcome Area	Outcome Measure	Timescale
R&D activity	• Low carbon propulsion R&D projects initiated	**2013 to 2023:** The APC may be expected to stimulate crowding in of investment into low carbon propulsion technologies over the course of its lifetime. While funding commitments may need to be made in full by 2020 (on the basis of an average duration of projects of around 3 years), it is also possible that the stimulus encourages investment in these technologies over a longer timescale.
	• % of R&D targeted at low carbon propulsion technologies	
	• New entrants to the low carbon propulsion technology area	
	• R&D expenditure	**2013 to 2023:** Direct impacts on the R&D expenditure and employment of applicants should in principle be visible amongst all successful applicants for both the duration over which public support is provided, and beyond (given the likely engineering challenges that will remain before the technologies can be commercialised). However, it will only be possible to quantify such effects once there are a sufficient volume of projects funded.
	• R&D employment	
Technical progress	• Technology Readiness Levels	**2013 to 2023:** Technical outcomes will be observable both over the duration of the projects funded (and will be immediately visible in monitoring information). However, further development will be required following project closure to commercialise the technologies, and additional technical development outcomes might be anticipated.
	• Manufacturing Readiness Levels	
Collaboration	• Inter-firm collaborations	**2013 to 2023 (and beyond)**: The APC has the potential to have immediate effects on levels of collaboration between firms and with academia (as well as technology transfer). Effects can be expected to be continuously observed over the 2013 to 2023 period, though it is possible that the size of the effects may increase in magnitude over time (e.g. if APC aids the formation of novel relationships that strengthen over time). Such effects may also have some permanence (enduring beyond the lifetime of APC).
	• Industry-academic collaborations	
Technology Transfer	• Number and value of licensing agreements	
	• Value of sale of IP from academia to industry	
Intellectual	• New IP registered	**2013 to 2023 (and beyond)**: As with technical

Outcome Area	Outcome Measure	Timescale
Property	• Value of IP	development outcomes, IP outcomes will potentially visible over the duration of APC projects (IP might be registered at any point during, or following, the delivery of an APC project).
Skills Development	• Number of R&D workers employed in automotive sector	**2013 to 2023:** Impacts in the labour market might be expected to follow a similar pattern to the crowding-in effects described above.
	• Wages of R&D workers employed in automotive sector	
	• Knowledge spill-overs	**2016 to 2026:** Knowledge spill-overs might arise once R&D projects have completed, with the first round of projects coming to an end in 2016).
FDI	• Levels of FDI in automotive sector	**2013 to 2023:** On the assumption that the public support available through APC will be a key driver of any FDI impacts observed, it is anticipated that such effects may be visible over the duration of the programme. However, to the extent that any FDI is driven by the accumulation of expertise (rather than the availability of support), then such impacts may endure well beyond the lifetime of APC.
Economic Impacts	• Sales of vehicles integrating APC technology	**2020 to 2035:** The downstream economic impacts of APC will arise once the technologies involved have been commercialised, and are available on the market. As suggested above, applicants to the first rounds of APC do not expected to generate significant sales of vehicles integrating relevant technology until 2020 (and the last round of projects funded might be expected to launch products to market in 2030). The extent to which those technologies generate lasting effects on the employment, output and productivity of vehicle producers will depend on how rapidly the technologies become obsolete, and as such, economic impacts might be expected to endure beyond 2030.
	• Turnover	
	• Employment	
	• GVA	
	• Average Labour Productivity	
	• Total Factor Productivity	
	• Imports as % of total inputs	
	• Export sales	
Environmental impacts	• CO_2 emissions profile of vehicles sold	**2020 to 2035:** Environmental impacts will be driven by the diffusion of APC funded technologies, and might be expected to be delivered over similar timescales to the economic impacts involved.
	• Particulate matter associated with vehicles sold	

2.7 Wider external influences on success of APC

The APC is being delivered within a complex policy environment with a wide range of activities that will have the potential to influence the extent to which it is able to achieve its strategic objectives. These include activities in the following areas:

- **R&D infrastructure:** A range of investments have been made in the R&D infrastructure that are likely to support the development and genesis of projects that may later receive funding through the Advanced Propulsion Centre. Of particular relevance are the creation of the High Value Added Manufacturing and Transport Systems Catapult centres (the physical locations of these centres are spread across academic institutions across the country, through APC UK Ltd is co-located with the Transport Systems Catapult centre at Warwick University). The Catapults have been created with a view to enabling industry and academia to collaborate more effectively in translating basic research findings into large scale manufacturing, and may also have a role in stimulating the development of new ideas.
- **R&D subsidies:** Subsidies for R&D targeted at the development of low emissions vehicles are available through the Low Carbon Vehicles Innovation Platform (a series of funding competitions managed by Innovate UK) as well as through research grants funded by the Engineering and Physical Sciences Research Council. These subsidies have been mainly targeted at either basic research or early stage R&D projects (TRL 1 to 5). It is not anticipated that the APC (being targeted at late stage R&D projects) will overlap with or duplicate these programmes, though it is anticipated they will likely supply a pipeline of projects with the potential for APC funding.

Both of these activities imply that the projects funded through APC may have involved a set of wider public subsidies. This is not as problematic as it may appear, as APC provides the final tranche of spending prior to commercialisation of the technologies involved, if an impact evaluation focuses on examination of the additional or incremental costs and benefits associated with the APC[22]. However, there may difficulties if the subsidies provided through APC *causes* the genesis of new projects that would only be visible (at least in the short term) in the activities within the Catapult Centres or in projects funded by EPSRC or LCV-IP.

Secondly, there are a set of policies that may indirectly contribute to the goals of the APC:

- **Consumer incentives:** The Government has introduced an array of incentives for consumers to adopt ULEVs. These include 'plug-in' car and van grants offering up to £5,000 and £8,000 of the cost of a new ultra-low emissions car or van (managed through the Office for Low Emissions Vehicles), the Low Carbon Vehicle Procurement Programme (LCVPP) for public procurement of hybrid vans, and fleet consultancy through the Energy Saving's Trust through the Plugged-in Fleet's initiative. Grants are also available for purchasing a dedicated domestic re-charging point. These consumer incentives are (if effective) likely to raise demand for ULEVs, potentially offering further confidence to manufacturers to make longer term investments in their development and enhancement.
- **Infrastructure:** The OLEV led **'**Plugged-in Places' initiatives is also providing £30m in match funding to partnerships across the private and public sector to install re-charging infrastructure (in eight locations). Again, this may act to raise confidence amongst

[22] Though it would, of course, create substantial complexities regarding attribution and additionality for any evaluation of the upstream public funding that aimed to separate (for example), the effects of the LCV-IP from the APC.

consumers and manufacturers alike, stimulating further adoption and investment in R&D activities.
- **FDI promotion:** Finally, the Automotive Investment Organisation has been created (within UKTI) to promote the UK as a location for foreign automotive investment. If the AIO is successful in attracting new automotive production or research facilities to the UK, then this may in turn lead to the genesis of new investment in R&D.

As such, these wider initiatives are both likely to contribute to the broader strategic goals of the Advanced Propulsion Centre and will be delivered simultaneously. This has substantial implications for any evaluation activity aiming to understand the broader effects of the APC (as it will be highly challenging to achieve any quantitative separation of the effects of the APC relative to other relevant initiatives being funded across Government).

2.8 Summary

- **Levels of evaluation:** An evaluation of the Advanced Propulsion Centre might seek to understand its impacts at two levels. Firstly, the direct effects of the APC will be experienced in terms of the influence of R&D subsidies on the technical development of successful projects (and at a later stage, the effect of the propulsion systems developed on the product markets concerned). However, the APC may have effects that will accrue beyond the immediate population of grant beneficiaries (for example, through providing strategic co-ordination of R&D efforts, raising confidence in the private sector that public support will be available on a long-term basis, and catalysing new collaborative activities). These impacts may be visible in higher levels of R&D spending directed towards the development of low carbon propulsion technologies on broader basis, as well as through other measures such as the attraction of FDI. These latter aspects imply a focus on the broader collection of actors (firms, academic institutions, and Government) operating in the low carbon technology space.

- **Conceptualising APC projects:** For the purposes of an evaluation, it may be helpful to understand each project both as an entire propulsion system in its entirety, and a series of sub-projects reflecting the development of individual components. Such a strategy would allow more flexibility, for example, to capture scenarios in which individual components find widespread commercial application.

- **Wider Government policy:** The wide array of cross-Government interventions to support the adoption and development of low carbon vehicles is likely to create a number of challenges for evaluation. These issues are less significant for an impact evaluation of the R&D subsidies provided through the programme (as other initiatives provide subsidies at stages of technical development that are ‘upstream’ to APC, so a focus on the incremental effects of APC funding is not necessarily problematic). However, any attempt to quantitatively separate the broader strategic impacts of APC (i.e. those accruing to those beyond the population of firms benefitting from subsidies) from wider policies will be highly challenging owing to their close to simultaneous timing.

- **Economic impacts:** The APC could have economic impacts through raising the productivity of the UK automotive supply chain and through increasing the market share of UK producers (by displacing production from overseas territories). Given the highly competitive nature of the automotive industry, it is anticipated that productivity impacts will be largely captured by consumers (with the APC acting to preserve the profitability and competitiveness of UK automotive manufacturers, against the possible counterfactual scenario of long term decline).

- **Environmental and health externalities:** The APC may improve the environmental performance of vehicles produced in the UK, though the extent to which this will lead to either net reductions in emissions or improvements in human health will be dependent on how far they displace vehicles of inferior technical specifications.

- **Time horizons:** The timescales over which APC will deliver its impacts are anticipated to be long-term in nature. Although sales forecasts suggest that reasonable volumes of vehicles integrating APC funded technology may be achieved by 2019/20, the full impacts of APC are unlikely to be observed until after 2030. As such, evaluation in the short-term may be better focused on establishing the causal effects of the APC in accelerating the development of the technologies concerned.

- **Quantitative significance:** The sales expectations presented by applicants, however, are quantitatively significant (with 650,000 passenger vehicles sold in 2026/27 expected to integrate APC funded technology across the first two rounds of the APC – relative to 2m produced in the UK in 2014). If these sales expectations are broadly realistic (and the development of the technology involved was to some degree contingent on public support), then the impacts of APC could be sufficiently significant to be visible in product market data.

3.0 Measurement of Key Outcomes

This section explores the range of options available to measure the outcomes identified in the theory of change and logic model above; with a focus on determining those outcomes that might be feasibly measured and those that may require further investigation through qualitative research techniques.

3.1 Unit of analysis

As set out above, the evaluation needs, as far as practicable, to establish outcomes at two levels:

- **The direct impacts of the R&D grants:** The effects of R&D subsidies provided through the APC, which will be visible at the level of the firms and R&D projects concerned (and potentially in the products into which the technology is ultimately integrated).
- **The wider impacts on the low carbon propulsion technology area:** Additionally, there is a potential interest in collecting broader measures of the outcomes of interest across the population of actors operating within the low carbon propulsion technology area (notwithstanding the issues involved in separating the effects of the APC from other policy interventions in this area). This will necessitate the use of an approach to understanding change that fits with analysis of complex innovation systems.

One of the key issues involved in exploring the latter aspect is defining the boundaries of the low carbon propulsion technology area (and the collection of active actors within that space). A possible strategy is outlined in the box below.

Defining the Low Carbon Propulsion Technology Area

The 'IPC Green Inventory' was developed to simplify searches for patents for environmentally sound technologies and is based on the International Patent Classification[23]. This framework includes the patent classifications for hybrid vehicles, brushless motors, electromagnetic clutches, regenerative braking systems, electric propulsion systems, combustion engines operating on gaseous fuels, power supply from force of nature, and charging stations for electric vehicles. As organisations to which patents are assigned (and the individuals responsible for the invention) is public information (accessible via PatentScope or PATSTAT), this classification system can potentially be employed to identify a set of UK based individuals, firms and academics that have been active in this technology area (over the last 10 years, for example). These records could then be linked into other datasets, to provide longitudinal data on a range of measures relevant to the firms or academics concerned.

A feasibility exercise was completed as part of this study, involving extracting all patents applications filed with the European Patent Office under the technology areas

[23] IPC Green Inventory, World Intellectual Property Organisation. Available at http://www.wipo.int/classifications/ipc/en/est/ (accessed March 2015).

Defining the Low Carbon Propulsion Technology Area

defined under the Green Inventory (using PATSTAT) between 2000 and 2015, as well as extracting data on all patents filed by applicants to the IDP4, IDP7 and Low Carbon Truck Demonstrator programme (funded through the Low Carbon Vehicle Innovation Platform) between 2000 and 2015. Analysis of total patenting activity suggested that this technological definition captures substantial volumes of patenting activity, but may be too narrow to capture all relevant activity. For example, some applications to both the LCV-IP and APC involve the development of flywheel technology to store rotational energy. While it was possible to identify directly relevant patents in the data (for example, one firm filed six patents relating to flywheels in 2012 and 2013 following an application IDP4 in 2010), flywheels are not included in the Green Inventory and this activity would be missed by adopting this definition of the technology area.

As such, it is likely that further refinement of the definition of the low carbon propulsion technology against the International Patent Classification would be needed as part of a main-stage evaluation in light of the specific technological proposals made by APC applicants. This process could potentially be streamlined through using the textual analysis tools provided on the World Intellectual Property Organisation website (IPCCAT). Passages from application forms could potentially be coped into this tool to help classify the technology areas being targeted by individual projects (though there is a possible issue here, in that the applications are provided to Innovate UK in confidence and submission of this technical information through an internet based portal could be deemed a breach of this confidence).

Such a strategy would also likely fail to capture all relevant actors (for example, if there are actors that have elected to protect technology through secrecy). However, other sources, such as monitoring data relating to early stage R&D subsidy schemes (such as the LCV-IP or EPSRC) could possibly be used to fill gaps.

3.2 Data collection options

The range of options for impact and economic evaluation will typically be maximised where it is possible to source longitudinal (ideally annual) micro-data (i.e. observations at the level of the firm, R&D project, or product of interest) on the outcomes of interest and a set of appropriate control variables. Three types of data source were explored as this part of this scoping exercise:

- **Programme/monitoring data:** A rich set of data is provided by the application, appraisal and monitoring information collected by Innovate UK (including evidence on the progress of projects and the outputs being delivered by APC funded projects, as well monitoring of the R&D, training, and capital spending of successful applicants).
- **Administrative and secondary data:** The Government, automotive trade bodies and other agencies collect a range of administrative data through routine processes that capture the outcomes of interest on longitudinal basis. Such datasets can often be used to identify the relevant set of firms or products of interest for the purposes of evaluation studies. Additionally, Government sponsored and other surveys can also be helpful in providing both firm level observations (as well as broader contextual indicators that might be used to track the performance of the technology area overall).

- **Primary research:** Finally, where there are gaps in the evidence base, these can be filled through primary survey research with the firms concerned.

Detailed notes on each of the sources explored are included in Appendix A. The section below outlines their potential use in populating the evaluation framework above.

3.3 Key Outcomes and Prioritisation

Drawing on the analysis in Section 2 above, the table overleaf identifies the key outcomes which an impact evaluation will need to track. The collection of each data point is then detailed further underneath the table. In terms of prioritising the outcomes of interest, the following hierarchy has been applied:

- **Leverage of R&D expenditure and technical progress:** The bulk of APC resources have been directed at providing large scale grants for defined R&D projects. The highest priority for an impact evaluation moving forwards will be to determine how far the APC has been (1) effective in leveraging the investment of private resources in targeting these technological goals (particularly given the hypothesised market failures inhibiting investment in these areas, and (2) the acceleration of progress towards the technical goals of the APC by UK automotive manufacturers (i.e. commercialisation of low carbon propulsion technologies).

- **Downstream direct economic impacts:** The central direct economic impacts of APC will occur through the integration of technology supported through the programme into vehicles for commercial sale and their adoption by consumers. These are considered of equal importance to the nearer term effects on R&D expenditure and technical progress, though are likely to occur over longer timescales (and as such, have been given ‘Medium-High’ priority).

- **Direct collaboration, technology transfer and spill-over effects:** The APC also aims to secure a range of collaboration and knowledge spill-over effects. These effects are considered of comparatively high importance, but of less centrality in demonstrating the direct impacts of the programme in terms of input and output additionality (and have been classed as ‘Medium’ priority).

- **Broader crowding-in, co-ordination, and labour market effects:** A range of indirect outcomes are also anticipated as a consequence of the APC. However, owing to the large range of policies with the

- **Consumer welfare and environmental effects:** Consumer welfare and other environmental effects are considered the lowest priority for a future impact evaluation. It is assumed that owing to broader climate change legislation, low carbon propulsion technology would still ultimately be developed outside of the UK. As such, there might be an expectation that these outcomes would be delivered in the absence of the APC, and are considered the lowest priority.

Table 3.1: Mapping Outcomes to Datasets

Outcome Area	Outcome Measure	Direct or Indirect	Priority	MI	Patents	Web of Science	Other Monitoring	MVRIS	BSD	ARD/ABS	BERD	Other	Primary surveys	Issues
R&D activity	• Low carbon propulsion R&D projects initiated	Indirect	Low-Medium				■						■	It is anticipated primary surveys will be required to establish the full portfolio of low carbon propulsion R&D projects. However, monitoring of LCV-IP or OLEV schemes may be illustrative of a pipeline of new projects.
	• R&D expenditure	Direct and Indirect	Highest	■	■						■		■	Simple patent counts are a useful proxy measure of R&D expenditure. BERD data will only be available on a longitudinal basis for known R&D performers.
	• R&D employment	Direct and Indirect	Highest								■		■	Primary surveys will be required to measure effects in terms of overall impacts on R&D employment.
	• % of R&D targeted at low carbon propulsion technologies	Direct and Indirect	Low-Medium		■								■	Analysis of patent counts by technology area could potentially reveal impacts on research focus.
	• New entrants to the low carbon propulsion technology area	Indirect	Low-Medium		■									Analysis of the organisations to which patents are assigned could reveal new entrants.
Technical progress	• Technology Readiness Levels	Direct	Highest	■									■	Primary survey research will be required to determine technological progress amongst any comparison group.
	• Manufacturing Readiness Levels	Direct	Highest	■									■	

Outcome Area	Outcome Measure	Direct or Indirect	Priority	MI	Patents	Web of Science	Other Monitoring	MVRIS	BSD	ARD/ABS	BERD	Other	Primary surveys	Issues
Collaboration	• Number of, and investment in, inter-firm collaborations	Direct and Indirect	Medium											Primary surveys would only provide basic measures of collaborative activity, though monitoring information (including that associated with other programmes), bibliometric (co-authorship of publications), and joint registration of patents could all be illuminating as to broader collaboration patterns in the industry.
	• Number of, and investment in, industry-academic collaborations	Direct and indirect	Medium											
Technology Transfer	• Number and value of licensing agreements	Direct	Medium											It is anticipated that primary surveys will be required to establish the value of any licensing agreements or also of IP emerging from APC projects, though the HE-BI survey (HEFCE) may provide instructive further details.
	• Value of sale of IP from academia to industry	Direct	Medium											
Intellectual Property	• New IP registered	Direct and Indirect	Medium											The number of citations by patents is a useful proxy indicator of the patents value (with self-citations also shown to be correlated with the ability of the patent holder to commercially exploit the technology).
	• Value of IP	Direct	Medium											
Skills Development	• Number of R&D workers employed in automotive sector	Indirect	Low-Medium											The BERD dataset is likely to be the most reliable source of information on total R&D employment within the automotive sector.
	• Wages of R&D workers employed in automotive sector	Indirect	Low-Medium											Wages rates for R&D workers in automotive sector can be established through the ONS Annual Survey of Hours and Earnings.
	• Knowledge spill-overs	Direct and Indirect	Medium											Citation patterns are a useful proxy indicator of knowledge spill-overs (if noisy).
FDI	• Levels of FDI in	Indirect	Medium											The ONS Annual Inquiry into

Outcome Area	Outcome Measure	Direct or Indirect	Priority	MI	Patents	Web of Science	Other Monitoring	MVRIS	BSD	ARD/ABS	BERD	Other	Primary surveys	Issues
	automotive sector													Investment in the UK will provide headline figures of FDI flows.
Economic Impacts	• Sales of vehicles integrating APC technology	Direct	Medium-High											If is feasible to track APC funded technology into vehicle models, then SMMT data could provide detailed information on vehicle production.
	• Turnover	Direct	Medium-High											Longitudinal micro-data on turnover and employment are available in the BSD (with lags) and ARD/ABS, though primary surveys could be employed to provide additional measures.
	• Employment	Direct	Medium-High											
	• GVA	Direct	Medium-High											The ARD provides longitudinal data on output and the necessary measures required to estimate productivity (though only for large firms), though primary surveys could be employed to the information required (though the accuracy of such data may be lower)
	• Average Labour Productivity	Direct	Medium-High											
	• Total Factor Productivity	Direct	Medium-High											
	• Imports as % of total inputs	Direct	Medium-High											If it is feasible to obtain access, HMRC micro-data on imports and exports could be exploited to obtain information on imports and exports. SMMT data also provides information on vehicles earmarked for exports (though clearly only applies to finished vehicles).
	• Export sales	Direct	Medium-High											
Environmental impacts	• CO_2 emissions profile of vehicles sold	Direct	Medium-High											Technical specifications are provided in SMMT data.
	• Particulate matter associated with vehicles sold	Direct	Lowest											These measures are unobservable directly, and would need to be

Outcome Area	Outcome Measure	Direct or Indirect	Priority	MI	Patents	Web of Science	Other Monitoring	MVRIS	BSD	ARD/ABS	BERD	Other	Primary surveys	Issues
	• Noise associated with vehicles sold	Direct												inferred from secondary data.
Consumer Welfare	• Increase in consumer surplus	Direct	Lowest											
	• Improvement in QALYs associated with improved air quality	Direct	Lowest											
	• Improvement in QALYs associated with noise reduction	Direct	Lowest											
Robustness of data				High	High	High	High	High	Med.	High.	High.	Var.	Med.	In general, sources of administrative data will be tend to be high, though there are some issues with the timeliness of the data held within the Business Structure Database. Surveys tend to be less reliable sources of financial data (though procedures can be put in place to maximise quality). There are also some issues of coverage.
Coverage				Succ apps	All	All	All	All	All	Large firms only	R&D perfo rmers	Var.	All	

3.4 Programme Monitoring Data

A large range of monitoring data is collected through the administration of the programme, organised under three headings:

- **Economic monitoring** captures progress against financial targets (i.e. defrayment of grant expenditure) and delivery of outputs (e.g. jobs created or safeguarded). These measures are of primary use for the purposes of process evaluation, though will feed in useful information on the gross costs incurred in the delivery of APC projects.
- **Technical monitoring** describes the technical progress made with regard to each component forming part of the propulsion system (including TRL and MRL levels, associated IP generated and sales achieved)
- **Company monitoring** captures three firm level measures of investment activity: training expenditure, capital investment levels, and total R&D expenditure (annually).

As such, the monitoring information collects a wide range of evidence on the outcomes of interest that could be of potential use in an evaluation of APC (in particular, the longitudinal tracking of the technologies involved, and company level measures of company expenditure decisions. It is also helpfully structured at the level of individual components (rather than at the level of the propulsion system overall). However, the monitoring information has a number of limitations:

- **Time:** Monitoring information will only be available over the duration of projects, and as funding will only available to take these technologies to TRL8, there will be important aspects of progress (such as their integration into commercially produced vehicles on a large scale) that will not be captured.
- **Coverage of a counterfactual:** The bulk of monitoring information relates only to successful applications, and any additional observations would need to be collected for groups of firms selected as a counterfactual (or if there was any interest in exploring outcomes on a broader basis than the population of grant applicants). It is not anticipated that this difficulty could be resolved through on-going monitoring activities, and primary research would be needed to collect this information.
- **Level of detail on R&D activity:** An evaluation would also ideally explore the effects of APC on the nature of R&D activities (e.g. expenditure on low carbon propulsion R&D projects) alongside effects on total expenditure, to examine how far subsidies have been effective in changing technological priorities. Monitoring information only provides evidence on total expenditure and could not currently be used to explore such outcomes, though could potentially be expanded to collect this information.
- **Tracing componentry into products:** At present, there is no way of tracing components developed into specific vehicles, and this will be critical in establishing the long term commercial and economic effects of APC.
- **Company measures:** The range of measures collected at a firm level, though helpful, are fairly limited in the sense that they focus only on investment decisions, but do not capture the potential economic impacts of the APC (e.g. on overall firm employment and GVA).

While not all of the issues identified above can be resolved through adjustments to monitoring information, some straightforward changes could substantially enhance the impact and economic evaluation options available as set out in the box below.

Recommendations: Monitoring			
Post-project monitoring	It is recommended that projects are monitored beyond the duration of APC funding to capture any downstream effects (including integration of components into vehicles for large scale manufacture).	**Priority:** High This is likely the only way in which some central outcomes (e.g. integration of components into commercially produced vehicles) can be established effectively.	**Cost:** Medium Adoption of this recommendation will place additional burdens on applicants and Innovate UK.
Tracing vehicle models	Where applicants have integrated APC funded componentry into vehicles available for commercial sale (including vehicles produced overseas), they should be required to report the specific model(s) through monitoring (ideally using MVRIS codes, so sales can be linked into SMMT data).	**Priority:** High Such information will be critical in examining the product market effects of the APC, and could not necessarily be obtained through other means.	**Cost:** Low This would only require minor adjustments to monitoring tools, and would impose only limited additional burden on applicants (though clearly post-project monitoring would also be required).
Company measures	The range of measures monitored through company monitoring should be expanded to cover: • Employment • Turnover • Wage expenditure • Profits • Total R&D expenditure on low carbon propulsion technologies	**Priority:** Medium: To some extent, information on economic monitoring, while critical in the long term for an economic evaluation, can be gathered through alternative means including primary surveys of applicants or through data-linking. However, these approaches may be more costly than extending monitoring, may not offer data that is neither as robust nor timely as might be gathered through monitoring.	**Cost:** Low Regular monitoring of these variables will likely mainly place additional burdens on applicants in the collation of these measures (though finance officers should routinely be able to compile these measures from accounting data). This burden could be minimised by completing the process annually (for example) and utilising light touch and user friendly tools. Additionally, the changes required represent an incremental change on existing Innovate UK monitoring processes.

3.5 Monitoring of other programmes

In addition to APC monitoring information, it may be helpful to collect additional monitoring information captured through the delivery of other programmes.

Early stage R&D programmes

The data collected through the monitoring of other initiatives targeted at earlier stages of the R&D cycle (such as the competitions managed through the Low Carbon Vehicles Innovation Platform, or ESPRC grants) could be helpful in establishing both prior costs incurred in the delivery of APC funded projects, as well as in examining the size of the project pipeline on a broader basis (and the range of actors within the technology area). It is anticipated that it will be straightforward to link records of applicants across schemes For example, APC uses application forms are based on a template developed by Innovate UK that has been also used to administer the LCV-IP. These forms capture the CRNs which could provide the unique reference number that would facilitate linking at a firm level (though it may not be straightforward to compile these details, and data-sharing agreements would need to be put in place). However, tracing individual projects as well as academic applicants may be more challenging (as project titles may change, while the names of the individual academics are not currently captured in APC application forms). As such, it is anticipated that engagement of Innovate UK and ESPRC would be required to support this tracing process. Such an exercise is not anticipated to be problematic, as Innovate UK in particular are strongly engaged in the delivery of the Advanced Propulsion Centre (and were able to provide significant detail on a number of LCV-IP competitions for the purposes of this scoping report).

A feasibility exercise has been completed as part of this scoping report, examining how far it is feasible to link monitoring records across different programmes and highlight any possible evaluation issues this might raise (which are given consideration in the following chapter). This exercise included linking records of collaborating applicants to the first two rounds of the Advanced Propulsion Centre with those associated with three past competitions funded through the Low Carbon Innovation Platform, A number of practical challenges were encountered in implementing the linking of these monitoring records:

- **Constancy of Companies House Reference Numbers:** Companies House Reference numbers were not always consistently recorded across applications to the different competitions even where the named organisation was the same. This was a particular issue for the larger firms in the sample, and it is possible (if not likely) that this is a consequence of the ownership structure issues identified in the following bullet point). As a consequence, the linking of these records was completed on a manual basis (using the name of the firm as well as other identifiers like the CRN), rather than automatically through the CRN.
- **Ownership structure:** The larger firms in the sample tended to have ownership structures that complicated the linking process. For example, one large firm this parent was involved in one APC application and 8 applications to the three LCV-IP competitions under consideration. However, the involvement of the firm in these competitions was primarily recorded at the level of its subsidiaries. To simplify the linking process, firms were linked at the level of their parent rather than at the level of the subsidiary. In an evaluation study there may value in preserving this level of detail to more precisely identify the impacts involved (though if the intangible assets generated

through APC funded R&D projects lead to spill-overs across operational units, then this may only be visible at the aggregate level, though it should be possible in principle to extend the analysis to consider the relevant linked companies).
- **Changes in structure and ownership over time:** Further complications were introduced by changes in ownership structure over time. For example, one firm was involved in a second round application to the Advanced Propulsion Centre, but was subsequently been acquired by a large firm that featured both in applications to APC and the LCV-IP. Over the long timeframes anticipated for the APC evaluation, this is likely to prove problematic for any data-linking exercise if the firms subject to mergers or acquisition are integrated into new or existing operational units (rather than continuing to trade as separate units). In this scenario, it will no longer be possible to observe the firm level outcomes at the level of the original observational unit from the point of merger or acquisition (e.g. Jaguar Cars Ltd and Land Rover were merged into a single operational unit by Tata Steel in 2008, from which point it would no longer be feasible to track the performance of either of the originating firms). Care will be needed in the treatment of these cases. One possibility might be to aggregate the firms concerned in those years prior to the merger or acquisition to create a unit that can be tracked longitudinally (by summing R&D expenditure, employment, GVA and other variables of this nature), though clearly there would be concerns that the outcomes of interest would no longer be visible, particularly where the original firm was small and the acquiring firm was large. Additionally, this clearly implies that systematic monitoring of the ownership structure of applicant firms over time will be required (though the limited numbers of firms involved will mean this is likely to be a manageable task).

Nevertheless, this exercise has proved the feasibility of linking different sets of monitoring information to provide a fuller account of the total subsidies being received by firms involved in the APC. In addition, on many occasions it has been feasible to trace individual R&D projects through different programmes, as described in the following section. As such, linking monitoring data across different programmes has the potential to supply important additional information for the purposes of any future quantitative analysis.

Other subsidy programmes

There is also possibility that unrelated programmes could contaminate results: for example, the automotive sector has been a major beneficiary of the Regional Growth Fund and the Advanced Manufacturing Supply Chain Initiative. These schemes provide capital investment, training, as well as R&D subsidies, and have the potential to influence the set of key outcomes of interest if APC applicants have benefitted from these programmes (e.g. capital spending supported through the RGF could serve to raise the average labour productivity of applicants). The collection of monitoring data from these programmes could potentially help control for their influence (a parallel data-linking exercise has been undertaken to determine the degree of overlap with AMSCI, suggesting APC beneficiaries have also benefitted to some degree from the public support available). The datalinking exercise described above was also extended to the first four rounds of the Advanced Manufacturing Supply Chain Initiative, with similar analytical issues encountered to those identified above.

Recommendations: Monitoring and Data Collection			
Tracking ownership structure	It is recommended that the ownership structure of and any mergers and acquisitions involving applicants to APC are tracked over time through monitoring to support future data-linking activities.	**Priority:** Medium It may be feasible to trace changes in ownership structure as part of an ex-post evaluation, though the task will be considerably eased through monitoring.	**Cost:** Low-Medium Adoption of this recommendation will place additional burdens on applicants and Innovate UK.
Collation of monitoring information	It is recommended that a main-stage evaluation contractor seeks to collect evidence on the broader public support received by APC applicants (provided that sample sizes will support a detailed econometric analysis) to help control for their influence over the outcomes of interest.	**Priority:** Medium The collection of this data will provide helpful controls and improve attribution to the programme, though it is unlikely that it will be possible to account for all support received by applicants.	**Costs:** Medium The costs of assembling this information should not be understated (though portals such as Gateway to Research may ease the process to some degree).

3.6 Administrative and Secondary Datasets

There are a range of administrative datasets that might be exploited in an evaluation of the APC. This section outlines the key datasets explored, and how they might be used.

Patent Data

Computerised patent registration records (available on a global basis through PatentScope or on a European basis through PATSTAT) could potentially be exploited in a range of ways to provide useful evidence in support of an evaluation of APC. As outlined above, they can be used to identify the range of actors operating with the low carbon propulsion technology area. However, records can also be linked to the population of grant beneficiaries to explore a range of questions it may not be feasible to investigate otherwise:

- **Patent activity:** Patent counts have been shown to be correlated well with measures of R&D expenditure[24]. As all patents are assigned to a technological classification, the data can be employed to create longitudinal data to explore two questions - how far the APC has stimulated additional R&D activity in the area of low carbon propulsion amongst grant activity, and how far the APC has led to changes in research priorities (by examining the percentage of patents registered by beneficiaries in this technical field). Such data could also be used to identify any new entrants to the technology area

[24] 'A Penny for Your Quotes: Patent Citations and the Value of Innovations,' Manuel Trajtenberg, 2002

(i.e. organisations registering patents relevant to low carbon propulsion technologies for the first time).

- **Citations:** Every patent is accompanied by a list of citations to prior patents (potentially added by the applicant, the patent attorney, or the patent examiner) that set the boundaries of the property right, as well as a set of bibliographic references. Total citations and self-citations have been shown to be correlated with the total social welfare (consumer and producer surplus) and the appropriability of the patented invention[25]. As such, tracking citations to relevant patents registered by beneficiaries could be helpful in providing proxy measures of the commercial and social welfare effects of APC.
- **Spill-overs:** Citations have also been shown to be a (noisy) indicator of knowledge spill-overs[26], and analysis of pattern of citations made by APC applicants could help identify (for example) linkages to the R&D infrastructure (including the Catapult Centres). Equally, citations to patents registered by APC applicants may be helpful in establishing the strength of knowledge flows at the local or international level (as patents provide information on the geographical location of patents) or to identify if any technology developed has found application in other industries (e.g. marine or rail).
- **Collaboration:** Patents also provide a list of inventors and the organisations to which the patent is assigned. As such, analysis of this evidence can provide measures of collaboration (e.g. joint registration of patents) on a longitudinal basis, which could be used to explore the causal effects of APC on collaborative activity.

Although a rich dataset, patent information tends to provide only proxy measures of the underlying phenomena of interest. Additionally, the data is subject to significant lags: records are not publicly available for 18 months after application documents are received by the patent authority.

In order to examine the potential issues involved in more depth, further datalinking work was undertaken, involving the extraction of patent records for each of the successful and unsuccessful applicants to three LCV-IP competitions identified above were extracted from the Espacenet on-line database. Patent searches were limited to the period 2000 to 2015, and to those where the applicant organisation was based in Great Britain. This led to the generation of a sample of 5,834 individual patent records, providing information on the named inventors, the applicant organisation, the priority date (the date the relevant documentation was received by the patent office of concern), and the classification of the patent against the International Patent Classification codes (a framework describing the technological focus of the patent). In addition, all low carbon propulsion technology patents (using the definition described in Section 3.1), where the first filing was to patent authorities in Great Britain, Germany, France, Spain and Italy were extracted from PATSTAT between 2005 and 2015 to provide further insight into the nature of patenting activity in this technology area. This provided a range of insights:

- **Datalinking:** It was comparatively straightforward to link records of LCV-IP applications to computerised patent records. Of the 152 individual firms involved in LCV-IP applications, around 68 firms had registered patents (though only 20 had registered patents that were classified as ‘low carbon propulsion’ within the Green Inventory

[25] Ibid.
[26] The Meaning of Patent Citations: Report on the NBER/Case-Western Reserve Survey of Patentees, Adam Jaffe, Manuel Trajtenberg, and Michael Fogerty, 2002.

described above). An examination of the patents filed against application forms suggests that in many cases, it is possible to identify specific patents that may have emerged from the projects. As an example, one applicant registered 6 patents relating to the use of flywheels between 2013 and 2014 which appear to be directly related to a successful application to the LCV-IP in 2012. As such, the analysis partly confirms the potential value of patent data in providing cost-effective measures of the possible technical impacts of APC.

- **Practical issues:** For some large companies applying to the LCV-IP, patent filings may be made by a firm based overseas, even where the relevant knowledge was produced in the UK. For example, patents relating to research and development by Ford operational units in the UK tend to be filed by Ford Global Technologies (which is recorded as a US based organisation). In such cases, this issue was resolved by focusing on those patents that were first filed in Great Britain and these issues would need to be treated with care if this data is to be exploited effectively in an impact evaluation.
- **Low carbon propulsion R&D activity:** In aggregate, low carbon propulsion patent filings accounted for just under 10 percent of overall patenting activity amongst the LCV-IP applicants of interest (though as noted above, there are some concerns that the technology definition adopted was too narrowly defined). The data gathered suggested that low carbon propulsion patent filings expanded significantly amongst LCV-IP applicants from 2012 onwards (this pattern is also visible in the volume of low carbon propulsion filings across GB as a whole).
- **Coverage of overall patenting activity:** The 152 applicants to the LCV-IP accounted for 375 patent filings in the low carbon propulsion technology area between 2005 and 2014, a high proportion of the 484 filed with patent authorities in Great Britain over the same period. As such, it is anticipated (provided that there is a strong correlation between those applying for LCV-IP and APC funding) that the applicants associated with APC will represent a large share of the range of organisations that are active in this technological area.
- **Concentration of IP holdings:** Large automotive manufacturers and Tier One suppliers hold a large share of the IP holdings in the low carbon propulsion technology area. For example, four firms accounted for 443 of the 532 low carbon propulsion patents filed by LCV-IP applicants between 2000 and 2015. This is also reflected in data at a European level: the five firms holding the largest number of patents in this area were Bosch, Daimler, Peugeot-Citroen, BMW, and ZF Friedrichschafen. These firms held 3,841 patents first registered with the patent authorities in Great Britain, Germany, France, Spain and Italy between 2005 and 2015 (more than 50 percent of the 7,625 registered over this period). This concentration of IP holdings will mean that there will be likely significant outliers in present in any patent records obtained, making it more challenging to isolate the quantitative impacts of the APC using statistical methods. As such, there may be value in running all analyses both including and excluding the larger firms involved.
- **Collaboration:** The analysis suggested that the patenting data may be less valuable in terms of demonstrating collaboration. Around 20 percent of the low carbon propulsion patents registered in Great Britain between 2005 and 2015 involved multiple applicants (indicative of collaboration), compared to 28 percent in Germany and 24 percent in France. However, an inspection of the specific patents registered by LCV-IP applicants suggests that this may underreport collaboration. For example, the aforementioned flywheel project was delivered by a consortium of four collaborating firms, though only the lead partner was named as an applicant on the patent filing.

- **Spill-overs:** The data-linking activity was also intended to explore how far citation patterns might offer a useful means of identifying the possible spill-overs involved by examining citations to patents registered by LCV-IP applicants following their applications for funding. However, it was apparent from the data that there is a lag of perhaps two years between the date of application and any patent filings, and as the data available was highly truncated (i.e. reliable data on patent filings was only available up to the end of 2013 owing to lag between receipt of documents by patent authorities and their publication) it was challenging to generate any meaningful findings in this regard.

Automotive Registrations

In order to understand the impact of APC on product markets, detailed information on the production of vehicles will be required (ideally at a model level). As a high proportion of vehicles produced in the UK are destined for export markets, it is critical that such data is gathered at a European (if not global) level. A range of secondary datasets have been explored as part of this study:

- **MVRIS:** The Motor Vehicle Registration Information System is dataset combining DVLA records on new vehicle registrations in the UK (a proxy for sales), with detailed technical specifications (including CO2 emissions) and other details (such as country of production). While very detailed, this SMMT maintained dataset would unlikely be sufficient for an evaluation of APC owing to its narrow geographical scope (and supplementary data on other sources will be needed to provide a more comprehensive picture).
- **National vehicle registration authorities:** National vehicle registration authorities also collect and publish similar information and statistics[27]. Collection of this data through liaison with these authorities may be one strategy for compiling the detailed data needed, though this will inevitably be a labour intensive task and it may not be feasible to gather data for every EU Member State. No attempt has been made to gather the underlying model level data (the published data provides brand level breakdowns), but it is anticipated that there will be differences in data collection practices across countries that would also need to be accommodated in the evaluation.
- **Proprietary datasets:** Finally, additional proprietary datasets (such as those compiled by Ward Auto[28]) provide model level data on sales and production on a more or less global scale. Accessing this data comes with an unspecified charge, but could potentially be exploited in an evaluation of APC.

In terms of the technical specifications, the MRVIS data provides a range of variables that will be of interest in determining how far APC has delivered against its technical goals of decarbonising propulsion technologies. The table below provides a range of technical measures that are generated through the testing conducted by the Vehicle Certification Agency (VCA). The data is then compiled by the DVLA, and by the SMMT in the MVRIS dataset. It must be noted however that SMMT do not collect information on the registrations of agricultural vehicles; which can instead be sourced via the Agricultural

[27] For example, German vehicle registration data is available from Kraftfahrt-Bundesamt. See http://www.kba.de/EN/Statistik_en/Fahrzeuge_en/fahrzeuge_node_en.html (accessed March 2015).
[28] Available here: http://wardsauto.com/ (accessed March 2015).

Engineers Association (note that to date, no APC application has focused on the development of agricultural vehicles).

Table 3.2: Fuel consumption and emissions variables

Variable	Description
gCO_2/km	The tested value of CO_2 emissions of a vehicle per kilometre.
MPG	The average fuel consumption of a vehicle
kWh/100km	Energy consumption for electric vehicles

From the range of projects that have been funded by the APC to date, it may be necessary to standardise the measures of efficiency so that the whole portfolio of projects can be assessed as a whole. Agricultural vehicles report their emission values in terms of emission per hour. Zero emission vehicles can be ranked in terms of kWh/100km. These measures will need to be standardised if comparisons are to be made across all vehicles. In the US, a MPGe value is used or Miles per gallon equivalent, but this is not a measure that is regularly reported[29] in the UK or Europe. It will also likely be helpful to track the overall efficiency of vehicles produced by OEMs integrating APC funded technology (and a sales or production weighted figure might be developed using model level data).

VML Datasets

The final sources data explored as part of the study were the administrative and survey datasets held within the ONS Virtual Micro-data Laboratory. These datasets contain a wide range of longitudinal data that will potentially be informative for a main-stage evaluation of the APC, and can be exploited if it is possible to identify the relevant firms within these datasets. The Inter-Departmental Business Register is the sample frame or source data for all of these databases and surveys, and individual firms can be identified either if their Companies House Reference number (CRN) is known, or via their name and address.

As previous studies have shown (e.g. the scoping study for AMSCI), Innovate UK application forms collect these details, making it straightforward to achieve high matching rates between the IDBR and beneficiary records. A feasibility exercise was completed as part of this study, with 46 out of 48 firms identified within the VML (further details from this exercise will be available from the data-linking results, if the outputs are cleared by the Office for National Statistics[30]).

[29] The US Environmental Protection Agency use MPGe values on labelling for electric vehicles so comparisons can be drawn across all types of cars.
[30] At this stage, the number of beneficiary firms is small and there is a risk that the data may be potentially disclosive.

Table 3.3: VML Datasets[31]

Dataset	Description
Business Structure Database	The Business Structure Database is an annual snapshot of the Inter-Department Business Register, and can potentially be exploited to obtain longitudinal measures of employment and turnover. This data has some weaknesses, as the data held within the IDBR is often subject to lags that are not identified within the data (so there is a risk that an employment figure attached to a particular year, for example, is based on information two years out of data). As such, the information is generally more appropriate for examining impacts over long timescales.
Business Expenditure on Research and Development	The Business Expenditure on Research and Development (BERD) dataset is an administrative source held by the ONS. The database draws from a survey sent to five thousand firms every year and always includes the top 400 R&D spenders. It is anticipated that the large OEMs supported by the APC will be covered by this survey. Coverage will likely be lower among the smaller firms that will form part of the population to be sampled. A single SIC code is used to indicate the focus R&D work within each of the 400 largest firms only. This means that it may not possible to collect data on the technology focus of R&D activity among the firms surveyed.
Annual Business Survey / Annual Respondents Database	Finally, the Annual Business Survey is a large scale survey of enterprises in the UK, which includes a financial enquiry aiming to establish levels of capital investment, turnover, GVA, employment, and other financial measures (including information required to estimate Total Factor Productivity). The survey is mandatory for all large firms (250 employees or more) and as a consequence, provides a potentially useful longitudinal panel dataset that could be exploited in a main-stage study. However, the availability of the ABS is subject to some lags (i.e. in February 2015, the most recent data available was from the 2012 ABS). Such recording lags would need to be accommodated in the timetable for any evaluation of APC (though monitoring could potentially be adjusted to collect the data on a more rapid basis).

Contextual Measures

Finally, there are a range of measures collected through ONS surveys that it would be useful to supplement the detailed micro-data outlined above. In particular, it will be important to explore the potential effects of APC in the following areas:

- **Labour market:** If the APC stimulates substantial R&D expenditure then this may be accompanied by an increase in demand for appropriate skilled workers. This is turn may drive up earnings in the sector if there is an insufficient supply of individuals with the appropriate set of engineering skills required. As such, it may be helpful to contextualise the APC by examining data on labour supply (using the Annual Population Survey) and earnings (through the Annual Survey of Hours and Earnings). The UKCES sponsored Employer Skills Survey could also potentially provide useful (though general) evidence on the skills issues faced by the automotive sector.
- **Foreign Direct Investment:** It may also be helpful to track levels of FDI in the automotive sector over time, though published ONS statistics to not provide a

[31] The team has obtained matching rates to each of these datasets, but they cannot be shared owing to disclosure issues. However, these results suggested that matching rates to the BSD and the ABS were high, though the BERD may find less widespread application in the study.

sufficiently detailed breakdown to explore trends in FDI effectively. An alternative source of information is the European Investment Monitor, that tracks UK FDI projects (primarily through news sources), and can be used to identify automotive manufacturing investments (at a European level)[32].

Recommendation: Administrative Datasets			
Integration of secondary data	It is recommended that the main-stage evaluation make best use of the array of secondary micro-data available (including patent records, bibliometric data, the firm level datasets within the VML, and the MVRIS data). However, given sample sizes, disclosure issues may be eventually problematic, and contingencies based on primary research and monitoring are advised. The issues will require further review at a later stage once there is a clearer picture of sample sizes.	**Priority:** Medium-High The availability of longitudinal data will substantially enhance the scope of evaluation options available.	**Cost:** Low-Medium Exploiting these datasets will be relatively cost-effective, though the costs involved in data assembly should not be understated.

3.7 Primary Surveys

Although secondary sources can provide evidence on a wide range of outcomes, there are a number of gaps that can only be filled using primary surveys of applicants. In particular, in the absence of monitoring information from projects that were unsuccessful in their funding application (that may form a potential counterfactual group), comparable information may need to be collected from this group. Additionally, there are a number of variables of interest that may merit exploration through surveys:

- R&D expenditure
- Percentage of R&D relating development of low carbon propulsion systems
- R&D employment
- Collaboration with other firms and academic institutions
- Spin-outs
- Licensing of intellectual property (and associated revenues)
- Progress of R&D projects (measured against TRL and MRL scales), particularly for non-APC funded projects and APC projects beyond the lifetime of project funding.
- Production and sales volumes of APC funded propulsion systems and/or componentry
- Overall turnover, employment, wage expenditure, and profits (to measure GVA).

[32] Access to the data does come with a charge, although regular reports are produced. See for example, ‘Winning the Race – But Still More Opportunity: EY’s Attractiveness Survey UK 2014,’ that suggested that the UK attracted 15 percent of automotive assembly FDI projects in Europe in 2013. The publication also provides information on attitudes to investment in the UK, though not broken down by sector.

- Consumption of intermediate goods and services and the geographical distribution of suppliers (to support an indicative assessment of any supply chain impacts beyond those captured by the firms in the collaboration)

Such a survey would require respondents to provide detailed financial information, as well as accurately code the technical development of their project against the TRL and MRL scales. To maximise the reliability of any information gathered through the survey, it is advised that respondents are sent a datasheet outlining the information required in advance of a survey to maximise the reliability of data collected. Alternatively, application forms could be adapted to collect this information (meaning surveys would only be required following project completion).

Observations would ideally be taken at three points in time: at the beginning of the APC project, on its completion (or planned completion date for unsuccessful projects), and an appropriate period following the completion of the project (perhaps three to five years following completion). This would clearly challenging for projects that have already started, though given their early stage of delivery there may be an opportunity to collect this information either as the earliest opportunity, or to gather the information retrospectively at project closure.

Ideally, a survey would sample both collaborators and lead applicants. The application form at present only captures details of lead applicants, and while APC UK Ltd holds contact details for the collaborating firms, they are not available for projects that were unsuccessful in their application for APC funding. As such, it is suggested that application forms are adapted to capture this data to maximise the coverage of any ex-post evaluation surveys.

Recommendations: Surveys and Monitoring			
Adapt application forms	Adapt application forms to collect additional baseline data on the projects and the firms concerned.	**Priority:** High Additional baseline information data will be required to measure both intermediate outcomes and economic outcomes.	**Cost:** Low This will place an additional burden on applicants, though it is anticipated that finance teams will have the majority of information to hand Applicants routinely add information on TRL and MRL stages of the various components of their projects within application forms.
Applicants surveys	Undertake surveys of applicants (successful and unsuccessful) at project completion (or planned project completion) and 3 to 5 years following completion to track outcomes over time.	**Priority:** High Surveys will be critical in understanding the intermediate effects as well as the economic outcomes of the APC (particularly if there are concerns about the reliability or ability to retrieve data from VML datasets).	**Cost: Medium** Resources will need to be invested in a rolling programme of survey research to collect the data of interest, though given the number of firms involved to date, this may not be a costly exercise.

3.8 Outcomes not directly observable

There are some outcomes that are not directly observable: in particular, the noise output of associated with vehicles integrating APC technology, and the human health impact (i.e. QALYs gained associated with reduced levels of particulate matter in the air). Instead, such effects may need to be modelled (and these issues are given greater consideration in Section 5). However, these outcomes are considered of the lowest priority for an evaluation, as flagged in Section 3.3.

3.9 Summary

- **Secondary datasets and monitoring:** A wide range of the potential outcomes of interest can be measured to greater or lesser degrees of reliability through secondary datasets or monitoring. However, several enhancements to monitoring could be made to improve the ability of any main-stage evaluation to exploit this data, including capturing a wider range of longitudinal measures at a company level through monitoring, extending monitoring beyond project completion, and capturing information on the UK or internationally produced vehicles into which APC funded technology has been integrated.

- **Application forms:** Additionally, a range of adjustments could be made to application forms to improve data availability (particularly for projects that were unsuccessful in their funding application to the APC). This would include capturing the contact details of collaborating firms, and potentially a broader range of baseline characteristics of those firms (that can then be tracked over time either through monitoring or survey research).

- **Role of surveys:** Surveys will be required if there is an interest in capturing the intermediate (and to some extent, the economic) outcomes of the APC. Such surveys would aim to take observations at project completion and 3 to 5 years following completion to provide a long-term perspective on the outcomes of interest (and baseline observations if application forms are not adapted to capture the metrics of interest), and would cover all firms and institutions involved in APC funded projects.

- **Unobservable outcomes:** It will not be possible to directly observe the noise and human health outcomes of associated with the adoption of vehicles integrating APC funded technology.

4.0 Impact Evaluation Options

The following sections explores the methodological options available for assessing the causal effects of the APC programme (including consideration to the application of qualitative methods). This section gives detailed consideration to the issues that might be involved in constructing an appropriate counterfactual group of non-beneficiary firms, as well as exploring the potential to apply a range of econometric techniques to assess the impacts involved as robustly as possible.

4.1 Sample Sizes

This section outlines a range of quantitative and qualitative methods that might plausibly be applied in an evaluation of APC. However, the application of quantitative methods in particular is dependent on the availability of sufficiently large sample sizes to identify the causal effects of interest. The evidence gathered through this study suggests that, over the first two rounds, there were been 48 firms named in APC applications[33], raising significant concerns as to how far an econometric analysis might feasible. However, as application volumes appear to be rising, this constraint may ease in the future (and clearly this will require review in advance of commissioning a main-stage study).

Recommendation: Revisit Scoping Study
In advance of commissioning a main-stage study, a further review of potential sample sizes (including the number of unsuccessful applicants) is advised to determine the feasibility of applying the range of econometric methods set out in this section and the optimal approach to selecting the counterfactual.

4.2 Counterfactual selection

A robust quantitative assessment of impacts will require the selection of an appropriate sample of firms and other actors in the low carbon propulsion technology that have not benefitted from APC support to act as a counterfactual (with the counterfactual defined as what may have occurred in the absence of the APC). In line with the evaluation framework set out in Section 2, this might include:

- Non-recipients of R&D subsidies (to explore the specific impact of the grants).
- Actors (firms and academic institutions) in related technology areas or in other international territories to explore the broader indirect effects of the APC.

[33] A further 15 applications were received under rounds 3 and 4 after this report was drafted.

Applicants

For an assessment of the impacts of the R&D subsidies provided through the APC it will be necessary to identify an appropriate counterfactual group of non-beneficiaries. However, as application to the programme is voluntary, and selection into treatment is based on an appraisal process judging the technical and commercial merits of the application, there would be significant concerns that any group of firms selected as a counterfactual would systematically differ in both observed and unobserved characteristics to grant beneficiaries in ways that may bias results:

- **Non-applicants** to the programme are likely to differ to applicants in ways that are correlated with the outcomes of interest. As an example, there may be some foreign owned firms that have little interest in applying for (or are unaware of the availability of) grants through the APC if they complete the majority of their R&D within their home territory. In such a scenario, comparisons against successful APC applicants (who by virtue of their application to APC have signalled some interest or intention to undertake R&D in the UK) would likely overstate the impact of the programme. Equally, non-applicants (even where matched in terms of sector, size, location and ownership characteristics) may be pursuing different R&D goals which may benefit their future sales (for example, in improving safety), and may also be an inappropriate comparison group for those seeking subsidies through the APC.
- **Unsuccessful applications:** These issues can in part be addressed through focusing on applicants who have been unsuccessful in their applications to the APC: the firms involved with these can be assumed to share a range of observed and unobserved features with successful applicants (and also have prepared a set of technological proposals that can potentially be tracked alongside those of successful applicants). However, unsuccessful applicants are also likely differ in unobserved ways to successful applicants which will likely be correlated with the outcomes of interest (for example, there may be a less convincing engineering rationale for their proposed technological solution, which would imply that they would less likely to successfully commercialise the technology, regardless of the availability of subsidies through APC).
- **Unsuccessful projects:** If there are high numbers of repeat applications from individual firms (including for different projects), this may limit sample sizes available for any econometric analysis. An alternative strategy would be to configure the analysis at a project level. Such an approach would enable an assessment of project level outcomes (e.g. technical progress, leverage of investment into the project, and commercial outcomes), though would be more restrictive (e.g. it would not be possible to examine the impact of APC on firm level productivity if the focus was solely on unsuccessful projects).
- **LCV-IP applicants not applying to APC:** Finally, there may be a set of LCV-IP beneficiaries that have not made an application to the APC that could act as a comparison group. Again, there would be concerns that this group of non-applicants would systematically differ to successful applicants in unobserved respects. For example, the projects involved may have been or may be aborted because of technical issues, or the firms involved may not have sufficiently strong links to an OEM to allow them to pass the eligibility criteria for APC.

The strategy of focusing on unsuccessful applicants and/or projects is likely to be the most robust (as it addresses the highest proportion of the unobserved characteristics over which the two groups might differ).

Application of the econometric techniques outlined below should then be applied to further minimise the issues associated with selection bias. The data-linking analyses completed suggests that these issues are potentially significant: for example, successful applicants to IDP4 were more active in making low carbon propulsion patent filings in the years preceding their application for funding than unsuccessful applicants. Secondly, as illustrated in the table below, successful applicants to the first two rounds of APC were more likely to be in receipt of subsidies provided through other Government programmes (particularly the LCV-IP), and it will be critical that an evaluation is able to control for the possible influence of these other funding streams on the outcomes of interest.

Table 4.1: Applications to and funding committed through APC, AMSCI, and LCV-IP by successful and unsuccessful APC applicants

	Average no. of APC applications	Average APC funding committed (£)	Average number of AMSCI Applications	Average AMSCI funding committed (£)	Average number of LCV-IP applications	Average LCV-IP funding committed (£)
Unsuccessful APC applicants	1.12	0	0.35	61,176	0.47	211,270
Successful APC applicants	1.33	2,196,858	0.86	71,031	1.48	869,300
Total	**1.24**	**1,214,053**	**0.63**	**66,622**	**1.03**	**574,918**

However, there have been very few applicants who have been unsuccessful in securing APC funding, and it is advised that the option of utilising LCV-IP beneficiaries not applying to the APC as a reserve pool of comparison observations is retained should sample sizes prove too small.

Recommendation: Counterfactual Selection	
Choice of counterfactual	It is recommended that unsuccessful applicants/projects are selected as the preferred comparison group, as a means of minimising issues of selection bias amongst non-applicants.
Contingency options and sensitivity analysis	Other counterfactual options – particularly LCV-IP applicants not applying to the APC, should be retained as contingency options. If resources permit, it may desirable to use this group as a secondary comparison group to provide checks on the robustness of results to the selection of controls.

Alternative technology areas

The APC aims to achieve a broad range of impacts in terms of co-ordinating and catalysing investment into developing low carbon propulsion technologies. As such, a range of costs may be incurred by actors beyond the firms associated with APC funded projects – for example, if non-applicants are encouraged to invest in new low carbon propulsion R&D projects as a result of the prospect of securing subsidies for late stage development (which may also lead to as possible benefits in the form of accelerated technical development). In order to examine these effects, it may be possible to identify a comparison sample of firms and academic institutions (using a similar approach to that identified in Section 3) that are active in an alternative technological area to explore the broader causal effects of the APC. Possibilities include:

- **Other automotive systems:** Propulsion systems are only one system integrated into vehicles, and alternative automotive technologies (such as gearboxes) may offer one a set of possible comparison technology areas. However, there are a range of possible issues with such an approach. Firstly, the sales of firms involved in the production of these other technologies are likely to be linked to success of OEMs in developing low carbon propulsion technologies (a positive spill-over effect). At the same time, the APC may lead applicants to prioritise R&D activity targeted at low carbon propulsion systems at the expense of these alternatives (a negative spill-over effect). Finally, there is likely to be significant overlap between the actors in these related technological areas (particularly at the top of the supply chain), making difficult to make comparisons for some outcomes (i.e. OEMs will likely be members of both the treatment and control groups). Other interventions (e.g. subsidies available through AMSCI or other schemes) may also influence the rate of technological development in related areas.
- **Areas with upstream but no downstream subsidies:** There are currently five technology areas with an Innovation Platform (Low Impact Buildings, Stratified Medicines, Assisted Living, Sustainable Agriculture and Food, and Low Carbon Vehicles). Not all of these platforms benefit from the scale of downstream subsidies provided through APC, and may offer alternative ways of developing a counterfactual technology area. LIB-IP in particular has been driven by a similar set of policy imperatives and is aimed at decarbonizing the built environment, and could be particularly attractive as a possible counterfactual technology area (though the technologies themselves might be considered simpler, and in less need of both downstream subsidies to take them market and parallel investment in infrastructure).

However, two significant issues will prevent these possibilities providing anything more than 'reference cases.' Firstly, there is a significant selection bias problem: the APC was developed in response to both the scale of the strategic opportunity, and the level of co-ordination present in the automotive industry (illustrated, for example, by the development of the technology road-map). Other technology areas may not share these features, and comparisons may well overstate the effects of the APC on the outcomes of interest.

Possibly more problematically, any estimates of the impact of APC on the outcomes of interest using such an approach will conflate its effects with the array of other Government policies that are likely to be influential over the outcome (other technology areas will be subject to similar issues, such as the role of CERT, CESP and ECO in stimulating demand for energy efficiency measures in residential properties). As such, these methods may be more appropriate as part of an over-arching evaluation of the Government's co-ordinated investment in this technology area, rather than an evaluation of APC in particular (and there remain substantial issues over the feasibility of such a study).

Recommendation: Indirect Impacts of APC

Given the substantial challenges involved in providing a robust quantitative assessment of the indirect effects of APC, it is suggested that the main-stage evaluation focuses on providing a quantitative outline of the broad changes in investment and collaboration in the development of low carbon propulsion technologies using the secondary data that is available. This should be supplemented by qualitative research strategies (as described below) to unpick the role of APC grants and APC Ltd in contributing to the changes observed.

International comparisons

Another possible means of exploring the effectiveness of the APC (or at least, the total package of Government support for the development of low carbon propulsion technologies) would be to undertake an econometric study relating the overall performance of the automotive industry in different territories to the overall levels of consumer incentives, infrastructure investment, and R&D subsidies offered by the relevant national Government. Results could then be used to estimate the incremental impact of the APC (by applying the estimated coefficients to the total subsidies provided).

While such a study could identify correlations between total R&D subsidies and the performance of the sector, there would again be significant issues of selection bias: those Governments electing to provide significant R&D subsidies will also likely be those with an automotive manufacturing industry that is sufficiently significant to absorb them. Application of the longitudinal panel methods described below could potentially reduce these concerns (as estimates would be robust to any time invariant and unobserved country level characteristics), though it is anticipated that any findings could not be treated as any more than indicative. Equally, collection of the necessary data on the overall subsidies provided by the range of nation states concerned would be a labour intensive exercise.

Recommendation: International Comparisons

An international study may be feasible to examine the national impacts of the APC on some key metrics of interest could possibly yield some insights of interest. However, there will be significant challenges in assembling the macro-data required and the delivery of robust insights are far from assured (owing to differences in national contexts). As such, this is deemed a low priority option for inclusion in a main-stage evaluation study, though BIS has commissioned an international benchmarking study that may yield further insight into the possible value of such an approach.

4.3 Before and After

A before and after evaluation strategy (in the context of an interrupted time series design) involves tracking the outcomes of interest for the beneficiary group alone and does not involve the selection of a counterfactual group. This is a weak evaluation design, as it does not establish a high degree of confidence that the changes were due to the policy of interest (although the approach may be sufficient in some contexts where there is a high degree of confidence that there are no significant external influences over the outcomes of interest). However, if is it is not possible to implement a before and after approach, then neither more robust evaluation strategies will not be feasible. As demonstrated in section 3, it will be feasible to collect a sufficiently large range of longitudinal data, and a before and after evaluation strategy might be feasible.

Recommendation: Before and After

Before and after methods are feasible in principle, but offer a low level of confidence that a causal relationship has been observed. As such, they are only recommended if the sample sizes do not permit the application of more robust evaluation strategies (which as highlighted before, will require confirmation at a later stage given the possible risks involved), and if it can be used in conjunction with other methods.

4.4 Matching

Issues of selection bias can be partly addressed by building a counterfactual group based on finding the most similar firms to those that have benefited from APC grant funding (a process known as matching). If all factors that influence the selection of projects within the programme can be observed and measured, then matching methods have the potential to provide estimates of impact that are unbiased. However, given the selection processes involved with the APC, such a strategy is likely to be problematic as appraisal scores will need to be included as a matching variable. As by definition, successful applicants will in the main have received higher scores than unsuccessful applicants, there will only be a very small number sharing sufficiently similar scores to create a ‘match’ (e.g. this issue was encountered in the AMSCI evaluation scoping study, which employs a closely related fund architecture to the APC).

This issue may be less problematic if the volume of proposals meeting the minimum scoring criteria begins to exceed the funding available, leading to an the selection of proposals from a pool of ‘fundable’ projects by an Investment Board or similar. In such a scenario, matching may be more effective as successful and unsuccessful proposals may share similar technical assessment score and value for money measures. Additionally, matching methods might also be helpfully be utilised to ensure the characteristics of projects are balanced (for example, in terms of technology types, baseline TRL and MRL levels, cumulative levels of R&D expenditure, and the like). This would require the exclusion of appraisal scores from the first stage probit models underpinning Propensity Score Matching, however, and as such, supplementary methods would be needed to address the main issues associated with selection bias (such as the panel techniques described below).

Recommendation: Matching

The design of the processes for allocating resources through APC creates substantial challenges for the application of matching methods (such as Propensity Score Matching). However, the application of these methods could potentially act to balance treatment and comparison samples in terms of observable characteristics other than measures of project quality (e.g. baseline TRL and MRL levels). Contingent on sample sizes, it is suggested that the application of these methods are integrated into an impact evaluation of APC, but only in conjunction with other methods described below that will be more effective in addressing those observable and unobservable characteristics driving success in the application process.

4.5 Longitudinal panel techniques

The availability of longitudinal data from the various data sources, noted in the previous section, may allow for the creation of a longitudinal panel covering APC beneficiaries and unsuccessful applicants or non-applicants. Longitudinal panel techniques (such as fixed effects or difference-in-differences) extend a standard regression model so as to control for unobserved variables. Where particular characteristics remain invariant across time or invariant across observation units (or groups of observation units) they can be estimated. In practice, this involves the inclusion of dummy variables for each firm in the panel in the regression model (or de-meaning the relevant time series), which captures the influence of all time invariant characteristics over the outcomes of interest (alternatives include random effects models).

Where measures are taken solely at the baseline and follow-up period, such models will be restricted to controlling for firm specific unobserved characteristics (as the number of observations will be limited). However, using the annual data that tends to be available from administrative datasets, it will be feasible allow for a broader range of fixed effects such as unobserved time, sector or location specific shocks. Application of this basic method could enable all successful and unsuccessful applicants to be included in an analysis, and would result in estimates of the average treatment effects involved. However; this methodology would not be able to account for changes in the unobserved characteristics of individual firms involved.

Additionally, such strategies can be adapted to integrate monitoring data from other programmes that might be thought to have a contaminating influence over the outcomes of interest (such as RGF or AMSCI). This data could supply additional control variables to be used in regression models to support a quantitative separation between the impacts of APC and these other schemes.

Recommendation: Longitudinal Panel Methods

On the assumption that longitudinal data will be collected through primary research methods and data-linking, it is recommended that longitudinal panel methods are integrated alongside matching strategies as one method of assessing the impacts of APC grants. At a minimum, survey data will permit the application of difference-in-difference methodology, and to the extent that annual data can be extracted from the ONS VML and other secondary datasets, fixed effects methods should be applied to provide deliver results of potentially greater robustness and insight (such as modelling the persistence of outcomes over time). These methods might attain level III on the Maryland Scale of Scientific Methods (contingent on availability of data for comparison groups, though this is viewed as a low risk).

4.6 Pipeline Methods

The APC programme plans to run a number of competitions each year, however there have been two projects funded via an out of competition facility. Due to this round by round approach, it may be possible to make use of firms who have yet to become beneficiaries. This could be achieved by using firms successful in later rounds as a counterfactual for those supported in earlier rounds. Such a strategy would require annual observations for the treatment and comparison groups.

Such a strategy is robust if there is no correlation between the outcome of interest and the timing of an application. Given the mission oriented nature of the APC and the nature of the market failures involved, with highly specific technological goals, there is a risk that this may not hold. Applicants in earlier rounds may have systematically different attitudes to risk and product development that those involved in later applications (given the incentives to delay investment until there is greater certainty over the future path of technological development). Given the comparatively small number of OEMs in the UK, there is also a risk that the same firms appear in multiple rounds, creating challenges in constructing a counterfactual from those successful in later rounds (though this issue could possibly be dealt with by modelling the ‘treatment’ as the cumulative subsidies received). Finally, the validity of this methodology would be threatened if thematic or technology specific rounds of the APC were funded (though applicants to these rounds could potentially be excluded in any such analyses).

Nevertheless, this option should be re-examined once the distribution of applicants and repeat applicants is known.

Recommendation: Pipeline Methods

Pipeline methods (using later successful applicants as a counterfactual for earlier successful applicants) have the potential to more effectively address the issues associated with selection bias driven by observable and unobservable characteristics than the longitudinal panel methods described above. If the key underlying assumptions are satisfied, this might attain Level IV on the Maryland Scale of Scientific Methods. However, potential challenges – particularly the likelihood of repeat applications – may limit scope to apply this approach. The issues involved will require re-investigation at the point at which the scoping work is revisited.

4.7 Regression discontinuity design[34]

The architecture of the APC is such that the applicants are assigned into treatment on the scores received through two appraisal processes: a technical assessment led by Innovate UK, and a value for money assessment led by BIS. An application is funded if it exceeds minimum scoring thresholds in both appraisal processes. This competition design leads naturally to the possibility of adopting a Regression Discontinuity Design strategy, in which those applications that 'just made it' are compared to those that 'just missed out.' Such a strategy can be comparable in robustness to a randomised control trial (on the basis that random variations in the appraisal process will produce balanced samples in the vicinity of the threshold), provided a number of key assumptions are satisfied.

Amongst these assumptions is the principle that there should be no interaction between the scoring process and the treatment status. The process evaluation which ran in parallel to this scoping study has illustrated that this assumption is not satisfied in the case of APC: as illustrated in the chart below, a number of applications passed the technical appraisal, but initially failed the value for money assessment. In several cases, discussions with the applicant led to an improvement in the value for money associated with the project. This in turn increased the value for money of the project from the perspective of the public sector, making the project suitable for funding. This dialogue helped to improve the suitability of projects for funding, but is likely to cause significant problems for an RDD approach to evaluation as it may create an imbalance between those that 'just made it' and those that 'just missed out' (on the grounds of the VFM). Firms that reject a reduction in project costs may not share similar characteristics to those that accept (as is clear in the figure, two applicants sharing similar appraisal scores to those benefitting from this practice did not see a change their treatment status) invalidating the design assumptions of a RDD.

Discussions with BIS have suggested that it is unlikely that there will be similar movements in the VFM scores in the future. As such, RDD methods may provide robust findings (and could be strengthened through the exclusion of the earliest rounds of APC). However, sample sizes are likely to be highly problematic for RDD methods in particular, which tend to be most robust where there are large numbers of observations in the vicinity of the scoring threshold.

[34] Fuzzy Regression Discontinuity Design methods have not been considered below as all project proposals meeting the minimum scoring thresholds have received funding. However, a similar set of issues will also apply should this fail to hold in the future (e.g. if the volume of funding requested by proposals exceeding these thresholds is in excess of the funds available).

Recommendation: Regression Discontinuity Design

There are some analytical challenges around the application of Regression Discontinuity Design in the context of the APC. However, the methodology would be in principle feasible to apply providing sample sizes prove sufficiently large and issues relating to changes in VFM scores following initial appraisal are negligible in the long term. Given its potential to deliver high quality results (Level IV on the Maryland Scale of Scientific Methods), it is recommended that the issues are revisited as part of future re-scoping work and if appropriate, integrated into a main-stage evaluation design (alongside longitudinal panel and pipeline methods if appropriate).

4.8 Randomised control trials (RCT)

As an approach, a RCT design represents a gold standard for the evidence that it generates. Assigning treatment randomly (in this case the grant funding) removes the selection bias from the groups being evaluated. There is a strong drive to introduce RCTs across government. However, there are several practical issues associated with applying an RCT process to the APC programme.

To pursue the RCT it would be necessary to randomly select a group of projects which were suitable for funding but exclude them from APC support. Randomisation could be applied at several stages: at the point of an application being received or once the full appraisal process had been passed. Given the small numbers of applications, in both cases this would most likely result in either a reduction in the ability of the APC to defray resources or, if the same spend profile was maintained, poorer quality projects being funded despite high quality projects being excluded (risking reputational damage). There are also political and ethical issues associated with random assignment into publicly funded programmes that would also need to be borne in mind.

4.9 Displacement

A key challenge for any quantitative evaluation of interventions designed to have effects on product markets is establishing the levels of displacement involved; the extent to which the implementation of the policy prevents other positive outcomes from occurring. In the case of the APC this requires establishing the causal effects of the intervention on the sales of other domestically based producers. Individual purchasing decisions reflect the careful consideration of factors such as style, quality, brand, reputation, price, energy efficiency and environmental impacts. But varying any of these vectors can be expected to change the aggregated demand and total number of vehicles sold. The highly focused nature of the APC, and the availability of detailed product market data, will mean that a more quantitatively rigorous approach may be more feasible than in many other scenarios.

If there have been any displacement effects as a consequence of the introduction of vehicles integrating APC technology, then this should be visible in a loss of market share for competing vehicle models. In principle, with annual sales data at a model level across the EU, it should be straightforward to develop an econometric model that estimates these effects, with the effect of APC modelled as a negative treatment effect on competing vehicle models, and non-competing vehicles utilised as a control group (with the vehicles integrating APC funded technology excluded from the sample). The set of competing vehicles might be identified by isolating a set of models with similar features that will be most likely to be subject to the spill-over (e.g. weight, price, seats, etc.) using the technical specifications in the MVRIS data (i.e. a form of distance-decay approach). Furthermore, this treatment effect can be split into two components (UK and non-UK) to explore questions around how far these externalities have affected domestic or non-domestic producers[35].

The econometric modelling would need to focus on market share rather than overall sales volumes (to allow for broader trends in the size of the automotive market), implying a logistic regression model rather than linear methods. Additionally, a set of control variables at a vehicle and country level will be required to allow for aspects such incomes in the countries concerned, as well as unobserved manufacturer and brand fixed effects. It is also anticipated that any displacement effect would be strongest following the introduction of the vehicle integrating APC technology, and would fall away as both the producers concerned as well as competing producers introduced improvements (gradually making the APC funded technology obsolete). This would need to be accommodated in modelling by allowing the strength of displacement effects to vary over time. Such an analysis would produce an estimate of the percentage of market share lost by competing firms, which could be applied to estimates of the overall impact on firm level output.

There is a problematic issue in that APC may lead to permanent loss of market share for competitors, if grant recipients are able to build on technological advances made that would not have originally been possible without APC funding. Such an effect may be visible at the level of the OEM rather than at the level of the model. A similar analysis focusing on market share at this level may also be feasible to explore such effects, though it may be substantially more difficult to identify causal effects at this higher level of aggregation.

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[35] An econometric model might be specified in basic terms as follows:

$$Y_{t,i} = \alpha + X_i\beta + \gamma \sum_{j=1}^{J_t} \left(e^{-\sum_{k=1}^{K} (\frac{x_{k,i} - x_{k,j}}{\sigma^{x_k}})} \right) + u_t$$

where Y is the sales of (non APC funded) vehicle j in period t, X is vector of vehicle level characteristics (price, weight, engine capacity, etc.), and the summation term is the sum of the differences between vehicle I and vehicles integrating APC funded technology (j), across the number of vehicles integrating APC funded technology in period t (J). This is represented by an exponential distance decay function taking the value of 1 where the characteristics of vehicle i and j are identical, and smaller values where vehicle characteristics differ. This term is increasing in the number of vehicles integrating APC funded technology available on the market, and could be interacted with a dummy variable relating to the country in which vehicle i was produced (UK or overseas) to estimate displacement effects within the UK, and augmented with fixed effects terms to capture unobserved vehicle characteristics, such as branding. The co-efficient γ will in principle capture negative impacts on the sale of competing vehicles.

Recommendation: Displacement

The availability of detailed product market data through the MVRIS system offers an opportunity to examine displacement effects in more quantitative detail than is normally feasible for evaluations of this nature. The feasibility of the analysis is not necessarily linked to the number of vehicles integrating APC funded technology that are launched to market (though it would be desirable to pursue such an analysis once there were multiple products on the market). However, it is dependent on the traceability of APC technology into specific models and is therefore contingent on the implementation of the recommendations to enhance post-project monitoring set out in Section 3.

Carbon emissions

This modelling approach could also be extended to examine how far vehicles integrating APC funded technology accelerated the adoption of more energy efficient vehicles. If APC has displaced less energy efficient vehicles, then this should be visible in a reduction in the average emissions of vehicles sold within the segment into which the vehicle is introduced (again, using non-competing vehicles as a control to capture technological advances that might have been made anyway). As there is substantial detail available on the technical specifications of vehicles, such an analysis will be feasible.

Component sales

There is a possibility that displacement of vehicles produced in overseas territories could create negative effects for UK based manufacturers if they supply componentry to the Primes concerned. Equally, displacement effects within the UK may also have impacts on overseas suppliers of components. In principle, it would be feasible to allow for this if it was possible to trace the geographical origin of each component (or major component) associated with each vehicle model, and the proportion of the value of the vehicle it accounted for. However, this will most likely place too great a demand on the data it would be feasible to collect as part of a main-stage study, and an assumption that these two effects offset each other will likely be required as a simplification measure.

Uncertainties

The extent to which the above analyses will be feasible will be in part dependent on the (currently unknown) success of APC projects in developing propulsion systems that find commercial application in sufficient volumes to permit the statistical analyses involved. As such, further review is suggested at a later stage, once these aspects are known in greater detail.

4.10 Spill-overs

The methodologies set out above have the potential to capture any effects accruing to the partners involved in APC funded projects. However, the scheme has the scope to deliver a range of spill-overs to actors not directly involved in the project. Such effects might be mediated through broader collaboration beyond the partners involved in the project, broader effects by which partners with no relationship with those involved in APC projects are able to build on the technologies developed (e.g. through reverse engineering), or via local and regional networks (e.g. through the 'collision' of actors in space or through clustering or agglomeration effects).

Network Effects

In principle, the APC selection process creates a sample of treated and untreated network nodes (actors collaborating with APC applicants and collaborating partners) that could be exploited to examine any spill-over effects mediated through broader collaboration. If it is possible to identify these actors (and longitudinal data on the relevant outcomes of interest), then it may be feasible to extend the basic econometric methodologies outlined above to examine the causal effects involved.

The main anticipated challenge will be obtaining details of these broader collaborative relationships. It is considered that this information will be too complex to be collected reliably through primary survey research or monitoring. However, collaborative links may be visible through past applications to other collaborative R&D programmes. Innovate UK and EPSRC publish details of all successful applications, for example, though obtaining details of unsuccessful applications across all potentially relevant programmes will be highly challenging. Such records could be supplemented by data from patent records: patents list the inventors involved in the development of the relevant invention (including their organisation) and this could be exploited to identify other collaborative relationships that may not be captured in Innovate UK or EPSRC records. While such records will be likely partial, they could potentially be linked to the sources of secondary data outlined in Section 3 to provide longitudinal measures of the range of outcomes of interest.

Patent Citations

Although the methods above have the potential to generate some insight into the frequency of knowledge spill-overs (e.g. if there is a causal effect of APC on the number of citations to relevant patents registered by beneficiaries of R&D subsidies, then this would provide an indication – albeit noisy - that the scheme has led to spill-overs). However, such methods will not provide any indication of the value of those spill-overs, an aspect that is highly challenging to address empirically owing to the challenges involved in identifying the group of actors that have benefitted from a spill-over.

One potential possibility, however, would be to take the set of firms registering patents citing patents registered by APC funded organisations as a notional treatment group, and the set of firms of citing patents registered by unsuccessful applicants as a notional comparison group. These records could then be linked to sources of secondary data on firm performance (in particular the data available within the ONS Virtual Micro-data Laboratory). Similar methods to those described above could then be applied to generate estimates of the additional value of the spill-over effects involved (i.e. if the spill-over effects generated through APC funded activities are more valuable, then this should be reflected in the relative performance of the notional treatment and comparison groups described).

Local Spill-overs and Agglomeration Effects

An examination of local spill-overs and agglomeration effects is potentially feasible through a spatial analysis. In a similar manner to above, the selection process will create a number of treated and untreated locations receiving APC support (as defined by the physical location of the successful and unsuccessful applicants and collaborating partners, which is captured in application forms). If the APC leads to significant local spill-overs, this may be visible in the performance of firms (and possibly academic institutions) located in adjacent areas (with effects assumed to decay with distance). Such an analysis could also be extended to examine any effects driven by FDI (if it is possible to identify the location of relevant investments in R&D capacities in the UK).

The implementation of this method could involve defining businesses within (for example) a 10, 20, or 50km radius of APC beneficiaries as members of treatment and comparison groups (such an analysis might be usefully limited to firms operating in the automotive manufacturing sector). The longitudinal secondary data on firm performance described in Section 3 is largely georeferenced, and could be used to establish longitudinal measures of employment and turnover of relevant firms (as well as the number of relevant enterprises). Again, the basic econometric frameworks (including RDD methods) could be extended to explore how far it is possible to establish a causal effect of this nature.

Recommendation: Spill-overs
The selection process creates a number of opportunities to examine various types of spill-over effect (by creating treated and untreated potential recipients of spill-overs, through either collaborative links or via implied connections in space. There is a substantial uncertainty as to how far any impacts will be sufficiently strong to be visible amongst these organisations. However, the marginal cost associated with completing the proposed analysis will be relatively small, as it will require access to the same set of data as will be collected to examine the direct impacts of APC grants. As such, exploratory analysis of the manner suggested is recommended as part of a main-stage evaluation, again contingent on sample sizes.

4.11 Attribution

As noted in Section 2, APC provides downstream grants for low carbon propulsion R&D projects that may have received upstream support from other programmes. This may cause an attribution problem, in that multiple sources of public sector funding will have contributed to the same outcomes. However, it is anticipated that this will pose a more significant problem for evaluations of the upstream or early stage R&D programmes than for APC, provided the focus of evaluation is on the incremental effects involved. In the case of APC, it is anticipated that projects will not be able to seek follow-on funding to take the projects to market (i.e. APC will take the projects as close to market as is feasible within the State Aid guidelines) and other public programmes will not be instrumental in achieving these outcomes. This would not hold for early stage R&D programme, as projects may have otherwise stalled in the absence of APC.

4.12 Qualitative Strategies

Many of the key outcomes identified within the theory of change and the relationships illustrated in the logic model are subtle effects which will not be readily identifiable through quantitative analysis. For example, improved collaboration is a key aim of the programme, but is an immensely complex inter-organisational and interpersonal interaction to map.

Patent analysis and non-disclosure agreements can offer a snapshot indicating the presence of collaboration, but cannot explain how it developed, assess its quality and depth, or test the extent to which knowledge is exchanged or trust developed. Given the inherent delays associated with indicators such as patent filing, qualitative approaches may also offer an earlier indicator of impact as well as supporting an examination of effects beyond the immediate APC project.

The specifics of the APC programme make qualitative and case study approaches of particular importance. The challenges identified above with pursuing statistical approaches imply that case studies will be very important for assessing the impact of the programme. Two strands of case studies will be required. The first will focus on applicants and the second on the broader impacts of the APC.

A range of possible approaches to the case studies might be adopted, all of which will involve the triangulation of qualitative, quantitative and documentary evidence to test the hypothesised programme theory that was put forward in Section 2.5 (and competing explanation of the outcomes observed). In this context, the case studies would be broadly aiming to test the hypothesis that the grant funding provided through the APC was instrumental in accelerating the development of low carbon propulsion technologies, and in improving the market share and productivity of the firms concerned. The range of options considered (though this is not intended to be exhaustive) include:

- **Realist evaluation:** Using an understanding of the mechanisms of change implicit in the programme design and its intended impacts and outcomes as described from those involved in delivering the programme[36]. The application of these approaches would involve examining the institutional context in which the projects emerged (context), the role of grant funding in inducing additional investment in R&D and other associated inputs, such as collaboration (mechanism), and their role of achieving technological progress, commercialisation of the resultant technologies, and downstream performance of the firms concerned (outcome). A set of competing hypotheses linking these three aspects of the problem of causality would then be developed for each case. Evidence (qualitative and quantitative) relating to these aspects of the problem would then be systematically gathered to attempt to invalidate these competing explanations, leaving a residual set of explanations describing the range of contexts in which APC grant funding was instrumental in achieving the upstream technical and downstream economic outcomes of interest. Such a framework would be a helpful means of examining the effects of individual APC grant funded projects (in which the contexts, mechanisms and outcomes can be relatively clearly defined, and evidence comparatively straightforward to collect). However, they may be potentially less straightforward to apply in the case of those focusing on tracing back the potential influence of APC in the delivery of particular observed outcomes.

- **Contribution analysis[37]:** Contribution analysis focuses on testing a proposed theory of change and aims to illustrate that initiatives made a causal contribution to the outcomes observed. Explicit account of the possible external factors that might also have led to

[36] A review of the approach is set out in Easton (2010) Critical realism in case study research, Industrial Marketing Management 39 (2010) 118–128, http://www.mega-project.eu/assets/exp/resources/critical_realism_-_easton_1.pdf (Accessed March 2015)
[37] Mayne, J. (2001) Addressing attribution through contribution analysis: using performance measures sensibly. Canadian Journal of Programme Evaluation 16; 1-24

the changes observed are also required. These two aspects have been developed in the evaluation framework set out in Section 2. Evidence on the role of APC and external factors in contributing to outcomes observed should be then assembled to develop a plausible explanation of the extent to which APC was a causal factor involved. These methods might be best applied to an examination of the indirect impacts of the APC, where the broader outcomes relating to crowding-in, collaboration in the sector, and broader technical development, have the potential to be influenced by a wide range of different external factors.

- **Process tracing[38]:** Focuses on the likely explanations for results rather than the proposed theory of change. Competing theories that could explain the outcomes being observed (including the hypothesis that APC caused the outcome) are identified by the evaluator. Each should have an indication of how they can be tested so that a comparison of each can be made. Both qualitative and quantitative data can be used to verify a process is indeed occurring as suggested. Four logical hypothesis tests can be applied in this framework, giving varying strength to conclusions that are drawn from them. For example, if the industry sees improved growth in the firms benefiting from APC grants, an alternative hypothesis, such as changing economic conditions and/or decreasing real wage levels in the UK could be proposed as a source of this change. A wide range of evidence, such as impacts on non-automotive manufacturers, could be used to test the validity of attributing change to the programme alone. Process tracing methods might be most helpful where a specific outcome (such as the emergence of a new technology or a specific FDI project) has been identified and the aim is to establish the extent to which the APC can identified as a contributory factor in the delivery of these outcomes. An alternative to process tracing might be a General Elimination Methodology approach, which also seeks to rule about competing explanations for specific events.

Case studies exploring the effect of the APC on grant recipients

The unit of analysis for each case study will be the project which formed the application to the APC and the objective will be to investigate the role that the APC played in bringing this forward. The case studies will follow a soft systems methodology, focusing on the result of the project (regardless of whether it was successful in securing APC funding – though clearly there are some issues of relating to engagement of non-funded applicants, though the research undertaken as part of the process evaluation of APC and other similar evaluation shows that it is not infeasible), and then casting back to understand the role of various stakeholders, organisations, and the platform in driving this scientific, technical, commercial or social advance.

Each case study will depend on three complementary areas of research activity:

- Statistical analysis of firms involved with the application compared to a synthetic control (see Box 4 below for a detailed discussion of this methodology). This approach would make the most of the indicators developed and discussed above. These metrics will offer an initial hypothesis of impact to test, and will in this sense provide a research platform for the remainder of the case study research. This is especially important given the limited potential for traditional statistical analysis described above in Section 4.

[38] See Collier, D. (2011) Understanding Process Tracing, Political Science and Politics 44, No. 4, (2011): 823-30

- Document analysis tracking the evolution of specific technologies and their adoption or integration in vehicle models, the commercial performance of these models, any evidence of spill-overs into other automotive firms or industries. This would include research to review application forms, monitoring reports, technical papers, patent submissions and their citations, as well as secondary complementary data such as vehicle sales.

- Qualitative evidence gathering to validate the research through interviews with individuals responsible across each consortium. Case studies will be prepared on the basis of interviews with senior managers, academics and other partners reflecting the breadth of the collaboration which drives them. This will be essential for the study team to get a feel for the dynamics of the project. The following topics would be explored:

  - Project objectives.
  - History and context to unpick the genesis of the technology, including the origins of the idea, the sources of the IP, and the backgrounds of collaboration.
  - The activities undertaken to develop the technology as well as progress with delivery.
  - The relationship between the partners and their relative roles.
  - The financial model used to bring the project forwards, focusing in particular on the financial relationship between partners.
  - The financial and soft support received from the APC and other public sector bodies (benefits will need to be apportioned based on a view of their relative scale and role).
  - The expected use of the technology and wider benefits that can be associated with it.
  - Views on the wider impacts of the programme including, but not limited to, on skills and investment. Wider IP effects also to be investigated focusing on the scope for the IP generated within the project to have other applications and the likely pecuniary and knowledge spillover routes to achieving these impacts.
  - The wider context of the project – how is it situated with respect to other activities of the partners involved and related other schemes in the UK and abroad.
  - A conjectured counterfactual. i.e. a discussion of what partners believe would have happened had funding not been received.

The key point at which to deliver this research would be at the end point of the supported project – i.e. when APC funding has been fully disbursed. However, it would be advantageous if initial research could commence on project inception. A follow-up wave three years after the completion of the project would be required to identify the breadth of impacts from the APC discussed above.

Synthetic Control Methods for Comparative Case Studies

Synthetic control methods can be used in this instance to provide a quantitative structure for case study analysis. This is a statistical technique which helps to estimate the significance of the aggregate impacts of interventions. The technique creates an artificial and tailored counterfactual for each case to be investigated.

The approach makes use of a weighted comparison of control units where the weights are chosen such that they best bring the comparison group result in line with the treatment group before the intervention. Sometimes termed a ‘synthetic clone’, this can be thought of as a delivering or defining a statistically derived partner which is not subject to treatment – in this case it will be an organisation which reflects the applicants had they not received funds for R&D from the APC. The approach therefore offers an initial hypothesis of what could be expected for a firm (or a consortium) in terms of sales, turnover or other metrics had they not received APC funding as a starting point for the research.

Originally introduced by the academics Abadie and Gardeazabal in a 2003 AER paper the approach is becoming increasingly widely used for policy evaluation. Of most relevance for this study Fremeth et al. have applied this methodology to look at the impact of US government support and Treasury oversight on Chrysler following the financial crisis. This methodology was selected for the research because of the small number of auto firms considered to be of relevance, and the even smaller number of these that accepted government assistance. This study uses data from WardsAuto of vehicle sales, average price, average fuel economy, maximum fuel economy, average size of engine, and the average weight of the vehicles sold as well as the market segment (e.g. luxury, small car, crossover etc.) to create a statistical counterfactual for their Chrysler case study. As is proposed in the evaluation of the APC, the synthetic control analysis is used here as a starting point to assess the likely anticipated performance of Chrysler. In this case it was found that Chrysler had performed substantially worse than the ‘synthetic clone’, prompting an exploration of effects such as consumer backlash, corporate governance, the balance between commercial and political objectives, and the reactions of competitors to government involvement in Chrysler.

Stanford University have produced and make freely available extensions for delivering this statistical analysis in the R, STATA and Matlab statistical software packages.

Case studies exploring the broader impacts of the APC

A second strand of case studies will be required to identify the indirect impacts of the APC, those effects that reach beyond the direct beneficiaries from the programme. This is especially important for understanding the impact of the programme on the broader automotive and low carbon propulsion system innovation ecosystem. This will depend on developing two types of case study. The first will focus on the emergence of new propulsion technologies and the second on new foreign direct investments.

Case studies investigating the emergence of new propulsion technologies

Given the scale and significance of APC funding and the ambition of APCUK Ltd. activities, it is realistic to expect the programme to have some impact on a large proportion of the new low carbon propulsion technologies emerging from the UK up to 2030. As a result, by preparing case studies around specific advances in low carbon propulsion technologies it should be possible to identify the relative role of the APC in bringing these forwards.

For each case study the unit of analysis would be a new technology, product or business model, and the objective would be to investigate the role the APC played in bringing this forwards. As with the project oriented case studies these will draw on a soft systems methodology to map the contribution of different actors in the innovation process as well as the formal and informal sources of IP that were used. Scoping would be required to identify an initial contact with a good understanding of how this technology has been brought to market. Then the research would rely on a snowball sampling approach – starting with interviews with individuals understood to be linked to the innovation, and broadening out across the network of actors identified as responsible by them or any supporting material. In this way, these technology oriented case studies could be expected to follow the reverse of the process described above for the project-based case studies. Interviews would start with those closest to the market and work backwards to identify the role of any APC funding, or support activities.

Case studies exploring the role of the APC within new foreign direct investments

A related set of case studies could be developed exploring the role of the APC in attracting foreign direct investment. For these the unit of analysis would be a major investment in the UK by a foreign automotive manufacturer in the area of low carbon propulsion systems. The exploratory task for the case study research would be to identify the role of the APC in the decision to invest. This would consider the potential for the APC to have directly supported the decision to invest (for example in order to access APC grants) or achieved indirect influence (such as by supporting a key partner for the investment). Preparing the case studies would depend on interviews with:

- The investor – to understand the motivations of the investor for selecting the UK
- UKTI – if they were involved in supporting the investment
- APC contacts with the investor – if applicable

4.13 Summary

- **Mixed method approach:** In principle, the recommended evaluation strategy is to adopt a mixed method approach. This would include an econometric study identifying the magnitude of the causal effects of interest, focusing solely on the R&D grants provided through the APC. This would complemented by case study research to examine the key processes by which those grants led to the impacts observed (identifying aspects of policy design that could be replicated or adjusted in the design of future policy), as well as the effects of the APC that are less straightforward to quantify (including the co-ordinating effects of APC Ltd, technological and knowledge spill-overs, and effects on FDI). The theory of change articulated in Section 2 would be refined through the study, and would ultimately serve as the organising framework for triangulating the range of quantitative and qualitative evidence gathered.

- **Uncertainties:** There are substantial uncertainties over the sample sizes associated with any future analysis, which may limit the potential application of quantitative methods. This should be kept under review before commissioning a main-stage evaluation.

- **Direct impacts of APC:** Contingent on sufficient sample being available, it should be in principle feasible to quantify the causal effects to varying degrees of robustness using the following strategy.

  - **Choice of counterfactual:** Unsuccessful applicants would be the preferred comparison group for an econometric analysis. However, if resources permit, the inclusion of other groups might be integrated into a main-stage evaluation (such as applicants to LCV-IP that did not apply to APC) to check on the sensitivity of results to the selection of controls.

  - **Econometric methods:** It is advised that the main-stage evaluation involves the application of a combination of econometric methods. This would include longitudinal panel methods, alongside potentially more robust pipeline (if appropriate) and Regression Discontinuity Design methods. Matching techniques could potentially be applied to refine samples in terms improving their balance with regard to the observable characteristics of the projects and applicants involved.

  - **Displacement:** The availability of detailed product market data will mean that quantitatively rigorous approaches to estimating displacement effects can be plausibly explored and should be pursued as part of an evaluation strategy. This would involve modelling the negative effects on the market share of competing vehicles following the introduction of vehicles integrating APC funded technology). However, these strategies can only be feasibly implemented if it possible to trace APC funded technology into specific vehicle models (as described in Chapter 3).

  - **Spill-over effects:** The architecture of the APC creates the possibility of broadening the definition of the treatment and comparison groups to include organisations that potentially might receive a spill-over benefit (including spatially adjacent firms, networks of collaborators beyond those named in APC applications, or those citing patents registered by APC applicants). It is difficult to predict the potential value of such analyses, but as they will exploit similar sets of secondary data, an exploratory analysis is recommended as part of a main-stage study.

  - **Contingency:** In the event that insufficient sample sizes are available, a before and after approach is recommended examining the gross outcomes of APC projects.

- **Indirect impacts of APC:** The APC has been designed to have broader impacts in terms of stimulating investment in low carbon propulsion technologies in the UK, effects that may be visible in a broader population of firms and academic institutions than grant applicants. To explore these effects, it may be feasible to both develop a 'reference' technology area as a comparator, and implement an international comparative study relating the availability of subsidies for R&D to the performance of the automotive sector. Such studies are likely to fall short of providing a true counterfactual, and will likely conflate the impacts of APC with the wide array of Government investment in this technology area. As such, while results may provide useful context for an evaluation (and framing the results of quantitative and qualitative research), a quantitatively rigorous separation of the impacts of APC from other policies is likely to be infeasible. As such, a before and after analysis drawing on the available secondary data is recommended, supplemented by qualitative research forming part of the case studies below).

- **Case studies:** Given the challenges involved in establishing robust quantitative estimates of the impacts involved, a programme of case study research is advised to examine the impact of APC on grant applicants, the emergence of new low carbon propulsion technologies, and the attraction of FDI projects. Case studies could be grounded in realist, process tracing, or contribution analysis methods, and would take three forms:

    - **Project case studies:** These would the application of synthetic control methods to provide an indicative assessment of the impacts of APC funding in specific cases. This would be complemented by a detailed programme of qualitative research with applicants (and non-applicants), technologists and/or engineers, and investors, and an analysis of the available secondary evidence.

    - **Technology oriented case studies:** Case studies could also be completed around any specific advances in low carbon propulsion technologies to identify the relative role of the APC in bringing these forwards. For each case study the unit of analysis would be a new low carbon propulsion technology and the objective would be to investigate the role the APC played in bringing this forwards. Research would rely on a snowball sampling approach – starting with interviews with individuals understood to be linked to the innovation, and broadening out across the network of actors identified as responsible by them or any supporting material (as a means of tracing effects back to APC funded activities).

    - **FDI oriented case studies:** For these the unit of analysis would be a major investment in the UK by a foreign automotive manufacturer in the area of low carbon propulsion systems. The exploratory task for the case study research would be to identify the role of the APC in the decision to invest. Preparing the case studies would depend on interviews with the investor, UKTI and APC Ltd (where appropriate).

5.0 Economic evaluation

This section sets out a framework for completing an economic evaluation of the Advanced Propulsion aligning with the principles of the HM Treasury Green and Magenta Books. An economic evaluation may typically take one of two forms:

- Cost-effectiveness analysis which explores the unit cost of achieving the impacts or results in terms that can be compared to other similar initiatives.

- Cost-benefit analysis which places a monetary value on the impacts delivered by the programme and links these to the costs involved with their delivery.

This section itemises the costs and benefits that may need to be accounted for in such analyses and explores how they might be estimated, and combined to provide metrics of value for money.

5.1 Key Issues

The feasibility of an economic evaluation will depend largely on the ability of an impact evaluation to provide robust measures of the costs and benefits of interest. As highlighted in the previous section, a comprehensive quantitative impact evaluation can only be plausibly be implemented if there is a substantial increase in the number of firms involved in preparing either successful or unsuccessful applications. As such, there are also some risks to the feasibility of completing a full economic evaluation of the APC (and as recommended, sample sizes will require review before proceeding with a main stage study).

Additionally, the scope of an impact evaluation will likely be limited to the effects of the R&D competitions funded through the APC. As highlighted in Section 2, the APC has ambitions to lever investment beyond this immediate population of grant beneficiaries, and as such, an economic evaluation focusing exclusively on the effects of these competitions will be likely understate both the costs and benefits of the APC.

5.2 Costs

A comprehensive cost-benefit analysis of APC would need to cover three forms of cost associated with the delivery of the programme:

- Costs incurred by BIS, Innovate UK, and APC UK Ltd in the development and administration of the scheme.
- Costs incurred by applicants in the preparation of their applications, and where successful the transaction costs incurred through compliance with the obligations of the Final Grant Offer Letter (and any other costs incurred beyond these requirements, such as entering into non-disclosure agreements).
- Additional resource costs incurred as a consequence of the subsidies provided through APC. It is anticipated these costs will be largely in the form of R&D expenditure.

These costs (and issues involved in their estimation and valuation) are set out in the following sections.

5.2.1 Programme administration costs

The delivery of the APC involves a broad range of administration costs that should be included within the scope of CBA of the scheme. The appraisal process adopted for APC has absorbed, and continues to absorb, a range of BIS and Innovate UK resources (largely in the form of staff time). This will cover both the development of a suitable appraisal methodology (and adjustments over time) alongside the time investments in undertaking the appraisals themselves[39]. Innovate UK will also incur costs through their monitoring of the programme. Additionally, APC Ltd. will incur a range of resource costs to fulfil their role in the delivery of the programme (which will be funded through a levy on total project expenditure).

The most straightforward element of these costs to estimate will be those incurred by APC Ltd. as the costs incurred will be directly visible in accounts. Equally, payments made to independent assessors should be available from Innovate UK. However, it may be more challenging to estimate the costs incurred by Innovate UK and BIS in delivering their roles in the appraisal, contracting and monitoring processes. These functions are not performed by a dedicated team of individuals within either organisation, and the staff costs involved cannot be straightforwardly isolated within budgets.

It may be feasible to undertake research with monitoring and finance officers within Innovate UK and analysts within BIS responsible for undertaking these tasks to determine the time absorbed by their role in delivering the APC (and the study team understands that a similar cost model has been adapted for the evaluation of the Regional Growth Fund that could be adapted for the purposes of this evaluation). Such estimates could then be combined with objective data on the frequency with or duration over which the relevant tasks have been completed (e.g. number of applications received, number of Final Grant Offer Letters agreed, and the number of funded projects and the duration), to establish an estimate of the total resource costs incurred in the administration of the APC. However, these costs may be relatively minor in comparison to the grants themselves, and a light touch approach to establishing them may be preferable.

5.2.2 Transaction costs

Lead firms and consortium partners – both successful and unsuccessful – will incur a range of costs in the preparation of their applications (as demonstrated in the parallel process evaluation). It is also likely that some firms that never get to the point of submission will incur costs (but may also derive benefits from) such as attending webinars, or attempts to enter into collaborative relationships that were ultimately aborted). Successful applicants are also required to complete a range of administrative processes in agreeing the collaboration agreement, in relation to the due diligence exercise, and in complying with monitoring obligations which clearly have associated costs.

[39] There are also potentially costs to other parts of the public sector through marketing and communications activity (for example, the roles played by BIS Local, the BIS Sector Teams, and LEPs in raising awareness of the scheme) that have not been considered here.

The parallel process evaluation has sought to estimate the unit costs associated with applicants' involvement in these processes (through applying the Standard Cost Model, albeit with small sample sizes) which will provide a range of values that might be applied in a later economic evaluation of the APC. However, there a range of issues that will require further investigation through a main-stage study:

- **Streamlining:** There has been a focus on how far process enhancements to the APC might be achieved, which may lead to some streamlining of the process in the future. As such, the unit values estimated through the process evaluation may overstate the costs involved. This issue will require review as part of a main-stage study.
- **Additionality:** Costs may not be wholly additional. For example, where projects would have otherwise been taken forward without APC subsidies, the firms concerned may also have entered into legal relationships (though not necessarily in the form of a collaboration agreement). While it may be feasible to establish measures of the causal effects of the APC on these types of cost by collecting longitudinal data from successful and unsuccessful applicants, the investment required to do so may not be proportionate given that they are likely to represent a small fraction of the total resource costs incurred Instead, it may be preferable to scale estimates of gross costs back using an additionality ratio representing the ratio of additional R&D expenditure to total subsidies.
- **Other transaction costs:** The time taken by the appraisal and due diligence processes may have cost implications for the firms involved, potentially 'freezing' areas of activity because of anticipated support which may ultimately not be forthcoming. Such costs to applicants may not be quantifiable but the issue still warrants exploration.

Again, these transaction costs may be minor relative to the scale of the grants available through APC. As such, detailed attention may not be required (estimates, for example, could be relatively straightforwardly updated through any survey research with applicants).

5.2.3 R&D expenditure

The key set of resource costs that are likely to be associated with the APC are the effects of the programme on R&D expenditure. These costs will be estimated directly through impact evaluation as described in the previous section (although gross R&D expenditures are monitored, not all of these costs will be additional). Unlike capital expenditures, firms typically treat R&D as cash expenditures (and do not typically amortise these costs over extended periods in a similar way to capital assets). It is advised that a similar approach is adopted in an economic evaluation of APC.

The broader activities of the APC UK Ltd (particularly if the co-location of engineers leads to the development of shared technology) could potentially lead to efficiencies in the R&D process. However, as these technologies will be shared (and in principle will be available to successful and unsuccessful applicants alike), it will not be feasible to quantify the net cost savings associated with such efforts with any degree of robustness. As such, and contingent on such shared technology emerging, this approach may overstate the resource costs associated with the APC (though as noted above, the exclusion of the broader effects of the APC could also lead to an understatement of the net costs involved).

5.3 Benefits

The benefits of APC can be broadly broken down in terms of those accruing to firms which are associated with subsidised R&D projects, and any positive externalities associated with the projects that cannot be internalised by the firms involved (which may include consumer surplus, reductions in environmental externalities, and improvements in quality of life mediated by air quality improvements or noise reductions as noted in Section 2).

Increase in GVA

The main benefits of the APC can largely be understood in terms of the increase in output (GVA) – or the sum of the net additional wages and profits accruing to workers and firms respectively as a consequence of accelerating the development of low carbon propulsion technologies. This increase in output can be understood as formed of two components:

- **Increase in productive efficiency:** An increase in output driven by an increase in the efficiency with which inputs are combined in the production process, driven by the development of vehicles integrating propulsion technologies. In the highly competitive automotive industry, such an increase in productivity may be observed in firms successful in their application to APC being able to maintain their output prices and margins at least relatively (with the profits of the comparison group gradually eroded by technological obsolescence as the price consumers are willing to pay for vehicles integrating older technology falls over time).

- **Increase in quantity produced:** An increase in productive efficiency may also allow firms to reduce their prices, claim additional market share (in domestic and export markets), and earn additional profits. If this market share is claimed from firms based overseas then this could lead to additional automotive production in the UK, leading to an expansion in output. The broader activities of the APC (as well broader the skills and expertise acquired through acceleration of the development of low carbon propulsion technologies) could also attract additional production to the UK mediated through FDI. However, the impact evaluation can only realistically develop estimates of the causal effects of the APC on the former of these aspects.

The impact evaluation strategies set out in the preceding section will potentially yield estimates of the causal effects of the APC on total output (GVA), employment and productivity (GVA per worker or Total Factor Productivity). These estimates could be combined to decompose estimates of the overall growth in GVA into a component driven by productivity growth, and a component driven by increases in the quantity produced. The former of these estimates can be potentially included within a CBA without adjustment (though there may potentially be an element of displacement if or where they arise from firms involved attracting more productive resources), though the latter would need to be adjusted in light of the estimates of displacement estimated through the impact evaluation.

Impacts on total levels of economic activity cannot be included within a CBA without analytical challenges, even where it is feasible to robustly estimate the displacement effects involved. An expansion in output in the automotive industry driven by increases in the quantity produced will absorb a range of factor inputs (including labour, finished goods and services, capital inputs, and raw materials), and the increase in demand could potentially place pressure on factor prices. In turn, this will crowd out marginal consumers of these inputs elsewhere in the economy, leading to reductions in output (implying the initial boost in GVA will only be short term). Given the risk of these types of general equilibrium effects, it is suggested that any economic evaluation presents benefit to cost ratios including and excluding effects on GVA that are not driven by productivity growth.

Consumer surplus

The APC may involve a range of consumer welfare improvements, most likely in the form of the reduced fuel consumption and exposure to volatility in oil prices. However, such effects have the potential to be offset by higher maintenance costs (including the cost of replacement parts). It is anticipated that an exploration of the causal effects of the APC on the present value of costs incurred by consumers purchasing new vehicles will be unrealistic (and may be marginal if the primary effect of the APC is to displace vehicles with similar technical specifications produced in overseas territories), and it is suggested that this aspect is excluded in an economic evaluation.

Environmental externalities

As suggested in the preceding section, it may be feasible to estimate the causal effects of the APC on the average emissions (per mile) of new vehicles sold. Such a result could be combined with estimates of the average lifetime mileage of a vehicle and the total number of new vehicles sold, to estimate the total reduction in carbon emissions caused by the APC. The DECC Carbon Valuation methodology provides appropriate shadow prices for CO2 emissions, that could be applied in such an evaluation. Where the APC has led to the introduction of electric vehicles (or vehicles powered by gaseous fuels), then the emissions associated with producing the fuels concerned will need to be accounted for in the analysis. For electric vehicles, such estimates could be derived from DECC assumptions on the future decarbonisation of the electricity grid.

Health impacts

Guidance on the valuation of the health impacts associated with reductions in PM-10 and NOx are set out in the Department for Transport's WebTAG guidance on the appraisal of transport interventions[40]. Valuations of such effects require two key inputs: estimates of the reduction in the air pollutants, and the scale of the population benefitting from these reductions. It will be highly challenging to develop empirical estimates of both of these parameters through the evaluation: technical specifications of vehicles available through secondary data do not provide the information required on PM-10 inputs, and it will be highly challenging to determine the latter (as the air pollution effects will vary by how far the vehicles concerned are driven across urban and rural environments). As such it is suggested that consideration of health impacts is excluded from a CBA.

Noise reduction

As noted previously, there is no realistic way in which the noise impacts of the APC can be estimated, and impacts mediated by noise reduction will need to be excluded.

[40] https://www.gov.uk/government/publications/webtag-tag-unit-a3-environmental-impact-appraisal-november-2014

5.4 Benefit to cost ratios

A cost-benefit ratio can be developed from the sections above through two routes. A benefit to cost ratio can be developed based on a comparison of the resource costs and benefits involved with the programme. Benefits per £1 of exchequer cost should also be estimated as far as possible.

An ex-post evaluation may also provide useful evidence to calibrate the VFM assessment of individual APC applications (or indeed other BIS programmes using similar approaches to allocate funds). This would involve an aggregation of the net costs and benefits associated with the VFM appraisals of successful applications, which be used to generate a BCR that could be compared with the results of an economic evaluation. To the extent that there is evidence that the appraisal process systematically under- or overstates the level of risk or deadweight associated with applications, this evidence could be used to help adjust existing guidance for appraisal officers.

6.0 Conclusions

This section concludes the paper with a summary of the key conclusions of this review and the recommended evaluation approach.

6.1 Scope of an Impact Evaluation

An evaluation of the Advanced Propulsion Centre might seek to understand its impacts at two levels:

- **Impact of grant competitions:** Firstly, the direct effects of the APC will be experienced in terms of the influence of R&D subsidies on the technical development of successful projects (and at a later stage, the effect of the propulsion systems developed on the product markets concerned). For the purposes of an evaluation, it may be helpful to understand each project both as an entire propulsion system and as a series of sub-projects reflecting the development of individual components. Such a strategy would allow more flexibility, for example, to capture scenarios in which individual components find widespread commercial application.

- **Broader impacts:** However, the APC may have effects that will accrue beyond the immediate population of grant beneficiaries (for example, through providing strategic co-ordination of R&D efforts, raising confidence in the private sector that public support will be available on a long-term basis, and catalysing new collaborative activities). These impacts may be visible in higher levels of R&D spending directed towards the development of low carbon propulsion technologies on broader basis, as well as through other measures such as the attraction of FDI. These latter aspects imply a focus on the broader collection of actors (firms, academic institutions, and Government) operating in the low carbon technology space.

6.2 Key Outcomes and Timescale for Delivery

This review has identified a wide range of key outcomes that may need to be explored through an evaluation of the Advanced Propulsion Centre. These are highlighted in the table below, which capture both measures that would need to be explored amongst grant beneficiaries as well as across the broader population of actors within the low carbon propulsion technology space. The table also specifies the timescales over which the outcomes might arise, and their priority for observation as part of a main-stage evaluation programme. It should be stressed that the long life-time of the APC (funding commitments have been made for 10 years), and the anticipated lags over which APC funded technology might be launched to markets, implies that a long-term evaluation strategy will be needed.

Table 6.1: Key Outcomes for an Impact Evaluation of APC

Outcome Area	Outcome Measure	Priority	Timescale
R&D activity	• Low carbon propulsion R&D projects initiated	Low-medium	**2013 to 2023:** The APC may be expected to stimulate crowding in of investment into low carbon propulsion technologies over the course of its lifetime. While funding commitments may need to be made in full by 2020 (on the basis of an average duration of projects of around 3 years), it is also possible that the stimulus encourages investment in these technologies over a longer timescale.
	• % of R&D targeted at low carbon propulsion technologies	Low-medium	
	• New entrants to the low carbon propulsion technology area	Low-medium	
	• R&D expenditure	Highest	**2013 to 2023:** Direct impacts on the R&D expenditure and employment of applicants should in principle be visible amongst all successful applicants for both the duration over which public support is provided, and beyond (given the likely engineering challenges that will remain before the technologies can be commercialised). However, it will only be possible to quantify such effects once there are a sufficient volume of projects funded.
	• R&D employment	Highest	
Technical progress	• Technology Readiness Levels	Highest	**2013 to 2023:** Technical outcomes will be observable both over the duration of the projects funded (and will be immediately visible in monitoring information). However, further development will be required following project closure to commercialise the technologies, and additional technical development outcomes might be anticipated.
	• Manufacturing Readiness Levels	Highest	
Collaboration	• Inter-firm collaborations	Medium	**2013 to 2023 (and beyond)**: The APC has the potential to have immediate effects on levels of collaboration between firms and with academia (as well as technology transfer). Effects can be expected to be continuously observed over the 2013 to 2023 period, though it is possible that the size of the effects may increase in magnitude over time (e.g. if APC aids the formation of novel relationships that strengthen over time). Such effects may also have some permanence (enduring beyond the lifetime of APC).
	• Industry-academic collaborations	Medium	
Technology Transfer	• Number and value of licensing agreements	Medium	
	• Value of sale of IP from academia to industry	Medium	
Intellectual Property	• New IP registered	Medium	**2013 to 2023 (and beyond)**: As with technical development outcomes, IP outcomes will potentially visible over the duration of APC projects (IP might be registered at any point during, or following, the delivery of an APC project).
	• Value of IP	Medium	
Skills Development	• Number of R&D workers employed in automotive sector	Low-Medium	**2013 to 2023:** Impacts in the labour market might be expected to follow a similar pattern to the crowding-in effects described above.

Outcome Area	Outcome Measure	Priority	Timescale
	• Wages of R&D workers employed in automotive sector	Low-Medium	
	• Knowledge spill-overs	Medium	**2016 to 2026:** Knowledge spill-overs might arise once R&D projects have completed, with the first round of projects coming to an end in 2016).
FDI	• Levels of FDI in automotive sector	Medium	**2013 to 2023:** On the assumption that the public support available through APC will be a key driver of any FDI impacts observed, it is anticipated that such effects may be visible over the duration of the programme. However, to the extent that any FDI is driven by the accumulation of expertise (rather than the availability of support), then such impacts may endure well beyond the lifetime of APC.
Economic Impacts	• Sales of vehicles integrating APC technology	Medium-High	**2020 to 2035:** The downstream economic impacts of APC will arise once the technologies involved have been commercialised, and are available on the market. As suggested above, applicants to the first rounds of APC do not expected to generate significant sales of vehicles integrating relevant technology until 2020 (and the last round of projects funded might be expected to launch products to market in 2030). The extent to which those technologies generate lasting effects on the employment, output and productivity of vehicle producers will depend on how rapidly the technologies become obsolete, and as such, economic impacts might be expected to endure beyond 2030.
	• Turnover	Medium-High	
	• Employment	Medium-High	
	• GVA	Medium-High	
	• Average Labour Productivity	Medium-High	
	• Total Factor Productivity	Medium-High	
	• Imports as % of total inputs	Medium-High	
	• Export sales	Medium-High	
Environmental impacts	• CO_2 emissions profile of vehicles sold	Medium High	**2020 to 2035:** Environmental impacts will be driven by the diffusion of APC funded technologies, and might be expected to be delivered over similar timescales to the economic impacts involved.
	• Particulate matter associated with vehicles sold	Lowest	

6.3 Measurement of Outcomes

A wide range of the potential outcomes of interest can be measured to greater or lesser degrees of reliability through secondary datasets or monitoring. However, surveys will be required if there is an interest in capturing the intermediate (and to some extent, the economic) outcomes of the APC. Such surveys would aim to take observations at project completion and 3 to 5 years following completion to provide a long-term perspective on the outcomes of interest (and baseline observations if application forms are not adapted to capture the metrics of interest), and would cover all firms and institutions involved in APC funded projects.

However, several enhancements to monitoring could be made to improve the ability of any main-stage evaluation to exploit this data, including capturing a wider range of longitudinal measures at a company level through monitoring, extending monitoring beyond project completion, and capturing information on the vehicles into which APC funded technology has been integrated. Additionally, a range of adjustments could be made to application forms to improve data availability (particularly for unsuccessful applicants to the APC). This would include capturing the contact details of collaborating firms, and potentially a broader range of baseline characteristics of those firms (that can then be tracked over time either through monitoring or survey research).

Recommendations: Monitoring			
Post-project monitoring	It is recommended that projects are monitored beyond the duration of APC funding to capture any downstream effects (including integration of components into vehicles for large scale manufacture). To be effective this will need to continue beyond the current committed funding period.	**Priority:** High This is likely the only way in which some outcomes (e.g. integration of components into commercial vehicles) can be established effectively.	**Cost:** Medium Adoption of this recommendation will place additional burdens on applicants and Innovate UK.
Tracing vehicle models	Where applicants have integrated APC funded componentry into vehicles available for commercial sale, they should be required to report the specific model(s) through monitoring (ideally using MVRIS codes, so it can be linked into SMMT data).	**Priority:** High Such information will be critical in examining the product market effects of the APC.	**Cost:** Low It is not anticipated that this would only require minor adjustments to monitoring tools, and limited additional burden on applicants.
Company measures	The range of measures monitored through company monitoring should be expanded to cover: • Employment • Turnover • Wage expenditure • Profits	**Priority:** Medium This information will support an assessment of the downstream economic impacts of APC (though could potentially be gathered through	**Costs:** Medium Clearly, this data may be more challenging for applicants to assemble (though in principle, should be straightforward to gather from internal finance teams).

Recommendations: Monitoring			
		other means).	
Adapt application forms	Adapt application forms to collect additional baseline data on the projects and the firms concerned.	**Priority:** High Additional baseline information data will be required to measure both intermediate outcomes and economic outcomes.	**Cost: Low** This will place an additional burden on applicants, though it is anticipated that finance teams will have the majority of information to hand Applicants routinely add information on TRL and MRL stages of the various components of their projects within application forms.
Applicants surveys	Undertake surveys of applicants (successful and unsuccessful) at project completion (or planned project completion) and 3 to 5 years following completion to track outcomes over time.	**Priority:** High Surveys will be critical in understanding the intermediate effects and economic outcomes of the APC (particularly if there are concerns about the reliability of VML datasets).	**Cost: Medium** Resources will need to be invested in a rolling programme of survey research to collect the data of interest, though given the number of firms involved to date, this may not be a costly exercise.
Tracking ownership structure	It is recommended that the ownership structure of and any mergers and acquisitions involving applicants to APC are tracked over time through monitoring to support future data-linking activities.	**Priority:** Low It may be feasible to trace changes in ownership structure as part of an ex-post evaluation, though the task will be considerably eased through monitoring.	**Cost:** Low-Medium Adoption of this recommendation will place additional burdens on applicants and Innovate UK.
Collation of monitoring information	It is recommended that a main-stage evaluation contractor seeks to collect evidence on the broader public support received by APC applicants (provided that sample sizes will support a detailed econometric analysis) to help control for their influence over the outcomes of interest.	**Priority:** Medium The collection of this data will provide helpful controls and improve attribution to the programme, though it is unlikely that it will be possible to account for all support received by applicants.	**Costs:** Medium The costs of assembling this information should not be understated (though portals such as Gateway to Research may ease the process to some degree).

Recommendations: Monitoring			
Integration of secondary data	It is recommended that the main-stage evaluation make best use of the array of secondary micro-data available (including patent records, bibliometric data, the firm level datasets within the VML, and the MVRIS data). However, given sample sizes, disclosure issues may be eventually problematic, and contingencies based on primary research and monitoring are advised. The issues will require further review at a later stage once there is a clearer picture of sample sizes.	**Priority:** Medium-High The availability of longitudinal data will substantially enhance the scope of evaluation options available.	**Cost:** Low-Medium Exploiting these datasets will be relatively cost-effective, though the costs involved in data assembly should not be understated.

6.4 Impact and Economic Evaluation

In terms of an impact and economic evaluation, a mixed methods evaluation strategy is recommended as follows:

- **Uncertainties:** There are substantial uncertainties over the sample sizes associated with any future analysis, which may limit the potential application of quantitative methods. This should be kept under review before commissioning a main-stage evaluation.

- **Direct impacts of APC:** Contingent on sufficient sample being available, it should be in principle feasible to quantify the causal effects to varying degrees of robustness using the following strategy.

    - **Choice of counterfactual:** Unsuccessful applicants would be the preferred comparison group for an econometric analysis. However, if resources permit, the inclusion of other groups might be integrated into a main-stage evaluation (such as applicants to LCV-IP that did not apply to APC) to check on the sensitivity of results to the selection of controls.

    - **Econometric methods:** It is advised that the main-stage evaluation involves the application of a combination of econometric methods. This would include longitudinal panel methods, alongside potentially more robust pipeline (if appropriate) and Regression Discontinuity Design methods. Matching techniques could potentially be applied to refine samples in terms improving their balance with regard to the observable characteristics of the projects and applicants involved.

    - **Displacement:** The availability of detailed product market data will mean that quantitatively rigorous approaches to estimating displacement effects can be plausibly explored and should be pursued as part of an evaluation strategy. This would involve modelling the negative effects on the market share of competing vehicles following the introduction of vehicles integrating APC funded technology). However, these strategies can only be feasibly implemented if it possible to trace APC funded technology into specific vehicle models (as described in Chapter 3).

- **Spill-over effects:** The architecture of the APC creates the possibility of broadening the definition of the treatment and comparison groups to include organisations that potentially might receive a spill-over benefit (including spatially adjacent firms, networks of collaborators beyond those named in APC applications, or those citing patents registered by APC applicants). It is difficult to predict the potential value of such analyses, but as they will exploit similar sets of secondary data, an exploratory analysis is recommended as part of a main-stage study.

- **Contingency:** In the event that insufficient sample sizes are available, a before and after approach is recommended examining the gross outcomes of APC projects.

- **Indirect impacts of APC:** The APC has been designed to have broader impacts in terms of stimulating investment in low carbon propulsion technologies in the UK, effects that may be visible in a broader population of firms and academic institutions than grant applicants. To explore these effects, it may be feasible to both develop a ‘reference’ technology area as a comparator, and implement an international comparative study relating the availability of subsidies for R&D to the performance of the automotive sector. Such studies are likely to fall short of providing a true counterfactual, and will likely conflate the impacts of APC with the wide array of Government investment in this technology area. As such, while results may provide useful context for an evaluation (and framing the results of quantitative and qualitative research), a quantitatively rigorous separation of the impacts of APC from other policies is likely to be infeasible. As such, a before and after analysis drawing on the available secondary data is recommended, supplemented by qualitative research forming part of the case studies below).

- **Case studies:** Given the challenges involved in establishing robust quantitative estimates of the impacts involved, a programme of case study research is advised to examine the impact of APC on grant applicants, the emergence of new low carbon propulsion technologies, and the attraction of FDI projects. Case studies could be grounded in realist, process tracing, or contribution analysis methods, and would take the forms specified in the table below.

Effects of APC on grant applicants	Broader Impacts of APC
Synthetic control groups: statistical tools known as synthetic control groups can be used to provide a quantitative structure for the case study analysis. This technique can be used to build an artificial, tailored comparison for a particular firm, or consortia to be investigated through the case studies, Drawing on the metrics discussed above, this approach will offer an initial hypothesis about the relative performance of the firms in question to test through the qualitative research. **Documentary evidence:** existing materials will provide a starting point for the in-depth investigation of case-study applicants. This analysis will draw on application forms, monitoring reports, technical papers, patent submissions and their citations, as well as secondary statistics such as vehicle sales. **Depth interviews with lead applicants and collaborators:** the most critical activity for the preparation of these case-studies will be to make contact with project participants to test and validate the hypotheses made about the projects from the data and documentary evidence. This would explore the history of the projects, the financial model used to bring it forwards, the activities undertaken, the relationship between project partners and their relative roles, the role of the financial and soft support received from the APC as well as other public bodies as well as the wider context of the project (such as related initiatives from the partners and their competitors)	**Emergence of new propulsion technologies:** Reflecting the scale and significance of APC funding, it is realistic to expect the programme to have some impact on a large proportion of the new low carbon propulsion technologies emerging from the UK up to 2030. Case studies can therefore be prepared around specific future advances in low carbon propulsion technologies. Each would focus on a new technology, product or business model, and the objective would be to investigate the role the APC played in bringing this forwards. These case studies would draw on soft systems methodologies to map the contribution of different actors in the innovation process. This would rely on a snowball sampling approach – starting with interviews with individuals understood to be linked to the innovation, and broadening out across the network of actors identified as responsible by them or any supporting material. **Foreign direct investment:** A similar case study approach could be pursued to investigate the role of the APC in attracting foreign direct investment. Here the unit of analysis would be a major investment in the UK from a foreign automotive manufacturer in the area of low carbon propulsion systems. An equivalent methodology could then be used to explore the role of the APC in their decision to invest in the UK.

6.5 Recommended Main-Stage Specification

This sub-section specifies the key data collection and analysis requirements identified through the scoping study.

1. Revisit Scoping

The proposed research programme set out below should be revisited by BIS in 2018 once the overall volume of applicants to the APC is known with more clarity. This exercise should focus on examining how far sample sizes are sufficiently large to support a detailed quantitative analysis. If not, the proposed work programme might be adjusted to focus on a quantitative demonstration of the gross outcomes (i.e. a before and after study). This may also be a useful opportunity to take stock of technological and other developments in the industry as the first set of projects reach completion, as means of identifying potential case studies for the programme of qualitative research proposed.

2. Interim Evaluation

An interim evaluation is suggested in 2018/19 (as the projects funded through the first funding calls reach completion). The primary focus of the evaluation should be in terms of addressing the following research questions:

- How far the APC has leveraged additional expenditure on low carbon propulsion technologies, both amongst beneficiaries of APC funded R&D subsidies and more broadly?

- How far has the APC accelerated the development of low carbon propulsion technologies (with a particular focus on the projects funded through the competitions)?
- How far has APC altered patterns of collaboration in this technological area, including increase the volume and strength of collaborative relationships both between firms in the automotive supply chain, and with academic institutions?
- How far has the APC led to – or encouraged - the initiation of new R&D projects in the low carbon propulsion technology?
- How far has the APC led to an improvement in the R&D capacities of the UK in relation to low carbon propulsion technology?
- What broader technological and policy developments have emerged since the APC was created (including the emergence of a preferred technological standard), and how are these likely to influence the impact of the scheme?

The evaluation should involve the following methods:

- **Analysis of monitoring information:** A review of the monitoring information data to examine technical progress, as well other results in terms of defraying grant expenditure, delivery of economic outputs, and collaboration patterns visible in application forms.

- **Applicant survey:** A random probability of survey of applicants to the APC (successful and unsuccessful) to gather information on the technological progress made, other supplementary outcomes of interest, and an indication of the length of time over which commercial impacts might be expected. It is anticipated that this survey will need to be delivered as a census, and may need to collect some baseline measures retrospectively.

- **Secondary data analysis:** Examining both economic and technological trends in the low carbon propulsion sector (including an analysis of patent data and broader monitoring data collected through other relevant programmes, such as the Low Carbon Vehicles Innovation Platform). This will include a data linking programme (to VML datasets, MRVIS and other model level vehicle registration data, and to PATSTAT or Patentscope) to provide longitudinal data on the outcomes of interest.

- **Case studies:** Delivery of set of case studies focused on (1) completed projects to provide in-depth information on progress made and role of APC subsidies in enabling this progress to be achieved, and (2) new developments in the technological area to explore how far they can be traced back to the APC and APC UK Ltd, including pipeline collaborative projects submitted for ESPRC or Innovate UK funding, new technical developments originating in the UK, and any FDI attracted.

3. Second Interim Evaluation

A second interim evaluation is recommended in 2022/23 to provide longer term evidence of the effects of the APC as the portfolio of projects funded draws to a close. The broad evaluation questions should remain similar to those adopted in the first evaluation. However, the evaluation should additionally seek to explore:

- What technical development has taken place following the completion of APC funded projects, and how far can this be causally related to the subsidies provided?

- To what extent has the knowledge generated through APC funded projects led to significant knowledge spill-overs within or outside collaborations?
- To what extent have APC funded technologies been integrated into vehicles in commercial production?
- What was the causal effect of the APC on the technical specifications of those vehicles (in terms of emissions)?
- What additional sales, output, productivity and employment can be attributed to the APC?
- How far has the introduction of APC funded technologies led to the negative effects on automotive production volumes amongst other UK based manufacturers (i.e. displacement)?

The evaluation should involve the following methods:

- **Analysis of monitoring information:** An updated review of the monitoring information data providing a final assessment of the gross outcomes achieved (technical progress, grant expenditure, delivery of economic outputs, and collaboration patterns visible in application forms).

- **Applicant survey:** A random probability of survey of applicants to the APC (successful and unsuccessful) to gather information on the technological progress made and the other supplementary outcomes of interest. This survey will involve a longitudinal follow-up with all respondents to the survey taking place in the interim evaluation, as well as covering all additional applicants to the APC between 2018 and 2023.

- **Secondary data analysis:** Examining both economic and technological trends in the low carbon propulsion sector (including an analysis of patent data and broader monitoring data collected through other relevant programmes, such as the Low Carbon Vehicles Innovation Platform). The secondary data analysis should also include a documents review to isolate any technological, policy or economic developments of significance (including any FDI in the sector).

- **Case studies:** The case studies undertaken in the first interim evaluation will be revisited to provide an assessment of the medium term outcomes involved. An additional set of case studies, exploring later projects and developments will also be selected to track the evolution of the programme (and its context) over time.

4. Final Evaluation

A final evaluation is recommended to take place in 2029/30 to provide a long term view on the impacts of the APC. This will allow some 6 years to elapse following completion of the projects funded and will focus exclusively on establishing the economic impacts involved. It is anticipated that further survey work with applicants may be unachievable at this stage, so the primary focus should be on secondary data analysis using longitudinal data on the performance of the firms concerned. Some additional case study research may also be helpful at this stage to contextualise the results.

The proposed specification for a main stage evaluation is summarised in the table overleaf.

Aspect	Interim Evaluation (2018)	Interim Evaluation 2 (2022)	Final Evaluation (2030)
Central focus	Effects on R&D spending and technical development, and broader investment patterns.	Effects on R&D spending and technical development, and broader investment patterns. Early evidence of commercial impacts, displacement, and spill-overs	Economic impacts of the APC.
Direct Impacts of APC			
Analysis of Monitoring Information	Covering the progress of projects funded between 2013 and 2018, covering technological and R&D expenditure and employment outcomes. Initial assessment of post-completion outcomes achieved by first tranche of projects.	Full statement of progress achieved by APC projects between 2013 and 2023, including post-completion outcomes achieved by those projects that were completed prior to 2022.	Full assessment of post-completion outcomes associated with all APC funded projects.
Survey of APC applicants	First survey wave of applicants capturing retrospective baseline measures and follow-up measures. Coverage of successful applicants, and if sample sizes are likely to permit application of econometric methods (even only in the longer term), unsuccessful applicants.	Second survey wave of applicants capturing follow-up measures of key outcomes. Coverage of successful applicants, and if sample sizes are likely to permit application of econometric methods (even only in the longer term), unsuccessful applicants.	Further surveys unlikely to be deliverable at this stage, owing to loss of institutional memory and time elapsed since grant funding provided.
Datalinking	Linking of applicant records to patent records, bibliometric data, and ONS VML datasets. Coverage of successful, unsuccessful and non-applicants to the APC.	Linking of applicant records to patent records, bibliometric data, and ONS datasets and VML. Linking to MRVIS if vehicles integrating APC funded technology have been launched at this stage.	Linking of applicant records to patent records, bibliometric data, ONS VML datasets, and MVRIS.
Econometric analysis (contingent on sample sizes)	Application of difference-in-differences, pipeline methods and RDD (where appropriate), focusing on questions relating to input additionality and technical progress.	Application of difference-in-differences, pipeline methods and RDD (where appropriate), focusing on questions relating to input additionality, technical progress, and economic impacts.	Application of difference-in-differences, pipeline methods and RDD (where appropriate), focusing on questions relating to economic impact.
Assessment of displacement	Not at this stage.	If vehicles integrating APC funded technology have been launched by this point in time.	Yes
Assessment of spill-overs	Not at this stage.	Exploratory analysis suggested as a possible	Exploratory analysis suggested as a possible

Aspect	Interim Evaluation (2018)	Interim Evaluation 2 (2022)	Final Evaluation (2030)
		option.	option.
Project level case studies	Consultation with key project personnel and synthesis of available documentary evidence.	Consultation with key project personnel and synthesis of available documentary evidence. Application of synthetic control methods to provide quantitative results.	Unlikely to be feasible at this stage.
Indirect Impacts of APC			
Analysis of secondary data	Focusing largely on crowding-in effects, relevant levels of R&D activity (including pipeline projects visible in LCV-IP, EPSRC applications), FDI projects and technological change.	Focusing on crowding-in effects, relevant levels of R&D activity (including pipeline projects visible in LCV-IP, EPSRC applications), FDI projects and technological change. Analysis to be extended to employment, productivity, and output in the automotive sector, and technical properties of vehicles for commercial sale.	Analysis focused on long term changes in performance of the automotive sector in the UK (including sales in non-domestic markets), and the technical properties of vehicles for commercial sale.
Technology case studies	Where it is possible to identify commercialisation of low carbon propulsion technologies.	Where it is possible to identify commercialisation of low carbon propulsion technologies.	Where it is possible to identify commercialisation of low carbon propulsion technologies.
FDI	Where it is possible to identify specific FDI projects of relevance.	Where it is possible to identify specific FDI projects of relevance.	Where it is possible to identify specific FDI projects of relevance.

Appendix A: Data sources

A.1 Programme/monitoring Data

There are three stages in the process of delivering APC funding that collect data on the applicants; the application process; the appraisal of applications and finally during the monitoring activity of successful project applications. All of these stages offer an opportunity to make use of the data collected for the purpose of benchmarking firms prior to project inception.

It should also be noted here that these stages also offer an opportunity to request further information on applicants and beneficiaries. Gaps in the overall data collected could potentially be addressed in these processes if it is felt that the administrative burdens on systems change and applicants proportionate.

The information gathered at these stages is set out below.

Application Forms

During the application process a range of helpful data is collected, primarily on the applicants themselves but also for collaborators. Within the application form itself, information is collected on the lead applicant and the details of the project. Additional information is requested in the appendices that may also facilitate benchmarking of applicants (such as details of current employment, turnover, parent company details and firm locations). Companies House reference numbers (CRN) are collected for all firms collaborating in an application; higher education institutions also provide contact details, such as the principal investigator. It should be highlighted that the collaborators listed in the application may change before a project begins work.

Of greatest use is the information on economic outcomes that is collected in Appendix E & F, which is used for the value for money (VfM) assessments by BIS. The data collected here, in excel format and narrative form, has to be set out so that accurate VfM assessment can be conducted. Project costs are broken down by spending in each year and by expenditure type (capital, training and R&D); full details of planned job creation and safeguarding are also recorded. Forecasts around impacts of technical improvements (GHG reduction and efficiency gains) are also detailed as part of the wider economic benefits generated by a project. These numbers are contingent on the sales and/or production levels that are forecast by the firm.

Not only does this appendix quantify exact numbers but it also gives a time frame for these activities. Additionally, job creation is attributed to specific firms and locations.

Assessment and Review Data

The process of technical assessment is consistently applied through all Innovate UK competitions. Innovate UK makes use of 5 independent technical assessors to review the 10 questions asked in the application form and to score each of these out of 10. These are compiled to give an overall score for a project. Scored returns are compiled in panel sheets provided in excel format along with written comments from the assessors. These are used to rank all applications within a competition round.

As stated above BIS makes use of the information in the application form and Appendix F to complete the VfM assessments. The results of these are presented in a clear excel document, which again includes commentary on rationale and any judgements made. The information gathered and reviewed in the VfM assessments are presently reviewed with the applicant prior to final decision; it is understood that when the number of applications increase this will not continue. Conversations conducted between applicants and BIS and/or Innovate UK, in relation to VfM assessments and appraisal are well documented and saved centrally.

Monitoring Data

Innovate UK collects data from projects on a quarterly basis and these are used to monitor progress against the plans agreed and formalised in the grant offer letter. All claims made by beneficiaries are checked by monitoring officers and have to be documented. Where firms have committed to job creation, this is also monitored.

- Innovate UK monitoring officers' review each project against 6 set domains
- Project scope – ensuring that projects do not deviate from their intended planned outcomes
- Timescale – deviations from the proposed timetable of activities is also closely monitored
- Costs – agreed costs of a project must be adhered to and there is limited scope for changes to the values agreed. Minor delays to spending plans are tolerated;
- Exploitation – the outcomes agreed as part of the Grant Offer Letter must be achieved
- Risk – assessors are tasked with ensuring projects identify risks to the successful delivery of their project
- Progress – assessing whether issues with technologies or outcomes from specific work packages are addresses so projects can be fully completed

Monitoring reports are narrative descriptions, and these are directed back to the programme team at Innovate UK. It is understood that some aggregate review is also conducted by Innovate UK; however at this early stage only 4 of the 6 projects funded have begun projects work.

BIS also conduct interviews with project leads every six months to monitor economic outcomes of the projects. This is done to compare activity with that which was forecast in the VfM assessments. Additionally, BIS look to record outcomes in relation to intellectual property, technology progression, and increases in investment by firms.

Collection method	Source	Data
Application form	Applicant. Pdf documents Appendix F – excel spreadsheet	• Lead organisation contact details (address, phone number, email) • Technology area • Private funding • Start date and project duration • Collaborator list, including CRN where applicable • Collaborator post code • Collaborator grant value • Detailed business plan – Appendix A • Project plan/ work packages – Appendix B • Collaborator profiles – Appendix C • Exploitation plans – Appendix D • Value for Money spreadsheet – Appendix E • Value for Money narrative – Appendix F
Technical Assessment	Innovate UK Excel documents	• Narrative response to each application form question (10 questions) • Compiled responses from each assessor • Assessor scores • Average scores and final score
VfM assessments	BIS Excel document	• Project level assumptions – gross additionality, displacement, risk, expected additionality • Job creation and safeguarding by year of project • Job levels and training levels (NVQ equivalent) • Expenditure on R&D, capital equipment and skills by year • Wider economic benefits – purchasing activity in the UK, sales, fuel efficiency saving, emission reduction
Monitoring data	Innovate UK Narrative reports; word/pdf document	• Narrative assessment of delivery against scope, timetable, cost, exploitation, risk, and technological progress. • Scored assessment of project from 1-5.
Aggregate reports	Innovate UK Narrative reports; word/pdf document	• Narrative reports from project lead at Innovate UK, assessing individual level progress and aggregate performance.
Economic monitoring	BIS Excel document	• Comparison of project delivery against plan for the following areas • Job creation and safeguarding by year of project • Job levels and training levels (NVQ equivalent) • Expenditure on R&D, capital equipment and skills by year • Wider economic benefits – purchasing activity in the UK, sales, fuel efficiency saving, emission reduction • Technological progress against plan, including all associate measures that are available including • New technology name • Technology ownership (IP ownership and value) • Previous investment in IP • Production location • End customers • TRL monitoring (beginning and end) • Project duration and cost (planned and actual) • CO_2 reductions (planned and actual) • Fuel reductions (planned and actual) • Additional targets set out in proposal (planned and actual) • • Wider firm level activity • R&D investment (value and proportion of turnover) • Capital investment (value and proportion of turnover) • Skills and training investment (value and proportion of turnover)

A.2 Administrative data

There are numerous sources of data from governmental sources that may be used in the monitoring the direct and possible indirect benefits of APC activity. Much of this data is available, with some restrictions on reporting, from the Office of National Statistics.

Due to the relative importance and value of the automotive industry nationally and internationally, many non-governmental sources of data also exist. Generally these are trade organisations that collect and compile data from their members. While these sources appear to have data of a good quality, it may be necessary to review their collection methods before numbers are used, as coverage may, or may not, be comprehensive.

VML Datasets

Various datasets can be accessed through the ONS Virtual Micro-data Laboratory (VML) that can provide firm level data on the beneficiaries of the Advanced Propulsion Centre that are commercial entities (where projects have collaborations with academic institutions this will not be collected). The datasets within the VML can potentially supply longitudinal observations at a firm level for the following outcome measures of interest:

- Business Structure Database: Employment and turnover (an annual snapshot of the Inter-Departmental Business Register or IDBR).

- Annual Respondents Database: A range of further measures are available through the Annual Respondents Database and the Annual Business Survey datasets (including GVA and other financial measures, such as capital investment). However, longitudinal data is only available for large firms (250 or more employees) and it is not anticipated that this dataset will provide any useful evidence for the evaluation.

- Business and Enterprise Research and Development Database: Expenditure on Research and Development, though longitudinal data is only available for known R&D 'performers'. The extent to which this will provide useful data will only be known once the data-linking process is complete.

- Labour Force Survey: Details employment levels by occupation and industry, estimates of numbers employed and hours worked.

These datasets can be linked via a unique reference number held within the IDBR. Therefore, if it is possible to identify beneficiaries and non-beneficiaries within these datasets this would likely address many of the challenges associated with collecting quantitative data. This process is made more straightforward where it is possible to collect Companies House Registration Numbers (CRN) as ONS maintains a lookup table matching CRN to their corresponding identifier within the IDBR. As such there are a number of issues to consider in exploiting this information

A final issue to raise is that the BSD is based on a snapshot of the IDBR, which may not be fully up to date at the time it is taken (for example, employment records are in part based on PAYE records, which may be in extreme cases be up to four years out of date). As such, it is advised that a range of quality checks are made against alternative sources (such as monitoring data and baseline employment and turnover values gathered at the application stage), to establish how far any substantial lags are present in data that may need to be accounted for in analysis (the effects of lags in the data are likely to be less severe over evaluations with longer timescales). As such, some verification of the BSD data (by examining correlations against self-reported data and values provided through the application process) will help determine how far these problems will create difficulties for the evaluation.

EPO Data

An additional source of data that should be noted relates directly to intellectual property (IP). Where R&D activity yields useful IP firms may wish to protect their work. Information on this activity will be held in the European Patent Office database (EPO). Patents can be searched for via the database using the applicant details, whether this is an individual or a firm, and again, this dataset can be exploited to provide longitudinal records outcomes of interest, including:

- Overall levels of patenting by APC grant recipients (both pre- and post-intervention);
- Joint patenting if it occurs (as a proxy measure for collaborative effects); and,
- Patent citations (to provide some measure of potential for spill-over effects).

No major difficulties are anticipated in exploiting this data source for the purposes of the evaluation. Economic monitoring activity conducted by BIS as part of the project monitoring arrangements can be supported by the evidence gathered here. This source should also highlight where IP is being registered in different territories (as part of patent families).

A.3 Secondary data on the automotive industry

There are a number of automotive specific organisations that collect data on sales and production that could be helpful in tracking the influence and impact of APC. The following list of potential data sources is not exhaustive due to the wealth of available resource in this sector, but represents the most helpful sources initially;

Department for Transport: Data on all vehicles registered in the UK can be found via their regularly published statistics. Publications are quarterly, and cover vehicle type (car, commercial, etc.), models, fuel efficiency, emissions, and engine size.

Vehicle Commissioning Agency (VCA): Details of emission levels, noise and fuel efficiency for all vehicles registered in the UK. Data is collected under test conditions and may not be a fully accurate record of values in ‘real world use scenarios’. VCA specifically warn against using data to rank vehicle performance when values are very similar. Emission levels are recorded based on the specific vehicle details identified by make, detailed model description; year registered, and engine size.

The Society of Motoring Manufacturers and Traders (SMMT): A trade body that promotes the interests of the UK industry nationally and internationally. This organisation collects data from all UK based automotive firms and produces regular reports on the numbers of jobs in the sector, production and registration activity. Much of this information is free to users.

European Automobile Manufacturers Association (ACEA): Represents European based automotive manufacturers, acting as a representative for the industry in Europe. Much like the SMMT, this body also collects data on production, trade, employment and registration.

International Organization of Motor Vehicle Manufacturers (OICA): A global repository for automotive. Global level data is accessible from this site. Data is reported annually detailing the volumes of production by firm and by nation.

Care will need to be taken when identifying vehicles. Due to the number of modifications or optional extras a car may have a unique identifier for a vehicle model does not exist. Certain extras, such as inclusion of an air conditioning system for example, can make significant differences to fuel consumption. This means that values reported will be for standard vehicles and model definitions may vary depending on the data source.

Appendix B: Technology and manufacturing readiness levels in the automotive sector

Technology Readiness		Manufacturing Readiness	
1	• Basic Principles have been observed and reported. • Scientific research undertaken. • Scientific research is beginning to be translated into applied research and development. • Paper studies and scientific experiments have taken place. • Performance has been predicted.		
2	• Speculative applications have been identified. • Exploration into key principles is ongoing. • Application specific simulations or experiments have been undertaken. • Performance predictions have been refined.		• A high level assessment of manufacturing opportunities has been made.
3	• Analytical and experimental assessments have identified critical functionality and/or characteristics. • Analytical and laboratory studies have physically validated predictions of separate elements of the technology or components that are not yet integrated or representative. • Performance investigation using analytical experimentation and/or simulations is underway.	**1**	• Basic Manufacturing Implications have been identified. • Materials for manufacturing have been characterised and assessed.
4	• The technology component and/or basic subsystem have been validated in the laboratory or test house environment. • The basic concept has been observed in other industry sectors (e.g. Space, Aerospace). • Requirements and interactions with relevant vehicle systems have been determined.	**2**	• Manufacturing concepts and feasibility have been determined and processes have been identified. • Producibility assessments are underway and include advanced design for manufacturing considerations.
5	• The technology component and/or basic subsystem have been validated in relevant environment, potentially through a mule or adapted current production vehicle. • Basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested with equipment that can simulate and validate all system specifications within a laboratory, test house or test track setting with integrated components • Design rules have been established. • Performance results demonstrate the viability of the technology and confidence to select it for new vehicle programme consideration.	**3**	• A manufacturing proof-of-concept has been developed • Analytical or laboratory experiments validate paper studies. • Experimental hardware or processes have been created, but are not yet integrated or representative. • Materials and/or processes have been characterised for manufacturability and availability. • Initial manufacturing cost projections have been made. • Supply chain requirements have been determine
6	• A model or prototype of the technology system or subsystem has been demonstrated as part of a vehicle that can simulate and validate all system specifications within a test house, test track or similar operational environment. • Performance results validate the technology's viability for a specific vehicle class.	**4**	• Capability exists to produce the technology in a laboratory or prototype environment. • Series production requirements, such as in manufacturing technology development, have been identified. • Processes to ensure manufacturability, producibility and quality are in place and are sufficient to produce demonstrators. • Manufacturing risks have been identified for prototype build. • Cost drivers have been confirmed. • Design concepts have been optimised for production. • APQP processes have been scoped and are initiated.
7	• Multiple prototypes have been demonstrated in an operational, on-vehicle environment. • The technology performs as required. • Limit testing and ultimate performance characteristics are now determined. • The technology is suitable to be incorporated into specific vehicle platform development programmes.	**5**	• Capability exists to produce prototype components in a production relevant environment. • Critical technologies and components have been identified. • Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated with components in a production relevant environment. • FMEA and DFMA have been initiated.

8	• Test and demonstration phases have been completed to customer's satisfaction. • The technology has been proven to work in its final form and under expected conditions. • Performance has been validated, and confirmed.	**6**	• Capability exists to produce integrated system or subsystem in a production relevant environment. • The majority of manufacturing processes have been defined and characterised. • Preliminary design of critical components has been completed. • Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on subsystems/ systems in a production relevant environment. • Detailed cost analyses include design trades. • Cost targets are allocated and approved as viable. • Producibility considerations are shaping system development plans. • Long lead and key supply chain elements have been identified.
9	• The actual technology system has been qualified through operational experience. • The technology has been applied in its final form and under real-world conditions. • Real-world performance of the technology is a success. • The vehicle or product has been launched into the market place. • Scaled up/down technology is in development for other classes of vehicle.	**7**	• Capability exists to produce systems, subsystems or components in a production representative environment. • Material specifications are approved. • Materials are available to meet planned pilot line build schedule. • Pilot line capability has been demonstrated including run at rate capability. • Unit cost reduction efforts are underway. • Supply chain and supplier Quality Assurances have been assessed. • Long lead procurement plans are in place. • Production tooling and test equipment design & development has been initiated • FMEA and DFMA have been completed.
		8	• Initial production is underway • Manufacturing and quality processes and procedures have been proven in production environment. • An early supply chain is established and stable. • Manufacturing processes have been validated
		9	• Full/volume rate production capability has been demonstrated. • Major system design features are stable and proven in test and evaluation. • Materials are available to meet planned rate production schedules. • Manufacturing processes and procedures are established and controlled to three-sigma or some other appropriate quality level to meet design characteristic tolerances in a low rate production environment. • Manufacturing control processes are validated. • Actual cost model has been developed for full rate production.
10	• The technology is successfully in service in multiple application forms, vehicle platforms and geographic regions. In-service and life-time warranty data is available, confirming actual market life, time performance and reliability	**10**	• Full Rate Production is demonstrated • Lean production practices are in place and continuous process improvements are on-going. • Engineering/design changes are limited to quality and cost improvements. • System, components or other items are in rate production and meet all engineering, performance, quality and reliability requirements. • All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. • Unit costs are at target levels and are applicable to multiple markets. • The manufacturing capability is globally deployable.

Appendix C: Analysis of the project portfolio

Drawing on an analysis of applications received to date as well as data from the appraisal process, this section summarises the support offered by the APC. This analysis has informed the development of the evaluation strategy. However, since only a small proportion of APC funds have been committed so far (£60m of £500m public funds), it is only possible to draw initial conclusions from the current sample about the likely pattern of future APC spending.

Applications

The APC has so far received 11 full applications. Four were received in Round 1 and five in Round 2. Two further applications were received through the exceptional process (denoted eAPC or exceptional applications). These exceptional applications have been invited to allow for some flexibility and responsiveness of APC for proposals that may be constrained by time pressures.

Table C.1: All applications by round

Round	Applicants	Total value of requested grants	Total value of proposed projects
APC1	4	£ 33,680,994	£ 61,995,304
APC2	5	£ 39,983,114	£ 77,114,289
eAPC	2	£ 25,749,288	£ 34,854,790
Total	11	£ 99,413,396	£ 173,964,383

Source: APC application forms

All applications to Round 1 were successful in securing funding, however only one application to Round 2 was successful. It should be noted however, that the two applications received out of competition are repeat applications from Round 2. As such, there are only two bids that have not been funded.

Table C.2: Successful applications by round

Round	Funded projects	Total value of grants	Total value of supported projects
APC1	4	£ 33,680,994	£ 61,995,304
APC2	1	£ 7,395,497	£ 11,262,589
eAPC	2	£ 17,683,313	£ 34,854,790
Total	7	£ 58,759,804	£108,112,683

Source: APC application forms

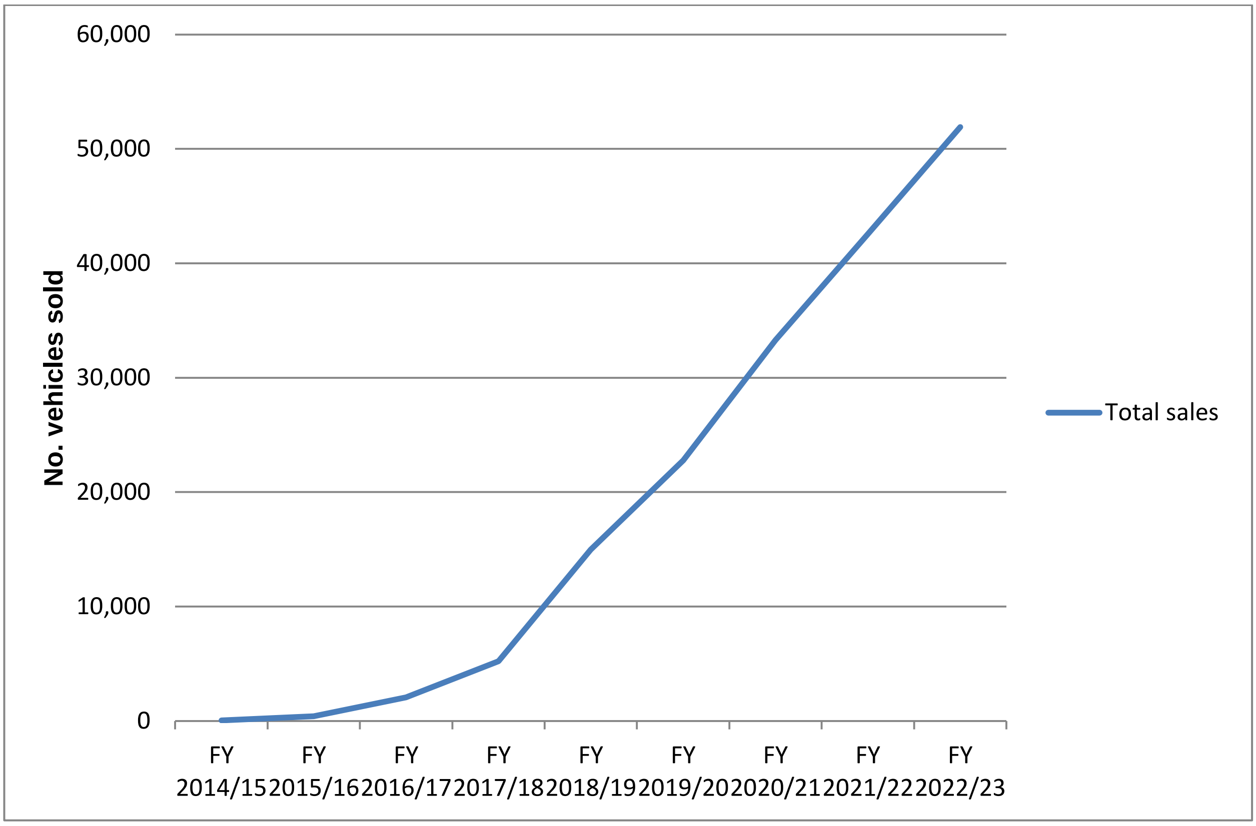
Anticipated benefits

In calculating the wider benefits gained from reduced vehicle emissions, applications have forecast sales of their vehicles. The tables below show the individual and combined forecast sales for commercial and private vehicles (these are separated due to the differing levels of sales in each class).

For the commercial sector, it would be anticipated that some 87,000 commercial vehicles would include APC funded technology by 2022/23. This number drops to 52,000 when counting the successful applications only.

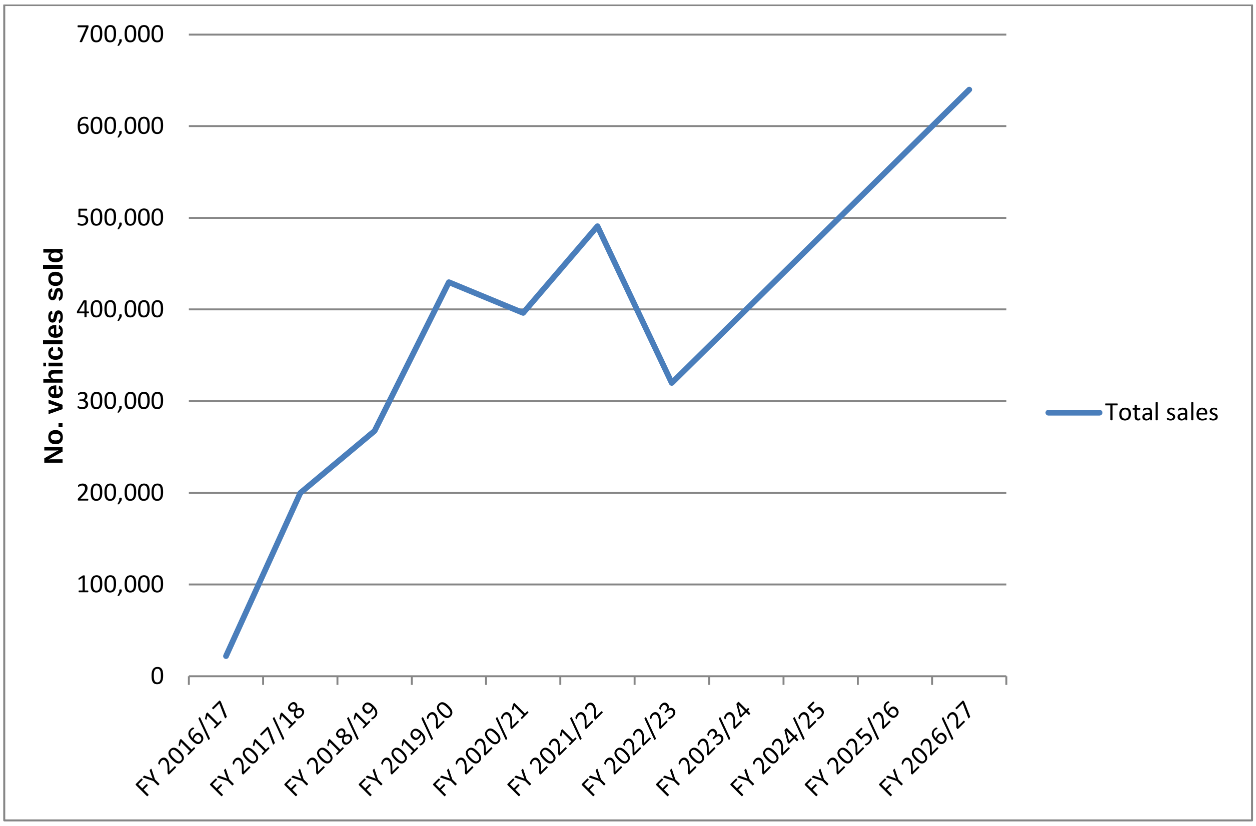
Only three applications have been received for private motor vehicles, of which one was a repeat application. If both projects achieve their sales target a further 50,000 will be produced for private use by 2021.

Chart C.1: Forecast sales for commercial vehicle projects



Source: APC VfM appendices of application forms

Chart C.2: Forecast sales for passenger vehicle projects



Source: APC VfM appendices of application forms

Technological themes and technological readiness

Of the applications already received, all but three relate to amendments or additions to an internal combustion engine (ICE). The sticky technologies41 identified by the Automotive Council and targeted by APC have been covered in these applications. These are:

- Electric machines and power electronics;
- Electric storage and management; and
- Internal combustion engines.

There is some degree of crossover between technologies, where several applications look to develop several ideas in one project. This balance is reflected in the range of successful applicants, both in terms of technology and application.

[41] http://www.automotivecouncil.co.uk/technology-group-2/_details the sticky technologies to be targeted by APC specifically. It has been suggested by the Automotive Council that experience gained in these areas of automotive propulsion will help to anchor future research and production activity by firms.

Table C.3: Technology and its applications

Technology/application	Passenger Car	Commercial	Public Transport	Diggers	Production Machines
ICE Petrol	3				
ICE Diesel		1	1	1	
Energy Storage and Energy Management	1	2	1	1	
Electric Machines		2			1

Source: APC application forms

The proposed projects are identified as contain significant novel aspects. Many propose new applications of, or amendments and refinements to existing technologies. One project submitted was a fully zero emission vehicle project. The appraisal data suggests that much of the innovation is in the application of existing technologies to new settings. There are several projects that look to make use of flywheels to recover and store energy for an electric hybrid system. Some projects are deemed to be highly innovative by assessors due to the production process that will be developed, rather than the product or par. There are also examples of electric motors, hydrogen fuel cells and electronic engine control. The resulting carbon savings range from 10% - 25%.

One of the stipulations of the APC programme is the level of development that a technology should have already achieved before applying for grant funding. The level of development is defined by its Technology Readiness Level (TRL) or Manufacturing Readiness Level (MRL); scales developed to track progress of R&D programmes. Both scales track development from identification of scientific principles to a technologies inclusion into mainstream production, or production processes42. Both run from the most abstract ideas at level zero to fully operational products, technologies and systems at level ten.

The APC programme targets projects between TRL5 and TRL8. This covers systems that have at the very least been tested in relevant environments and generated results that show it to be viable, but will also offer support to systems that are being development to an acceptable standard for use by customers.[43]

In all cases the applications suggest that their technology is at the TRL5 and MRL4. All but one application explicitly define the end point for their technology. The majority expect to reach TRL8, and to progress beyond MRL6. One application does not anticipate such

[42] For a guide to TRL and MRL for the automotive sector see: http://www.apcuk.co.uk/how-we-can-help/services/technology-readiness-levels/

[43] See Appendix B for full TRL and MRL definitions.

advanced end levels, but the application suggests that the technology will be included in production vehicles, suggesting that their project end state will be consistent with those of other applications.

Collaborations and lead applicants

The APC programme requires that applications are collaborative and must have an OEM or tier 1 participant, so as to facilitate a route to market. Across all applications there has been an average of slightly less than 6 collaborators per bid. Across all applications there have been applications from four OEMs.

There has also been significant involvement from universities with 7 unique institutional involvements. Finally, as noted in the table below, there have also been contributions from numerous SME firms, with at least one per application.

Applications have predominantly been led by large firms. Of the nine initial applications[44], three different prime, or OEM, firms have led consortia. Two different Tier 1 firms are represented. There has been only one bid led by an SME. There have been eight different lead applicants, as one lead applicant has made two applications. The majority of firms applying to the APC are already involved with the automotive sector. Two are two are relatively new to the sector but have experience from related areas of low carbon technology.

Table C.4: Technology and its applications

Round	Applicants	Funded	Ave collaborators	Unique OEM	Academics	SME
R1	4	4	5	2	5	4
R2	5	1	6.7	1	4	7
TD	2	2	6.5	1	0	4

Source: APC application forms

The numbers of collaborators in each project illustrates the number of distinct inputs that are required for projects to succeed. From the detail included in the application forms each firm has a clear and defined role in the projects. In most instances each collaborator is bringing specific skills and knowledge to the team. For several projects collaborators are bringing multiple technologies together with their project such as flywheels and hydraulic hybrid systems.

The ownership of IP appears to reside with the lead collaborators in most instances where IP is explicitly stated. Several applications suggest that where IP relates to existing modular systems and parts the ownership will reside with the relevant OEM; however, if other, more generally applicable, IP is discovered it can be registered by a collaborator.

[44] As noted above, two of the 11 applications were resubmissions.

Appraisals

The appraisals of application were conducted through two processes. Innovate UK completed an appraisal of projects using five independent assessors scoring on ten questions included in the application. Panel sheets have been analysed showing that from the initial reviews all applications scored over 70% (the average was 76%). However opinions of the assessors differed greatly. For all but two applications, the assessment score had a spread of results of results from over 10 percentage points; for half the spread was over 20 percentage points. Assessor scores were moderated, and it was at this point that the four projects from Round 2 were rejected.

The second appraisal process was a Value for Money (VfM) assessment. This is an assessment of the wider economic benefits that are accrued as a result of a proposed investment; summing impacts relating to job creation, skills and training and wider economic benefits (such as reductions in greenhouse gas emissions). Due to the small number of applications to date the VfM appraisal was conducted as an iterative process. In all but two applications the final VfM score was higher than the initial assessment; however, this did not always result in a passing score. Three of the four projects rejected through the Innovate UK process also failed on the VfM assessment.

Table C.5: VfM appraisal parameters

	Gross additionality	Displacement Multiplier	Net additionality	Project Risk	Net Expected Additionality
Ave.	43%	56%	24%	30%	16%
Min	15%	27%	11%	10%	8%
Max	60%	73%	42%	50%	29%

Source: APC VfM appendices of applications

As can be seen from the table above there was significant variation in the level of additionality and risk from the projects. The risk score relates to the likely severity of a risk rather than likelihood of occurring.

Levels of additionality are comparatively low. Net additionality was assessed as being under 25% on average. This may also be reflected in the rationale that several applications suggested that the work would go ahead but only when regulation required it.

Table C.6: Grant award adjustments

Grant request adjustments Round	Funded	Original value of successful applications	Value of final grants
R1	4	£ 33,680,944	£ 30,515,799
R2	1	£ 7,395,497	£ 6,000,000
TD	2	£ 18,251,483	£ 10,405,508

Source: APC application dataset complied by BIS

Funding rationale

There are a number of reasons given by firms for their application to the APC programme; there does not appear to be a consistent theme, although several issues reoccurred. Several firms noted that without funding from the public sector their projects would not go ahead. Although not explicitly stated in each application this appears in several cases to be as a result of competing projects that are more attractive to internal or external investors.

Some firms suggested that the funding allowed for the collaboration to occur; where a high risk technology was being developed, the easing of risk through sharing the burden with collaborators and public finance. The issue of reducing the risk of a project was mentioned by five of the nine unique applications reviewed. Several firms suggested that the project would occur in the absence of government funding but at a later date when regulation made inaction on progress towards low carbon propulsion systems unviable.

There is some indication from applications that support for projects will help them to accelerate; however, in these instances it is suggested that the advancements would occur eventually but in response to regulatory pressures. Several applications suggest that grant funding will allow for the UK to gain competitive advantage over international competitors, or that investment will allow firms to source more products and parts from within the UK.

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