WWW.FRONTIER-ECONOMICS.COM

Faraday Battery Challenge – Phase 1 evaluation

Final Evaluation Report prepared for UK Research and Innovation

19 OCTOBER 2023

Contents

frontier economics

frontier economics

Glossary

APC – Advanced Propulsion Centre

ATF – Automotive Transformation Fund

BEIS – Department for Business, Energy, and Industrial Strategy

CEO – Chief Executive Officer

CR&D – Collaborative Research and Development

DBT – Department for Business and Trade

DER – Driving the Electric Revolution

DIT – Department for International Trade

EU – European Union

EV – Electrical vehicle

FBC – Faraday Battery Challenge

FDI – Foreign direct investment. Investment from outside a country that involves the purchase of an asset, giving control over it.

FI – Faraday Institution

FTA – Free trade agreement

GDP – Gross domestic product. The value of goods and services produced by an economy in any year

GVA – Gross value added. The value of goods and/ or services produced by a sector, region or an economy (net of the effects of indirect taxes or and of subsidies) in any year.

HMG – His Majesty's Government

HMRC – His Majesty's Revenue and Customs

ICE – Internal combustion engine

IMF – International Monetary Fund

IP – Intellectual property

IPO – Intellectual Property Office

ISCF – Industrial Strategy Challenge Fund

Kw/H – Kilowatt hour. A measure of energy use per hour.

Li – Lithium

Li-S Lithium-sulphur

Na – Sodium

MNE – Multinational enterprise

NCUB – National Centre for Universities and Business

OECD – Organisation for Economic Cooperation and Development

OEM – Original equipment manufacturer. A business that produces goods that are either finished products or used as inputs in the production of other goods.

ONS – Office for National Statistics

PEMD – Power electronics, machines and drives

R&D – Research and development

ROOs – Rules of origin. Criteria in trade agreements that allow importing countries to determine the country of origin of a particular product, in particular to determine eligibility for preferential tariff treatment.

RUL – Remaining useful life

SciVal – Research analytics tool for gathering statistics on published research

SME – Small and medium-sized enterprise (in the UK, a business with fewer than 250 employees and turnover of less than £50 million per annum OR balance sheet total of less than £43 million).

STEM – Science, technology, engineering and mathematics

TCA – Trade and Cooperation Agreement (between the UK and the EU)

TRL – Technology readiness level. Levels 1-3 are associated with research, levels 4-6 with development, levels 7-9 with deployment. TRL level 9 is associated with readiness for commercialisation.

UKBIC – UK Battery Industrialisation Centre

UKRI – UK Research and Innovation

Value chain – a concept that describes industrial organisation and the way in which businesses are interlinked through the production, sale and acquisition of goods and services.

Executive summary

The Faraday Battery Challenge (FBC) was launched as part of the 2017 Industrial Strategy. This report evaluates the impact of phase 1 of FBC. Phase 1 ran from August 2017 to March 2022. The evaluation was done on the basis of seven evaluation themes. The table below summarises the findings against these themes.

Phase 1 summary of strengths and challenges

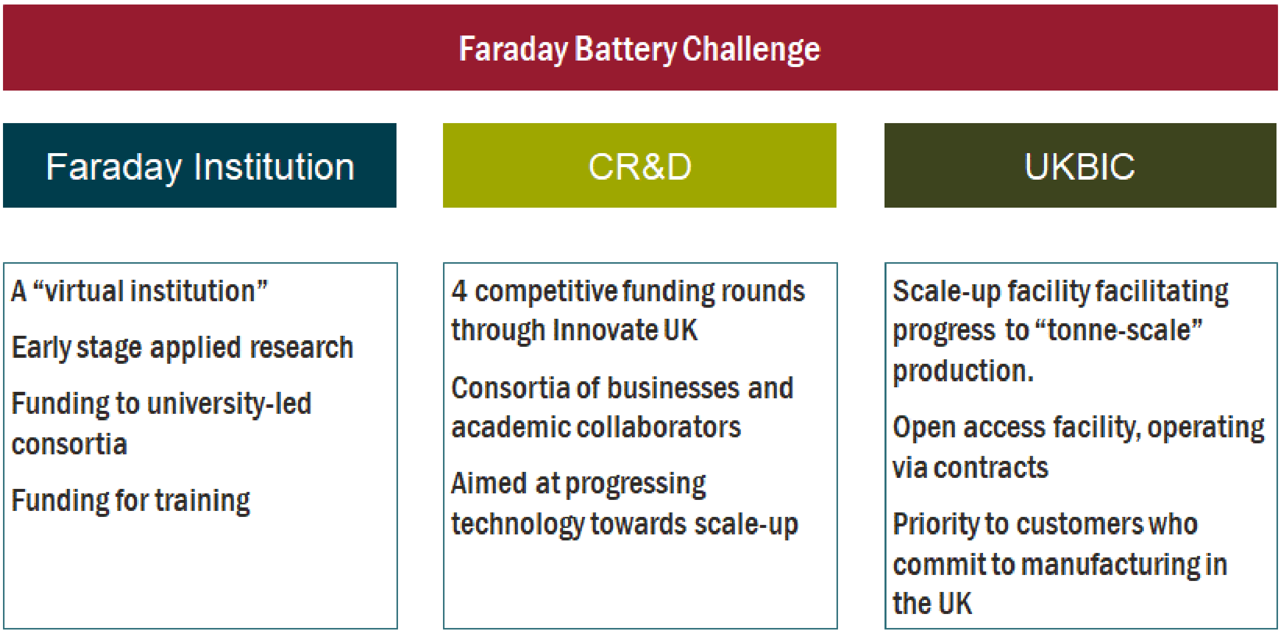
Evaluation theme	Key strengths	Key challenges
Establishment of an enabling policy framework	Positive contribution to investment framework (>90% of survey respondents). Essential contributions to ATF, developing the National Electrification Skills Framework and UK Battery Skills Framework. More than 5-fold increase in foreign investments in start-ups over the period 2020-22 compared to 2016-19.	Perceptions of the UK as a destination for foreign investment in batteries are unchanged since 2017 and are overwhelmingly influenced by factors that affect foreign investment more generally. Perception that longstanding bottlenecks to scaling up and commercialisation yet to be addressed. Dominant role of external factors, notably trade policy.
Systemic change in conduct of battery R&D	More than 640 publications through FI. 93% of publications appear in top quartile journals, while nearly 64% appear in top 10% of journals. FI research had higher impact than UK battery research and global research for period mid-2018-19. CR&D funding for 86 projects over 4 rounds. 71% of respondents said they would continue collaboration absent funding, and over 80% stated that collaboration had increased since FBC's inception.	Some degree of concentration in CR&D funding with three academic institutions accounting for 75% of funding Citation impact numbers show that UK has comparative strengths in battery research that predates FI, and that FI has not had a material impact on this. Impact of FI research seems to have dropped off more recently. Progress against UK automotive targets still underway.
Attraction of investment in R&D and innovation	More than 5-fold increase in foreign investments in start-ups. Development of UKBIC pipeline and leads.	Influence of broader UK-related factors determining investment, rather than battery-related interventions per se. Slower than expected start to UKBIC, requirement to recalibrate scale of operations.

Enhanced prospects for commercialisation	Survey of CR&D participants shows that reported expectations of profitability have risen over 7-fold since 2020. Evidence of progress through TRLs: of 86 CR&D projects, 81% had increased by at least 1 TRL. 45% were at TRLs 1 and 2 at the beginning of FBC engagement, only 5% were now still at this stage. Number of CR&D collaborations applying for patents had more than tripled since 2020.	Only a small proportion (4%) were at the stage of being nearly or fully commercialised and brought to market (TRLs 8 or 9). Concerns that the pathway to commercialisation was not happening fast enough to meet policy targets. Need to take account of regional particularities notably in skills as factor influencing commercialisation.
Development of battery capability and supportive ecosystems	UK EV battery technology start-ups raised close to $1.1 billion in the period 2020-22, which is a significant increase over the nearly $230 million reported for the period 2016-19. Evidence of learning-by-doing effects from UKBIC activities, and outreach. Data on leads point to significant UKBIC potential to reach non-automotive sectors.	UKBIC operated significantly below capacity and underperformed on revenues, mainly because of external factors. Progress to gigafactory establishment slow and affected by external factors. Skills development remains major challenge. 81% of survey respondents said there were fewer people with relevant skills than the industry as a whole currently needs, and 43% thought there would be fewer in future
Development of OEMS and other value chains	80% of survey respondents said funding had helped them to reach a later stage of development than they would have reached otherwise 57% said their FBC engagement had allowed them to reach the intended stage of development more quickly than they would have been able to do otherwise.	Survey responses show weaker effects on production capability: nearly half (48%) felt that their engagement with FBC had not had any impact on their production levels. Persistent concern about the development of production capability and in bringing research to market, and FBC's ability to address this. Strong effects of outside factors on decisions by OEMs.
Economy-wide impacts	Not detectable within the evaluation period. Positive results on systematic changes to the conduct of R&D and investment in R&D suggest potential future productivity effects.	Effects will be dependent on actual outcomes in gigafactory and OEM investment.

The purpose of FBC is to transform the research and development landscape for battery technology in the UK. This is a necessary condition for the emergence of new battery technologies and the establishment of large-scale battery manufacturing in the UK. That in turn is expected to contribute to the transformation of the automotive sector and related value chains in the UK. This transformation would help to meet objectives set for the phasing-out of the production and sale of motor vehicles that rely only on internal combustion engines by 2030 (and hybrids by 2035) and, more broadly, the UK's objective for net zero greenhouse gas emissions by 2050. It would also help to secure the future of automotive manufacturing activities in the UK.

FBC comprises three strands that together aim to create an ecosystem from research and development (R&D) through to scale-up facilities. These strands are the Faraday Institution (FI), Collaborative Research and Development (CR&D) and the UK Battery Industrialisation Centre (UKBIC). The activities of the strands are supported and coordinated by an overall governance structure that includes a programme board and an advisory board. This broad structure of the Challenge is depicted in Figure 1 below.

Figure 1 Overview of the Faraday Battery Challenge and activities, phase 1



FBC's strand-based structure is one of its distinctive features:

- FI opened in May 2018. It operates as a "virtual institution" in the sense that it acts as a platform that coordinates the work of around 500 scientists in 27 institutions. These collaborate with over 50 businesses working on ten large-scale research projects, delivering seed funding, studentships, industrial sprints and entrepreneurial fellows.
- CR&D has disbursed funds under phase 1 of the Challenge across four funding rounds, which cover feasibility studies and R&D since inception.
- UKBIC is an 18,500 square metre facility which commenced operations in 2021. It is aimed at scaling up battery manufacturing by providing investors with the possibility of progressing from gram- or kilo-scale operations, as takes place in laboratories or industry catapults, to tonne-scale operations. The ability to scale up was identified as a key step on the pathway to commercialisation.

The strand structure is designed to respond to the multiple market failures that, in the absence of targeted interventions, are likely to constrain the development and commercialisation of the technologies required to anchor large-scale battery manufacturing in the UK. While there are specificities to each strand, there are also significant interdependencies. Hence, there is a governance structure for FBC as a whole which coordinates the activities of the strands, leverages these interdependencies and engages in policy development.

Evaluation based on a contribution analysis

The evaluation follows a theory-based approach which supports a contribution analysis. The evaluation draws on an overarching theory of change and an associated logic model. Together, these set out the rationale for the intervention, the ultimate impacts expected and the causal pathways connecting the activities delivered to those impacts. In line with *Magenta Book* guidelines, the use of contribution analysis is justified for several reasons: (i) FBC benefits are likely to take many years to materialise in full; (ii) there are a wide range of intended outcomes and impacts; (iii) there is no natural "control group" that could support counterfactual analysis; and (iv) a multiplicity of factors both specific to the intervention and outside it can influence the sought-after impacts. A theory-based approach is useful as it helps to identify the specific causal mechanisms through which the intervention contributes to a range of desired impacts over different time horizons and the role of other factors.

A contribution analysis is counterfactual in nature. It does not seek to report what activities have been undertaken but how far these activities have contributed to outcomes and impacts in a manner that would not have been possible without the intervention. Counterfactual analysis is generally challenging, and more so in the presence of significant unanticipated external shocks. In the course of phase 1, the main shock was Covid-19, but it was not the only one. While trying to understand the counterfactual of what would have happened to the running or impact of the Challenge without Covid-19 is beyond the scope of this work, the pandemic is an important backdrop to bear in mind throughout the evaluation.

KEY MESSAGES AND RECOMMENDATIONS

We evaluated the contribution of FBC against seven evaluation themes which emerged from the theory of change. Our principal findings are as follows.

FBC has made a significant contribution to the establishment of enabling policy frameworks for investment in battery production, automotives and related value chains. It has done so, notably, through: (i) research and thought leadership, which has led to the creation of broader support mechanisms such as the Automotive Transformation Fund (ATF); (ii) the design of frameworks and programmes for the development of skills; and (iii) engagement with government departments to improve the investment landscape for large-scale battery investments. The efforts are reflected in survey data: over 90% of respondents had a strongly positive view of FBC's contribution to the investment climate for battery manufacturing in the UK. Investor perceptions of the UK as a destination for battery investment remain mixed because of a variety of factors which, in the main, are not related to FBC. But it is likely that the UK is in a better position to respond to these with FBC in operation rather than in a world in which it did not exist. Feedback from start-ups suggests a positive contribution of FBC to the rapid growth in venture capital fundraising by battery-related start-ups in recent years. Foreign investment in start-ups showed a step increase in foreign investment, by a factor of nearly five, in the period 2020-22 compared to 2016-19 (see below).

FBC has had material effects in generating systemic changes to the conduct of battery R&D. FI has generated increased volumes of academic research, with over 640 publications since inception. Citation data point to the high impact of its research relative to that of other UK battery research and worldwide battery research. However, there is no evidence, based on these measures, of spillovers from FI's research to the impact of UK research. FI's research programme has also fully integrated the UK Automotive Council targets. Funding through CR&D for over 80 collaborative projects has encouraged a greater trend towards collaboration, which appears to persist beyond funding. Around 70% of participants would continue collaboration even after funding had stopped. Survey evidence suggests that FBC has had a significant positive impact on progress achieved in relation to developing more advanced battery systems and components (see below).

There is some evidence that FBC has contributed to attracting investment in R&D. Data on foreign investment in start-ups show significant increases in recent years. Such investment amounted to $1.1 billion in the period 2020-22 compared to $230 million in 2016-19. This is a faster rate of increase than for venture capital-supported investments generally in the UK. The degree of attribution to FBC is not clear. However, stakeholder feedback suggests a positive contribution by FBC in tandem with other government interventions. This feedback also tallies with survey data on FBC's positive contribution to the investment framework for batteries. Interactions with UKBIC can be seen as one measure of international investor involvement in R&D. These have been significantly lower than planned because of external factors, but stakeholder feedback and data on expected projects and leads suggest continued investor interest in that model and the services offered by UKBIC.

There has been some enhancement of prospects for commercialisation, but obstacles remain.

The activities of FI and CR&D have contributed to stimulating developments at low to mid technology readiness levels (TRLs). While nearly a half (45%) of survey respondents were at TRLs 1 and 2 at the beginning of engagement with FBC, only 5% were now still at this stage. Around half of respondents envisioned a time frame of between one and five years for commercialisation. At the same time, only a small proportion (4%) were at the stage of being close to commercialisation and brought to market (TRLs 8 or 9). Data on patent filings also suggest an impact of FBC. Effects on scaling up, an essential step to commercialisation, are more limited. The establishment of UKBIC has the potential to provide significant support to this process. External factors such as Covid-19 and energy price shocks have acted as constraints on UKBIC's operations, but it has started to earn revenues and has an active pipeline of leads, which is indicative of its potential (see below).

There have been substantial contributions to the development of battery production capabilities and a supporting ecosystem. But significant challenges remain, notably in relation to skills. This is reflected in various trends, notably: (i) data on the birth of new businesses in batteries and related fields; (ii) evidence relating to foreign investment in start-ups and the role of venture capital; and (iii) data from CR&D close-out reports on investor perceptions of commercial prospects. Since it started operations in 2021, UKBIC has progressively ramped up its activities, targeting revenues of around £7 million in 2023-24. It has an active pipeline of some 250 leads, distributed across a range of sectors. Project close-out reports suggest material learning-by-doing effects. Progress towards the establishment of large-scale production via gigafactories is more mixed. FBC is recognised to have contributed to the emergence of Britishvolt as a prospect during the period covered by the evaluation. (However, Britishvolt's subsequent entry into administration and buy-out has slowed progress.) More broadly, there are outstanding challenges, particularly in the area of skills. Evidence from surveys and stakeholders point to persistent – and indeed, in some cases, increasing – gaps in skills. Efforts by FBC to develop programmes and frameworks for skills development could contribute to addressing this challenge.

There are some effects on the development of original equipment manufacture (OEM) and related value chains. These are mainly through the effects of FBC on technological capabilities: around 80% of survey respondents said funding had helped them to reach a later stage of development than they would have reached otherwise. But respondents reported less pronounced effects on production capability, with around half saying that their engagement with FBC had had some impact on their production levels and half saying there had been no impact.

Evidence of high-level impacts (e.g. on growth or productivity) cannot be detected at this stage. Positive effects in improving the conditions for R&D and supporting technological progress suggest that FBC can have positive impacts on headline economic indicators. These effects can be seen as leading or intermediate indicators of future high-level impacts. The continuing challenges encountered in progress towards commercialisation may have a dampening effect on these prospects.

Recommendations for the next phase of the Challenge reflect the significant shifts in the broader international context for battery production. Increased industrial policy rivalry based on a willingness to subsidise and (in the case of the USA) use local content requirements creates a more challenging environment for the UK. The ability to attract investment will rely even more heavily on the ability to provide access to advanced technologies and the conditions for deploying these. That requires further efforts to address bottlenecks to commercialisation pathways and addressing skills gaps.

Description of the theory of change

The theory of change can be summarised by the following propositions:

- The UK has legislated a target of net zero emissions by 2050. As part of this process, it has committed to phasing out the sale of new vehicles using internal combustion engines. It has legislated for the sales of cars using internal combustion engines to end by 2030 and hybrid engines by 2035. It has also implemented a plan to decarbonise transport more generally.
- The UK has a comparative advantage in motor vehicles and related value chains. This in turn means that specialisation in these sectors involves a more productive use of resources (labour and capital) in the UK. That in turn should stimulate economic growth faster than if these resources were directed elsewhere.
- It is important to the UK to secure continued vehicle production in a zero emissions world. For this, battery production at scale in the UK is a key factor.
- Investment in battery gigafactories in the UK will be more likely if investors can access leading technologies. Advanced technologies help to address the technical constraints on battery performance that limit the uptake and commercial viability of zero emissions vehicles.
- Stimulating the manufacture of batteries that embody breakthrough technologies requires a systemic transformation of the UK's battery R&D landscape. This includes reducing fragmentation in research and increasing its impact, developing industry-academic research partnerships and addressing the bottlenecks that often impede the commercialisation of research.
- Attracting investment in new technologies and transforming the production processes that generate or use these technologies are plagued with market failures. These involve incomplete and asymmetric information, capital market constraints, lack of skills, spillover effects and coordination problems, meaning that investment and production may stagnate at economically inefficient low levels.
- These in turn provide a case for government support, designed to provide the "big push" that is often identified by industrial policy economists as needed to break out of the stagnation trap. FBC is one of a range of interventions designed to deliver this big push.

Evaluation themes and approach to analysis

The theory of change enabled us to identify seven evaluation themes that underpin the contribution analysis:

1. Establishment of an enabling policy framework

2. Systemic change in conduct of battery R&D
3. Attraction of investment in R&D and innovation
4. Enhanced prospects for commercialisation
5. Development of battery production capability and supportive ecosystems
6. Development of OEMS and other value chains
7. Economy-wide impacts

Each of the evaluation themes is associated with a series of indicators or metrics that are designed to capture FBC's impact. The impact evaluation is counterfactual in nature. We seek to establish the extent to which observed impacts differ from what they would have been in the absence of the intervention over the period of interest (i.e. since the inception of the Challenge in 2017 until 2022).

Establishment of an enabling policy framework

FBC has contributed significantly to the establishment of an enabling policy framework for investment in battery production, automotive manufacture and related value chains. It has done so through a number of channels, including:

- Research contributions that played a significant supportive role in the creation of the Automotive Transformation Fund (ATF), which provides financial support and R&D and capital investment;
- The development of a National Electrification Skills Framework and Forum to support the development of essential skills through the development of training initiatives and standards;
- The UK Battery Skills Framework, which aims to provide a defined set of standardised skills that help businesses with planning and employees with identifying career pathways; and
- Close working between FBC leadership and the Department for Business and Trade (formerly Department for International Trade) to improve the investment landscape.

Reflecting these efforts, survey data provide evidence of strongly positive perceptions of FBC's contribution to the investment environment. Over 90% of respondents had a strongly positive view of FBC's contribution to the investment climate for batteries in the UK. Stakeholders also underscored the efforts undertaken by FBC to develop public understanding of battery technologies in contributing to a more robust public policy framework and mobilising mechanisms for public support. There is also evidence of robust trends in investment in battery technology start-ups since 2017. FBC has therefore made substantial contributions to the overall investment framework for batteries that would not have taken place in the counterfactual without FBC.

As one CEO of a start-up put it:

"*The biggest strength of the UK Battery ecosystem is perhaps the joint ambition of industry, government and academia. Together, they aim to promote, support and catalyse their interaction to create smooth, funded, efficient pathways from low Technology Readiness Levels through to scalable commercialisation. For instance, the Faraday Battery Challenge with its rather holistic funding portfolio, from Faraday Institution-funded STEM engagement at a pre-university level through to FBC-funded calls for grant funding industry collaborations. This ambition, and the actions that are being* *taken in line with it, are what I believe make it realistic for UK battery ecosystem players to fight and succeed in securing global leadership positions.*” (Ian Campbell, CEO and Founder at Breathe Battery Technologies)

However, the extent of this contribution is limited by the influence of broader factors that act as determinants of the overall investment climate in the UK. These factors are not necessarily specific to batteries and are ones which would have been observed in the absence of FBC. Thus the findings suggest that, while the UK is recognised as a leading destination for foreign investment in batteries, it is not the leading destination. This has not changed over the period since 2017 and indeed is largely in keeping with the UK's position in relation to foreign direct investment generally. Several factors, including trade policy (particularly relating to the EU), energy prices and geopolitical instability, have been identified as influencing investors' perceptions.

One of the objectives emphasised by the theory of change that underpins FBC was the requirement to address persistent challenges in translating the UK's strengths in applied research and institutional quality into commercial prospects. The findings also suggest that some of these longer-standing challenges still apply. In particular, stakeholders noted weaknesses relating to proof of concept at scale, although this could be mitigated by UKBIC's activities. One of the challenges to the UK is that the international competition for investment in battery technologies is escalating. This makes it more pressing to address the identified missing links and to supplement these efforts with further supportive policies, notably in the area of skills.

Systemic change in the conduct of battery R&D

The evidence suggests that via the activities of FI and CR&D, FBC has contributed to a systemic change in the conduct of battery R&D. FI has generated increased volumes of research outputs since its inception, including via international collaborations. There is evidence that FI has been associated with an observable increase in collaborative effort in academic research, both within the UK and internationally. According to FI annual report for 2021/22, FI has generated more than 640 publications since its inception. Close to 93% of publications appear in top quartile journals, while nearly 64% appear in the top 10% of journals. Around 44% appear in the top 10% most-cited publications. Data on citation impacts suggest that FI's research had a greater impact than that of UK battery research generally and global battery research between mid-2018 and 2021 before dropping off. In general, citation impact data show that battery research in the UK as a whole has had a greater impact than worldwide battery research and all UK research. This underscores the UK's comparative strength in the subject of battery research. However, this comparative strength predates FI and does not seem to have changed materially following the launch of FI's research activities.

The UK Automotive Council has set eight targets for battery development. These relate to cost; energy density (cells); power density (pack); safety; 1st life (pack); temperature (cell); predictability; and recyclability (pack). FI has developed a research programme that seeks to systematically address these targets. The programme has nine areas, which each address one or more of the targets. Breakthroughs will require more time. Information from FI reports progress across a number of these targets, particularly in relation to energy density and, to some extent, power density, lifetime and safety.

CR&D held four rounds of funding for collaborative projects over the evaluation period. Project close-out data are available for rounds 1-4, which involved 86 projects. The data point to high levels of satisfaction by consortia regarding their collaborative activities: around 70% of participants would continue collaboration even after funding stopped. This suggests a shift in attitudes towards collaboration that goes beyond the immediate effects of funding.

FBC is also perceived to have increased levels of collaboration in terms of numbers of collaborations. A very large majority (81%) of survey respondents continued to feel that collaboration on projects or grants concerning batteries had increased since FBC's inception in 2017. Most of these respondents attributed increased collaboration to FBC activity. Effects of progress through TRLs are reported in the section on "enhanced prospects for commercialisation" below (Section 2.3.4).

Taking all these findings together, it is plausible to infer that FBC has generated an increase in collaborative R&D over time which outlasts the impact of the initial support provided, and which is greater than would have been observed in the counterfactual case, i.e. absent FBC and CR&D specifically.

While a range of academic institutions receive funding via CR&D for collaborative projects, projects run by three institutions (Warwick University, Imperial College London and University College London) accounted for around 75% of the £30.3 million disbursed through CR&D in rounds 1-4. This could point to efficiencies via economies of scale and scope but may also raise questions about distributional effects.

Finally, while it is unclear how far progress has been made overall towards achieving breakthroughs against the eight automotive targets, survey evidence suggests that FBC continues to have a significant positive impact on their perceived progress in advanced battery systems and components. As already documented, FI has integrated these targets into its research programme.

Attraction of investment in R&D and innovation

High-quality data on investment in battery R&D per se are scarce in the UK and internationally. A report (Electric Vehicle Battery Tech in the UK 2023) shows that the levels of foreign investment in start-ups have increased significantly since 2017 (see Section 2.3.5 on "development of battery production capability and supportive ecosystem" for details). As start-ups are R&D intensive, and indeed are generally considered prime drivers of innovation, these trends can be interpreted as an indication of increased attractiveness for R&D investment. Clearly, the degree of attribution of these trends to FBC is unclear, but feedback from stakeholders involved in start-ups suggests that FBC backing, notably via FI, has played a significant role.

By definition, CR&D is designed to attract investment in R&D and innovation, whether domestic or foreign. As reported under the preceding evaluation theme, there is evidence of a durable increase in collaborations. Some of these involve foreign investors in the EU, Japan, the USA, Israel and Australia.

Given the nature of the UKBIC model, interactions with UKBIC can be seen as one measure of international investor involvement in R&D. Contracts have been signed, but to a lesser extent than planned with UKBIC revenues, and utilisation has been significantly below what was targeted. This is largely because of the influence of external factors, notably the Covid-19 pandemic. Nevertheless, stakeholder feedback and data on leads and expected contracts suggest continued investor interest in that model and the services offered by UKBIC. (See Section 2.3.5 on "development of battery production capability and supporting ecosystem" for a fuller description of UKBIC's activities and contributions.)

Enhanced prospects for commercialisation

The activities of FI and CR&D have contributed to stimulating developments at low to mid TRLs. For instance, FI has conducted a number of "industrial sprint" projects, i.e. projects which last 4-15 months and which target short-term industry needs for research and innovation that have been identified by companies.

Consistent with the interim evaluation, participants in CR&D projects reported significant effects of these on their expectations regarding commercialisation. Around half of survey respondents expected commercialisation within one to five years. Reported expectations of profitability have risen more than seven-fold in recent years.

Reported progress through TRLs has been significant. Of the 86 projects in CR&D rounds 1-4, 50 had increased by one stage, while 17 had increased by two stages and three had increased by three stages. In terms of where projects were in TRL stages, while nearly half (45%) were at TRLs 1 and 2 at the beginning of FBC engagement, only 5% were now still at this stage. Only a small proportion (4%) were at the stage of being nearly or fully commercialised and brought to market (TRLs 8 or 9). That percentage may serve to moderate findings regarding expectations of commercialisation and profitability.

There is some early evidence of intellectual property (IP) generation as a result of these projects. Data for CR&D collaborations show that the number of collaborations that were considering applying for patents has more than tripled since 2020.

As well as FBC's direct contribution to various patent opportunities in the UK, there is evidence of a specific increase in R&D outputs relating to electric vehicle (EV) battery technology in recent years. Data on patents filed with the UK Government's Intellectual Property Office (IPO) lists 53 battery patents that specify EV applications filed since 2013.

The evidence is mixed regarding the key issue of how far FBC has addressed the issue of de-risking scale-up and avoiding consequent bottlenecks to commercialisation. Some stakeholders outlined concerns that the pathway to commercialisation was not happening fast enough to meet policy targets. Some also observed that innovation had been supported at the national scale but that regional factors – particularly skills – also needed to be taken into account in order to support enhancements in manufacturing.

At the same time, stakeholders pointed to the establishment of UKBIC as a step in the right direction as it provides access to scale-up facilities that would not have existed in the absence of FBC. It was deemed to provide a “clear point of differentiation” between the UK and potential rival destinations for battery investment and production.

Development of battery capability and supportive ecosystems

The evidence suggests that FBC has made some contributions to developing battery production capability and pathways for a supporting ecosystem. Key indicators of this are the numbers relating to the birth of new businesses in batteries and related fields, and evidence relating to start-ups and the role of venture capital. In relation to start-ups, UK EV battery technology start-ups raised close to $1.1 billion in the period 2020-22, which is a significant increase over the nearly $230 million reported for the period 2016-19.

The extent to which FBC has contributed to this is unclear. In general, investment supporrted by venture capital was around 300% higher in 2022 compared to 2017, suggesting that trends in batteries partly reflect a more general trend in venture capital flows to the UK. At the same time, a comparison between battery-specific and general trends suggests that the battery sector is particularly attractive. This could reflect the UK’s range of interventions in favour of battery development, of which FBC is a part. Feedback from industry participants suggests that FBC is part of a broader enabling environment that facilitates fundraising. This is because it provides a viable pathway from low TRLs to scalable commercialisation (see quote attributed to Ian Campbell in the section above on etablishing enabling policy frameworks). In addition to that, data from CR&D close-out reports suggest that FBC has had a strong impact on participants’ perceptions of commercial prospects, and that this effect has increased in recent years.

While the activities of FI and CR&D have generated measurable, positive outcomes, the wider effects on industry at large are still emerging, and there are substantial challenges that need to be met. This is particularly the case in relation to skills, which will play a critical role in anchoring battery and related value chains in the UK and ensuring that there are wider benefits from investment in these sectors.

While the survey evidence and evidence from CR&D close-out reports suggest tangible impacts on skills, there is also evidence from surveys and stakeholders of continuing – and indeed, in some cases, increasing – gaps in skills. That likely reflects the fact that demand for such skills globally is escalating. Survey evidence gives a relatively sober picture of the current skills levels of workers in the sector: 81% of respondents felt that there were fewer people with relevant skills than the industry as a whole currently needs.

Within the UK, an increase in investment activity – from start-ups to forward plans by gigafactory investors – is also likely to stimulate demand and increase perceptions of skills gaps. In that sense, the more successful the UK and FBC are in pushing forward the attractiveness of the UK for battery production and related value chains, the greater is the pressure to address skills challenges. Indeed, perceptions on what will happen to the skills gap in the industry over the next five years are mixed. While just over a quarter of 112 survey respondents (26%) felt there would be more people with the relevant skills than the industry needs, over two in five (43%) expected that there would be fewer, including 28% who felt there would be significantly fewer people with the relevant skills than the industry needs.

Addressing skills issues will depend on broader policy settings beyond the sole remit of FBC. At the same time, FBC has been making substantial contributions to developing the enabling framework for skills. It has done this through its collaboration with other institutions, particularly the National Electrification Skills Framework and Forum and UKBIC's work in establishing a Battery Skills Framework. Both these initiatives target market failures that usually affect the development of skills through, respectively, network-based approaches and by developing common standards. These initiatives would enable the upskilling of workers who could transfer from other sectors as the battery and automotive sectors expand. This would help to address some of the labour market adjustment problems that economies face when some sectors expand and others contract. Strengthening the UK's ability to address skills and adjustment are channels through which FBC is able to deliver broader economic benefits that extend beyond those of battery production activities.

The activities of UKBIC are expected to provide a pathway to commercialisation. Since it began operations in 2021, UKBIC has ramped up its activities with projects across 24 client partners with a value of around £6.6 million. About a quarter, by value, are with partners who have also received CR&D funding. Feedback from major projects suggests material learning-by-doing effects. UKBIC is continuing its outreach efforts, targeting revenues of £7 million in 2023-24 and aiming to add 10-15 new customers. UKBIC had an active pipeline of leads totalling 250 as at March 2023, with 84 of these at the stage of actual project bids. Although this information relates to potential outcomes outside the evaluation period, it nevertheless reflects actions undertaken in the first evaluation period.

While outreach and pipeline activities will be relevant to outcomes assessed as part of future evaluations, these activities along with project experience contributed to learning-by-doing in the current evaluation period. Thus, UKBIC has taken steps to adjust the scale of its facilities to better target the range of client characteristics and needs in the scale-up process. The large majority of leads are from the UK, with some interest from clients in the US and EU jurisdictions. Data on leads suggest that UKBIC has significant potential to benefit sectors other than the automotive sector. Thus, while a large number of leads are from the automotive sector, nearly an equal number are from across multiple sectors, with a smaller number from the aerospace sector. If these leads are taken forward, they may help to address the views expressed by some stakeholders that FBC's focus remains too dominated by the automotive sector.

The establishment of large-scale production via gigafactories, which would represent the pinnacle of the battery manufacturing ecoysytem, remains a work in progress. During the first phase of the evaluation process, the difficulties faced by Britishvolt (which subsequently led to its entry into administration and then acquisition by Recharge) crippled what was seen as a leading prospect. Notwithstanding that, FBC's contribution via UKBIC to the development of Britishvolt's planned gigafactory had been noted:

"*UKBIC is an essential ingredient in BV's accelerated roadmap to market, providing a platform and environment that delivers high quality development cells in a time period that would be almost impossible in other territories.*" (Resident Head of Global Operations of Britishvolt, Graham Hoare)

Progress in the broader battery production ecosystem can also be observed through production at smaller scales than gigafactories. Thus AMTE Power has announced plans for a "megafactory" (with a capacity of 0.5Gwh/yr) in Dundee. AMTE also signed a contract with UKBIC in late 2022 for the manufacture of 60,000 ultra high power cells in a bid to boost its commercialisation plans. Commenting on the role played by UKBIC, Kevin Brundish, Director of Strategy at AMTE Power, stated that:

"*Our partnership with UKBIC is a crucial stepping-stone as we scale up our cell production rates to large-scale manufacturing levels. Coupled with testing being done at our existing facility in Thurso, it means we can provide greater certainty on cost and reliability of supply for our customers in the automotive and energy storage sectors. It's fantastic to be doing this work at a UK-based facility, championing home-grown battery IP and supporting the future of British manufacturing jobs*".

Development of OEMS and other value chains

Survey evidence suggests that FBC has had a positive, additional impact on the development of technological capabilities. Among survey respondents in receipt of FBC funding, almost all (94%) described FBC's engagement as having had a positive impact on the development of their technology. Furthermore:

- Eighty percent of respondents said funding had helped them to reach a later stage of development than they would have reached otherwise.
- Over half (57%) said their FBC engagement had allowed them to reach the intended stage of development more quickly than they would have been able to do otherwise.

Respondents detected somewhat weaker effects on production capability: nearly half (48%) felt that their engagement with FBC had not had any impact on their production levels. However, a significant share reported a positive impact regarding production levels, helping to increase production capacity more quickly (28%) and/or increasing it to levels that would not have otherwise been possible (15%).

Despite the establishment of UKBIC, concern remained amongst stakeholders about the challenges related to the development of production capability and in bringing research to market.

Survey respondents and case study interviewees also underscored the importance of multiple external factors outside the direct influence of FBC that could impact the development of value chains. Chief amongst these were trade policy and increasing competition from other jurisdictions.

Economy-wide impacts

Headline economic performance indicators (changes to growth in gross value added, productivity and wages, for example) were always going to be difficult to detect at this stage of the Challenge. This is mainly because the key drivers of such headline changes (battery production through gigafactories, production of EVs) lies several years into the future.

The key question was how far FBC would "shift the dial" on this front, in the sense of raising the probability that these impacts would materialise over the longer term. There are various possible channels through which FBC could do that:

- Long-term effects of systemic changes to the conduct of R&D. In particular, if the collaborative model fostered by FBC enables R&D (not just in battery-related disciplines) to be conducted more efficiently, this could increase the probability of innovation. That in turn could have long-term benefits in terms of productivity.
- Increased investment in R&D by businesses, particularly start-ups, and technological progress achieved by businesses, generates spillover effects. That in turn could stimulate further investment, with beneficial impacts on productivity and economic growth.
- Impacts of gigafactory investment and production on employment and economic activity, and the effects of anchoring motor vehicle production and automotive value chains on these variables.

There are some positive trends. There is evidence of systemic changes to the conduct of R&D and of technological progress (including prospects of favourable commercial outcomes) by businesses via interaction with FBC. There is also some evidence that the Challenge has contributed to improving prospects for gigafactory investment.

But these positive trends need to be qualified with the observation of continued difficulties in addressing barriers to commercialisation at scale, which has long been identified as one of the main hurdles the UK needs to overcome. Even though participants in CR&D reported significant expectations of profitability, these would need to materialise at scale. Moreover, self-reported expectations on profitability need to be tempered by findings on the reported effects of FBC on production capabilities and technological development.

Finally, and to keep this and future evaluations in perspective, it should be recalled that automotive and related value chains account for around 1% of UK Gross Domestic Product (GDP). In terms of expected effects on overall GDP, it is unlikely that the sum of all automotive-related interventions (i.e. including the ATF and other elements of the Automotive Sector Deal) will amount to more than a fraction of a percentage point of GDP. This is consistent with the effects attributable to similar policy changes. Spillovers may contribute to limiting additional effects. This reinforces the need for realism and circumspection when it comes to expectations about effects on headline indicators such as GDP and the value in a contribution approach that takes account of a variety of impact indicators.

Taking stock of FBC after phase 1

As already observed, FBC is a complex intervention. This reflects the complex needs associated with establishing new industries at scale and the need to address multiple market failures. FBC has helped to create a policy framework around batteries, including the prospects of support, which in turn creates expectations that this is a growth area. That is seen in the activity of investors in relation to start-ups, IP metrics, reported expectations of profitability and, to some extent, in forward announcements regarding gigafactories. FBC has also reshaped the landscape for R&D, particularly in regard to collaborations. These are all impacts that are unlikely to have been observed without FBC.

Despite some clear signs of progress, commercialisation at scale of new or breakthrough technologies continues to be a substantial challenge, and it is the key one to address in order to achieve the overall objectives pursued by FBC and the UK more generally. Skills gaps remain a substantial issue and may constitute a significant constraint. FBC's activities can help to address these and, in that sense, the UK may be in a better position to address these issues than it would have been in the absence of FBC.

An interim evaluation of FBC carried out in 2020 already made substantially similar points in relation to both strengths and weaknesses, particularly the continued challenge of commercialisation, which had been identified at the inception of FBC. The main issue for the UK is that, while there has been progress since inception and since the interim evaluation, this is in a context of increasingly ferocious international competition in this space. This competition pits the UK against jurisdictions such as China, the EU and the USA which have advantages of market scale over the UK. It is also not feasible for the UK to enter into a subsidy war with these jurisdictions. The window of opportunity for the UK to establish its presence in the group of leading large-scale battery producers is therefore narrowing. It will also need to find its place in a broader ecosystem which involves value chains and which may have these larger jurisdictions as their centre of gravity. In that context, having a structure such as FBC will likely leave the UK in a better position to meet these challenges.

To do this, there may need to be various adjustments to how FBC functions. A key issue will be the ability of UKBIC to help the UK meet the commercialisation challenge. Some of the efforts already initiated, such as adaptations to the scale of the facility and initiatives relating to skills, are important steps. The balance between financial sustainability versus "mission UK" is also a key question that needs to be clarified. By this we mean that a narrow focus on UKBIC covering its operating costs, and maximising utilisation rates to do so, may detract from working on projects that have a greater public benefit but lower financial returns.

FBC will also need to take account of matters that lay somewhat at the periphery of its remit in phase 1 but which are now central. These include, notably, recycling and circular economy matters, and compliance with sustainability standards more generally. The extra-territorial reach of measures such as the EU's sustainable batteries initiative will make access to EU markets conditional on demonstrating compliance in relation to production and process methods across the value chain as a whole.

Finally, as repeatedly observed by stakeholders, the impact on battery development of broader policy factors and external developments is a key matter, even if not all these factors or developments are within the UK's control. This context reinforces the need, in addition to any reforms in the way FBC operates in its second phase, for the UK to ensure that appropriate supporting policies are in place. These are both domestic and external ones. With regard to the latter, ensuring that the UK is not isolated in an increasingly fragmented system of global economic governance is likely to be vital for attracting manufacturing value chains.

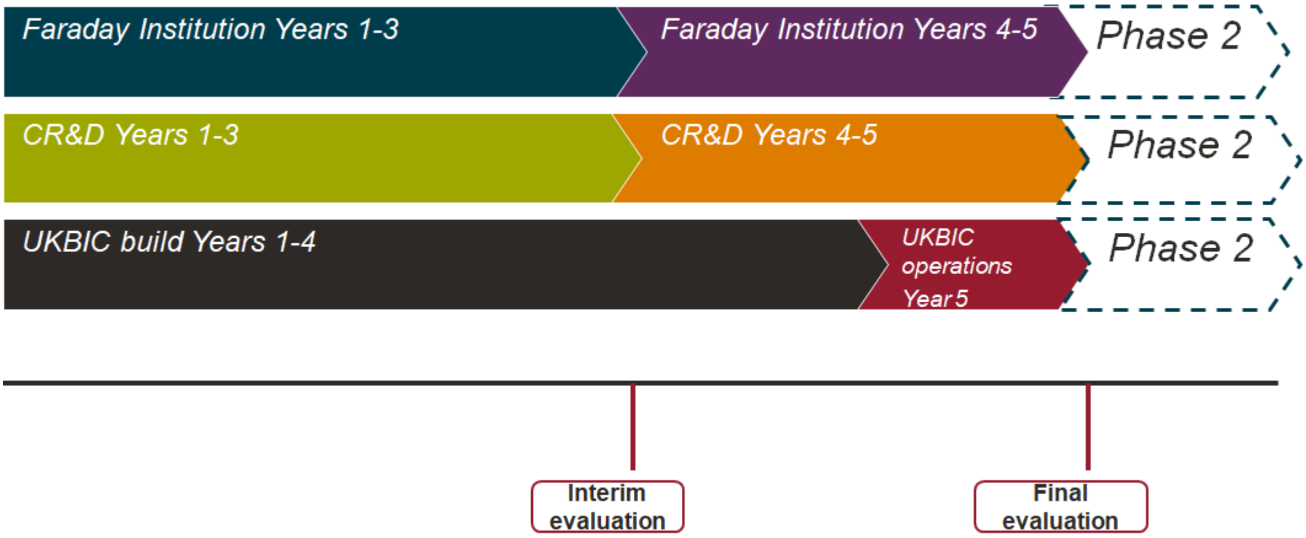
1 Introduction

1.1 Background and objectives

Frontier Economics, E4Tech and BMG were retained by UK Research and Innovation (UKRI) to undertake an impact evaluation of phase 1 of the Faraday Battery Challenge (FBC). Phase 1 of the Challenge ran from 2017 to 2022. Phase 2 will run from March 2022 to July 2025.

The evaluation took place over three stages: the development of the evaluation framework (delivered in July 2020); an interim evaluation delivered in March 2021; and a final evaluation, which took place from autumn 2022 to early 2023. The timing of these evaluation exercises in relation to the phasing of the Challenge is depicted in Figure 2 below

Figure 2 The Faraday Battery Challenge and the timing of evaluation activities



This final evaluation covers the whole period of phase 1, from 2017 to 2022. The evaluation framework, developed in 2020, follows a theory-based approach which supports a contribution analysis. By this we mean that the evaluation draws on an overarching theory of change which sets out the rationale for the intervention and objectives that are sought. In interventions such as FBC, which operate over multiple years and for which impacts may take multiple years if not more than a decade to manifest themselves, a theory-based approach is useful as it helps to identify the specific mechanisms through which the intervention contributes to a range of desired impacts over different time horizons. The approach also identifies different sources of information that can be used to evaluate the extent of these impacts and thus the contribution of the Challenge to these impacts.

The approach is in line with HMG guidelines as set out in the *Magenta Book*. As the *Magenta Book* states, "*Theory-based methods tend to be particularly suited for the evaluation of complex interventions or simple interventions in complex environments. In these situations, where determining the effect size can often be difficult, theory-based methods can confirm whether an intervention had an effect in the desired direction. For many of these methods, the aim is not to provide definitive evidence that the entirety of any measured change can be attributed to the intervention. Rather, they aim to explore whether the intervention definitively contributed to the measured change.*" [1]

A contribution analysis is counterfactual in nature. We seek to establish how far observed impacts differ from what they would have been in the absence of the intervention over the period of interest (i.e. from the inception of the Challenge in 2017 until 2022). As already observed, an interim evaluation was undertaken in late 2020/early 2021 and, for reasons explained in Section 2, it is relevant to take account of these findings and developments since then when undertaking this final evaluation over phase 1 as a whole.

As depicted in Figure 2, one major development since the interim evaluation is the launch of the operations of the UK Battery Industrialisation Centre (UKBIC). The launch had already been built into the evaluation framework through a series of indicators that were developed to track the activities of UKBIC and their outcomes. This was supplemented by further baseline work in 2021.

The commencement of UKBIC nevertheless introduced a significant new dimension to the evaluation, and one that is closely connected to a critical aim of the Challenge: bridging the gap between research and development (R&D), on one hand, and the commercialisation of new technologies, on the other, by addressing the problem of scaling up.

Consistent with the evaluation framework, we followed a mixed methods approach, drawing on surveys, stakeholder consultations and the analysis of data based on management information and industry and official data sources.

1.2 Structure of this report

The report is structured as follows:

- Section 2 sets out the context for the evaluation, including the theory of change and the policy context.
- Section 3 presents findings against the evaluation themes.
- Section 4 concludes.

---

[1] HMT (2020), *Magenta Book – Central Government Guidance on Evaluation*, p 43.

2 Context for the final evaluation

2.1 Overview of the Challenge

The Faraday Battery Challenge (FBC) is part of the Industrial Strategy Challenge Fund (ISCF). The ISCF is the vehicle through which the UK Government sought to invest £4.7 billion in the period from 2017 to 2021 to support the objectives set out in the Industrial Strategy White Paper[2] published in 2017.

FBC was initially allocated a funding envelope of £246 million, divided across three strands:

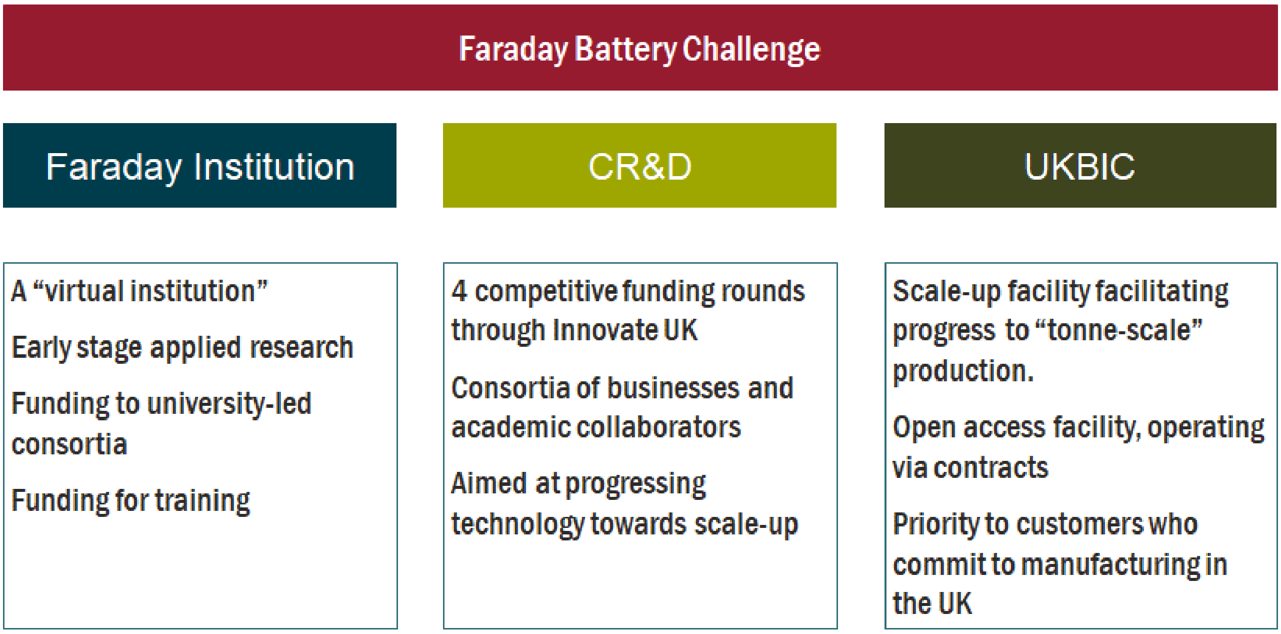
- Research (£78 million) managed by the Faraday Institution (FI). FI opened in May 2018, and scaled up to coordinate the activities of over 500 scientists in 27 institutions collaborating with over 50 businesses working on ten large-scale research projects, delivering seed funding, studentships, industrial sprints and entrepreneurial fellows.
- Collaborative Research and Development (CR&D, £88 million), which disbursed funds across four funding rounds covering feasibility studies and research and development (R&D) from inception to March 2022.
- £80 million for the UK Battery Industrialisation Centre (UKBIC), a facility for scaling up battery manufacturing which began operations in July 2021.

Largely in response to the effects of Covid-19, funding to each of the strands was increased in 2021, taking the allocations to £110 million for FI, £90 million for CR&D and £130 million for UKBIC, giving a total funding envelope of £330 million. The period over which the funding applied was extended to March 2022, and the period 2017-22 thus marks phase 1 of FBC. In July 2022, FBC phase 2, covering the period 2022-25, was formally approved.

The structure of FBC is summarised in Figure 3 below. More detail on each strand and on FBC as a whole can be found in Annex A.

2 The White Paper can be accessed here.

Figure 3 The Faraday Battery Challenge and its strands



The FI operates as a virtual institution, in the sense that its activities are not housed in a physical structure but are conducted through its collaborating institutions. Its focus is on applied early-stage research, at lower technology readiness levels (TRLs).[3] FI awards funding to university-led consortia to deliver applied research projects that are aligned to industrial needs. In addition, it provides funding for training programmes to grow a talent pipeline for UK energy storage R&D. Training includes provision of a four-year structured support programme for PhD students involving research on battery-related topics and training in work skills as well as training programmes for undergraduates.

The aim is to reduce the fragmentation of research and to foster collaboration and coordination of the UK research landscape across multiple disciplines and institutions. By harnessing and developing the UK's strengths in basic research, FI seeks to increase the likelihood of achieving major breakthroughs in battery technology which would help to secure the UK's position as a location for battery manufacturing. This in turn would enhance the UK's ability to attract, retain and capture value from electric vehicle (EV) manufacturing.

FI has three principal research streams:

- Optimising current-generation lithium-ion batteries. This consists of five focus areas: extending battery life, multi-scale modelling, recycling and reuse, electrode manufacturing, and lithium-ion cathode material;

[3] TRLs are a scale to assess the maturity level of a particular technology. Technology is usually embodied in a project. Therefore, any particular project is evaluated against the parameters for each technology level and is then assigned a TRL rating. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.

- Beyond lithium-ion: new-generation battery technologies. This consists of solid-state batteries, sodium-ion batteries, and lithium-sulphur batteries; and
- New battery-focused characterisation and analytical techniques intended to provide researchers with the tools to enhance their understanding of battery materials and their performance.

The CR&D programme is managed by Innovate UK and focuses on mid-TRL projects. The projects so far have been working on improving battery lifespan and range as well as the reuse, remanufacture and recycling of batteries at their end of life. The overall aim of CR&D is to ensure that UK battery technology is brought closer to market and that the supporting ecosystem to do this is developed. CR&D allocates its funding through competitive funding rounds. Four rounds have been held, in July 2017, January 2018, September 2018 and September 2020.

UKBIC is the third strand of the FBC, which was launched in 2017 with the ambition of making the UK a world leader in battery technology. UKBIC formally launched its operations in July 2021, later than originally planned, largely reflecting the effects of the Covid-19 pandemic. It is located in Coventry.

The UKBIC concept is itself experimental and a first of its kind globally. Apart from its linkages to the other two strands of FBC, its distinguishing features include the fact that it offers specialist services to support scaling up new battery technologies based on open access principles. In practice this means that customers pay UKBIC for the use of its facilities for activities to support scaling up. Once these activities have been completed, the investor is then responsible for large-scale production through its own facilities. UKBIC is intended to support the progress from lab conditions to mass production by enabling users to move to tonne-production.

UKBIC does not enter into large-scale production contracts and does not benefit from any intellectual property (IP) rights (e.g. through licensing). The protection of IP generated by customers is seen as a key selling point for UKBIC to customers over alternatives, particularly in Asia.

The main factor that UKBIC takes into account when considering partnerships with customers is the extent of their commitment to manufacturing in the UK, with priority given to those who make such a commitment. UKBIC management also conducts due diligence on potential contracting partners to screen them for financial and technical capacity.

The three-strand structure of the Challenge reflects the range of market failures that are involved in technological change and industrial transformation. As noted below, this involves transforming the landscape for R&D, notably reducing the fragmentation of research and increasing the quality of outputs; stimulating collaboration between academia and industry; and overcoming the obstacles to commercialisation. The last of these includes the process of moving from technologies that work at laboratory scale to those that work at industrial scale (i.e. a scale that requires eliminating significant variation in performances of technologies trialled at lab scale).

The range and specificity of these issues provides a rationale for the strands, which each have their areas of focus. At the same time, there are clear interdependencies across the functions played by the strands, hence the need to have an overall governance structure. This overall governance structure is found in the programme board, which in turn performs several functions: it coordinates the Challenge as a whole and helps to harness interdependencies, and it can draw on the experience of the Challenge as a whole to help develop policy frameworks and to engage in outreach.

2.2 Theory of change and evaluation themes

2.2.1 Overview of theory of change

The theory of change that underpins FBC and our approach to evaluation was the result of specific work conducted in 2020 in support of a revised evaluation framework. The main features of the theory of change can be summarised through the following propositions:

- The UK has legislated a target of net zero emissions by 2050 and, as part of this process, has committed to phasing out the sale of new vehicles using internal combustion engines (ICEs). It has also implemented a plan to decarbonise transport more generally.
- The UK has a comparative advantage in motor vehicles and related value chains. This in turn means that specialisation in these sectors involves a more productive use of resources (labour and capital) in the UK, and therefore will stimulate economic growth faster than if these resources were directed elsewhere.
- However, comparative advantage is a dynamic phenomenon. With the phasing-out of ICEs, motor vehicle manufacturing and related value chains need to be transformed to meet the technical and commercial requirements of a zero emissions industry. There is no guarantee that just because a country has been able to produce something in the past, it will continue to do so in the future.
- Whether zero emissions vehicles will be manufactured at scale in the UK is dependent on a range of factors, both technological and policy related. Among the former is the ability to access battery manufacturing at scale. This is a critical condition given the costs of transporting batteries and the share of batteries in the value-added of a motor vehicle. The UK will need therefore to attract investment in gigafactories that produce batteries at scale.
- Battery producers will be able to capture more value-added from motor vehicle value chains if manufacturing embodies advanced technologies. These would allow the UK to offset the attractiveness of alternative locations for gigafactory investment that may compete on costs. Advanced technologies will also help to address the technical constraints on battery performance that in turn constrain the uptake and commercial viability of zero emissions vehicles. They could also enable the deployment of batteries in other areas of transport.
- Stimulating the manufacture of batteries that embody breakthrough technologies requires a systemic transformation of the UK's battery R&D landscape. This includes reducing fragmentation in research and increasing its impact, developing industry-research partnerships and addressing the bottlenecks that often impede the commercialisation of research. These bottlenecks centre around the challenge of moving technologies from laboratory level to commercial deployment at scale. Beyond the effects on the commercialisation of new technologies, improvements to the R&D landscape can have benefits in and of themselves in terms of efficiencies.

- Attracting investment in new technologies and transforming the processes that generate these are plagued with market failures (see box below). These involve incomplete and asymmetric information, capital market constraints, lack of skills, spillover effects and coordination problems. meaning that investment and production may stagnate at economically inefficient low levels.
- These in turn provide a case for government support, designed to provide a "big push" to break out of the stagnation trap.[4] Moreover, investment dynamics tend to be self-reinforcing. Addressing the constraints to investment may increase investment but may also stimulate further investment through linkages and through the deepening of skills markets. By contrast, stagnation can also be self-perpetuating if investment is attracted to other locations.
- The disruption brought by new technologies and related value chains can lead to an unequal distribution of benefits and costs across societies. Intervention is needed to ensure that the transition process is a fair one and that opportunities created are not concentrated in a few specific locations.

[4] The "big push" idea reflects the view that multiple market failures lead to economic activities stagnating at a relatively low level of development, and that coordinated interventions are needed to remedy these. See for example Gans, J. (1998). Industrialization Policy and the "Big Push". In: Arrow, K.J., Ng, YK., Yang, X. (eds) *Increasing Returns and Economic Analysis.* Palgrave Macmillan, London. https://doi.org/10.1007/978-1-349-26255-7_17

Box - Examples of key market failures

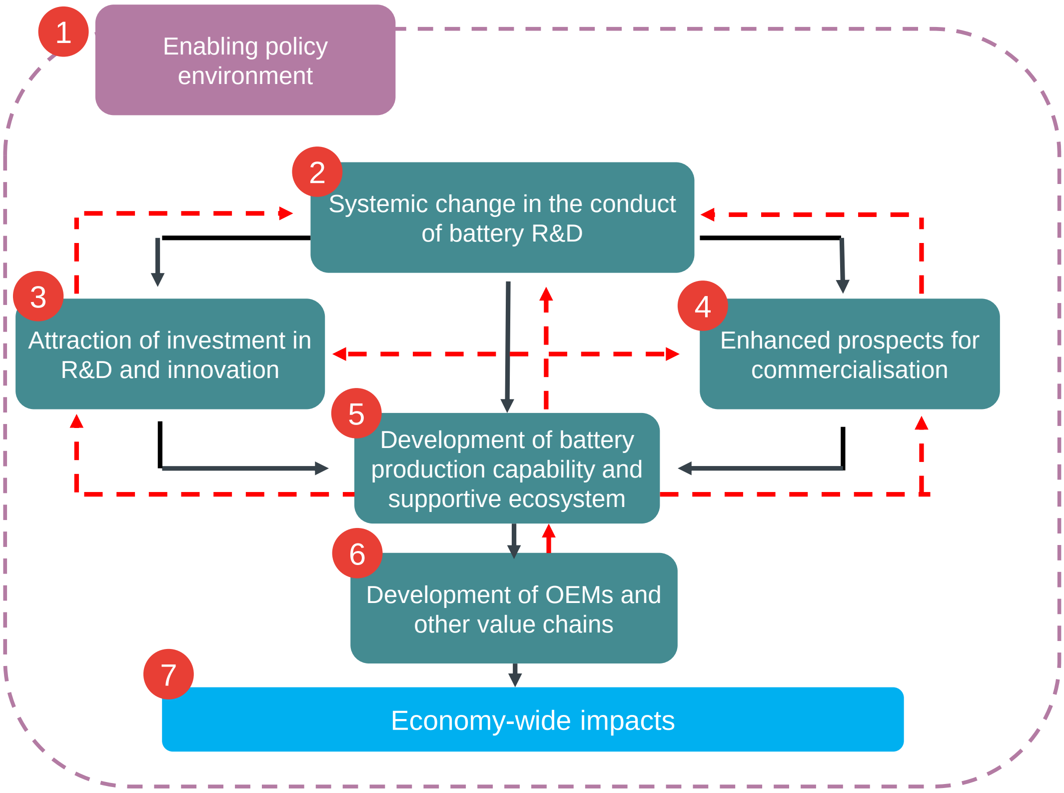
- **Coordination problems** arise when investors are unwilling to commit resources if they are unaware or uncertain of the actions of other investors. In particular, if investments are not reversible (i.e. their costs cannot be recovered or can only be recovered partially), deferring investments is attractive because it preserves the option of committing at a later date when more information is available. But, if multiple investors act in this way, investments may face lengthy delays and/or occur at inefficiently low levels.
- **Incomplete or asymmetric information**: building on the above, actors in value chains, as well as financiers, need to enter into relationships e.g. between suppliers and producers. Because nobody has complete information, it is not usually possible to write complete contracts. It may also be difficult to insure against specific forms of risk, especially in relation to new activities.
- **Spillover effects** reflect the fact that industrial transformation typically requires investment in innovation and knowledge inputs. The returns to these investments may be partially secured through intellectual property rights (IPRs). IPRs are unlikely to be effective in securing returns to investments at low levels of technology readiness.
- **Capital market constraints** refer to the fact that investors may find it difficult to mobilise financing on the scale required. Investments in transformative technological development necessarily involve many parties taking a number of “bets”. Some of these will not pay off, but those failures are valuable to the process of learning generally, even if not for a particular individual business or institution. Financial markets will typically not consider these wider, more socially valuable aspects of investment.

On the basis of this theory of change, we developed seven evaluation themes to inform the contribution analysis for impact assessment. These themes were informed by:

- A series of logic models for each of the strands and FBC as a whole. The purpose of these models was to provide a schematic representation of the intervention, linking inputs, activities, outputs, outcomes and impacts. The logic models are presented in Annex A. The logic models help to understand the functioning of the intervention and, of particular relevance for a contribution analysis, help to identify nearer-term outputs and outcomes that can act as predictors of longer-term impacts which may not be observable within the timeframe being evaluated.

- Interviews with industry participants and those involved in the delivery and design of FBC to identify, in the light of the theory of change, what conditions were particularly important to the success of the Challenge. This in turn helped to narrow down the wide range of metrics that could potentially have been considered on the basis of the logic model to a subset of ones that are particularly material to the success of FBC. These metrics could then be grouped into the evaluation themes as described in Figure 6 below.

Figure 4 Theory of change and seven evaluation themes



The figure captures the interdependencies between the different evaluation themes and the extent to which the effects are dynamic and self-reinforcing. Progress on any theme affects and is affected by several others. The interactions and feedback loops reflect the fact that technological change and industrial development can have self-reinforcing effects. Systemic changes to the conduct of battery R&D can raise the possibility of technological breakthroughs, which in turn attract investment in R&D and innovation, enhancing prospects for commercialisation. That in turn could contribute to the development of productive capabilities and supportive ecosystems. The development of these ecosystems and the spillovers they create further reinforce commercialisation prospects and can further support the systemic changes in R&D.

The blue bar reflects the overall impacts that are ultimately sought: economy-wide benefits such as economic growth, employment and wages.

The hatched line represents the "system boundary", i.e. the limits of the intervention. Beyond these limits lie other factors that affect the extent to which FBC can generate economic benefits. As highlighted in the framework report and the theory of change, it was recognised from the outset that FBC on its own would be unable to deliver the impacts sought. Even within the sphere of automotives, other interventions such as the Automotive Transformation Fund (ATF) were needed to provide direct mechanisms for financial support. Beyond that, the attractiveness of the UK as a location for investment in batteries and related value chains would be determined by broader policy settings in the UK, notably on trade, investment, labour markets and skills, and by the interplay between these and the policies of other countries, notably those that are rivals in the race to snare battery and EV value chains. As will be seen in this report, one of the particularities of the period over which the first phase of the Challenge took place is the profound instability that characterised many of these broader factors.

2.3 Explanation of evaluation themes

Each of the evaluation themes is linked to the theory of change. Progress against these themes is a way of measuring the impact of the Challenge. We provide a brief description of each theme.

2.3.1 Establishment of an enabling policy framework

A variety of market failures affect the development of battery and related value chains, and this in turn requires a number of coordinated policy interventions. In particular, interventions that support innovation need to be coordinated with trade, investment and environmental policies. A number of these interventions can be influenced by FBC actions, particularly those that relate to policy development and outreach activities carried out by the strands or the leadership of the Challenge as a whole. The aim of this evaluation theme is to track progress in the establishment of an enabling policy framework to stimulate investment in UK battery manufacturing, the anchoring of original equipment manufacturers (OEMs) in the UK and growth in related value chains such as chemicals.

2.3.2 Systemic change in conduct of battery R&D

This theme reflects the ambition of FBC to generate transformational change in the way in which R&D is undertaken in order to deliver breakthroughs in battery technology. There are several aspects to the transformation:

- A reduction in the fragmentation of R&D across multiple institutions working in isolation. The trend to collaboration, on one hand, is balanced, on the other, by competitions for funding, which are important to stimulate efficiency and to deliver value for money under government guidelines and under state aid rules;
- An increase in industry-academic collaboration, both in research activities and product development through placements and rotations;
- Harnessing of interdependencies across TRLs and from basic research through to commercialisation; and
- International collaboration within both academia and industry.

2.3.3 Attraction of investment in R&D and innovation

This evaluation theme tracks the extent to which resources are mobilised and committed to R&D and innovation by businesses operating in the value chains that are impacted by FBC. These resources can be human, physical and financial capital. The focus is primarily on private investment. This picks up on the idea that public support and interventions can unlock private investments in R&D and innovation by addressing some of the market failures documented in Section 2.2.

Sources of R&D investment will vary. Some of these will be multinational enterprises (MNEs). This is in line with trends seen over the last two decades. The role of MNEs in turn highlights the importance of policy frameworks to attract R&D investment.[5] Other sources include venture capitalists investing in start-ups.

2.3.4 Enhanced prospects for commercialisation

A recurrent theme in consultations was the recognition that, despite the UK's strengths in basic science and research, it has experienced difficulties in bringing innovations to a state of market-readiness. The scalability of production and large-scale testing were particular pinch points. References to the eight UK Automotive Council battery targets are also valid under this heading, as one of the medium-term aims of FBC is to ensure that breakthroughs against these targets are brought to a point of commercial viability.

The sequential structuring of the Challenge is intended to address this problem. This explains why links to the logic models of all three strands feature under this heading.

2.3.5 Development of battery production capability and supportive ecosystems

Global value chains are the driving force behind battery and EV manufacturing. The policy objective is not solely to attract these value chains but to ensure that the UK is able to capture value from them. The extent to which the UK can capture its share of value-added depends, in part, on the extent to which it can develop ecosystems of businesses supplying inputs (whether physical products or services) to these value chains. The quality of inputs provided will in turn increase the likelihood of anchoring these value chains. This is important as the UK is in competition with other jurisdictions that potentially have lower operating costs and/or direct access to larger markets. Investors may be willing to pay a premium on inputs if their quality is a source of competitive advantage.

Small and medium-sized enterprises (SMEs) are a particular focus under this heading. This is because they account for the large majority of businesses by number, and because their participation in value chains could offer them a route to global markets and the internationalisation of their operations, which they might otherwise lack.

2.3.6 Development of OEMS and other value chains

Along with gigafactories, the development of these value chains is the major prize as far as industrial strategy is concerned. Attaining this prize still lies several years in the future. Therefore, the principle objective at this stage of the evaluation is to develop a base of information that can help to assess the likelihood of this happening and to provide a platform for future evaluations. Recent

5 See for example OECD (2005), The Internationalisation of Business R&D: Evidence, Impacts and Implications.

announcements regarding cell manufacturing ventures fit into this leading indicator category along with assessments of investor contacts by FBC strands, notably UKBIC. Narrative information from case studies is likely to be needed to establish the materiality of FBC's interventions.

2.3.7 Economy-wide impacts

These impacts, in terms of employment, productivity and growth, are the overarching objectives of policy interventions. They are the determinants of the value for money achieved. The most direct channel through which these will be achieved is via the growth of battery production and the expansion of value chains. Indirect channels include the effects that systemic changes to science and research capacity and innovation can have on an economy-wide basis (through spillovers) across various sectors.

It will take time for these higher-level impacts to materialise. For the most part, therefore, the metrics in this evaluation theme will relate to future evaluations. However, collection of data in the current evaluation phase will help to develop baselines that support future evaluations. Collection of data from official sources can begin once the second phase is underway.

2.4 Broader contextual setting for the evaluation

It is necessary to consider the broader contextual setting for several reasons: (i) it will have an effect on metrics associated with the evaluation theme, and the issue will be to disentangle these from the effects of the Challenge proper; and (ii) related to this, the broader contextual developments are also useful to consider when developing the counterfactual scenario, i.e. what would have happened in the absence of the Challenge.

2.4.1 Domestic policy

Industrial policy interventions relating to automotives

Beyond the Industrial Strategy referred to in Section 2.1 (and which has formally ended both with the abolition of the Industrial Strategy Council and the Department for Business, Energy and Industrial Strategy functions now being split across other departments), the overarching policy context is set by the UK's net zero emissions target by 2050 which was legislated in 2019. In the aftermath of the economic shock caused by Covid-19, in 2020 the government announced a Ten Point Plan for a Green Industrial Revolution, which includes commitments in relation to the automotive sector. A Net Zero Strategy was published in October 2021, which included inter alia a commitment to ban by 2030[6] the sale of new vehicles using ICEs, promoting the use of sustainable aviation fuel and investing in clean electricity and hydrogen.

[6] The intention to phase out ICEs was first stated in 2017, with the initial timeframe being set for 2040.

In relation to the automotive sector, the imperative to achieve transformative technological change to enable the transition to net zero and support the continued presence of automotive value chains in the UK led to a series of supporting interventions beyond FBC. These include, notably:

- The establishment of an Automotive Transformation Fund (ATF) in 2020. Under this, the government has already allocated £500 million and made further commitments of up to £350 million.[7] The ATF has two strands:
  - Funding for R&D and feasibility work, aimed at providing findings that can be used to help businesses realise commercial opportunities in the EV supply chain in the UK and demonstrate the feasibility to invest through pilot scale projects; and
  - Capital grant funding, aimed at directly supporting capital investment in the EV supply chain in the UK.
- The Driving the Electric Revolution (DER) Challenge aims to be the catalyst for building £5 billion more power electronics, machines and drives (PEMD) products in the UK by 2025, encouraging industry across all sectors to invest and collaborate with academia to establish a PEMD supply chain. DER supports PEMD in multiple industries, including automotives.

The Ten Point Plan contained an overall commitment to a £2.8 billion funding package over the period to 2030, including the funding for ATF and £1.3 billion to extend the charging infrastructure for EVs.

Other factors

The Covid-19 pandemic and associated response measures (notably travel restrictions and restrictions relating to the workplace) had a significant impact on industrial activity in 2020 and 2021, particularly in trade-oriented sectors. This may have had some impact on collaborative research activity, and clearly hampered the launch of UKBIC. At the same time, responses to the slump in economic activity spurred an increase in government spending, notably via its Build Back Better strategy, which fed into the Ten Point Plan discussed above.

The UK also experienced periods of political instability, which may have adversely affected investor perceptions of the country, notably in the summer and autumn of 2022. A very extensive literature on investment underlines that instability – notably around long-term settings in fiscal and monetary policy – will induce investors to postpone or reconsider investments.

Finally, external energy price shocks and inflationary pressure resulting from this (see below) added to economic uncertainty.

2.4.2 External developments

At the time of the launch of the Industrial Strategy, the future relationship between the UK and the European Union was uncertain. The working assumption, as reflected in the government's 2018 White

[7] See DIT (2022), Automotive Roadmap – Driving Us Forward, p. 12.

Paper, was that there would be a deep free trade agreement in goods. This would have involved zero tariffs, liberal preferential rules of origin and regulatory alignment between the UK and the EU.

In the event, the Trade and Cooperation Agreement (TCA) signed by the parties in late December 2020 brought a measure of stability. In particular, for the automotive sector, it ensured duty free market access to the EU and allowed EU inputs to count toward originating content for the purposes of preferential rules of origin. That in turn helped to minimise friction in UK-EU value chains. Tighter product-specific rules of origin that govern how much non-EU and non-UK content can be used while still maintaining duty free access to the EU will be phased in in 2024. At the same time, the TCA represents a much lower level of integration between the UK and the EU than was previously enjoyed and than had been envisioned in the 2018 White Paper. Withdrawal from single market provisions for the movement of people adversely affected the supply of skills in the UK. Along with changes to border administration processes and withdrawal from single market disciplines on services including transport, this also adversely affected logistics functions in the UK, constraining the availability and raising the cost of inputs including components. The TCA is also subject to review, and parts of it may be suspended if one party is deemed not to be complying with its provisions. Moreover, the TCA allows various ways through which either party can take action against the subsidy measures used by other parties. This includes the subsidies provided under FBC and the ATF.

At an international level, economic relations between countries have become significantly more fragmented. The rise of geo-strategic concerns in the wake of Russia's invasion of Ukraine and longer-standing concerns in industrialised countries regarding China have led to the imposition of restrictive policies in relation to technology in the form of investment screening and export controls. These will undoubtedly make the operation of international value chains more complex and costly, which in turn will drive the role of cost factors in determining investment location. The UK, along with most other OECD countries, has also implemented investment screening measures, which may increase the uncertainty associated with investments in priority sectors, such as batteries, that are subject to ex-post reviews.

The same set of concerns has also led to an escalation in the use of subsidies in the area of "green tech" including batteries and EVs. Indeed, international competition via subsidies is now fierce, as demonstrated notably through the US Inflation Reduction Act. At the same time, various jurisdictions, notably the EU, are enacting policy frameworks that target the use of subsidies by partner countries.

Finally, the confluence of the energy price shock following Russia's invasion of Ukraine, supply-side shocks, reflecting the impact of China's zero Covid-19 policy, on manufacturing and shipping at a time of escalating global demand for goods, tight labour markets globally, and a scarcity of certain critical inputs (such as microchips) means that FBC has been implemented at a time of escalating cost factors and there is therefore greater sensitivity to cost in determining investments.

2.5 Establishing the counterfactual

The impact evaluation is a counterfactual analysis: we wish to understand the extent to which the benefits objectives achieved by the Challenge would have been achieved in the absence of the Challenge. As we identified seven evaluation themes and metrics within these to assess progress against these outcomes, the counterfactual analysis consists of understanding how far progress against these metrics would have been achievable in the absence of the Challenge. The baseline for the counterfactual comparison against these metrics is the state of the world in 2017.

The counterfactual is necessarily unobserved and hence we need to make several informed conjectures regarding what the state of the world may have been in the absence of the Challenge. While this is explored on a thematic basis in the main results section, the theory of change sets some broad parameters.

The counterfactual would still involve government support for the automotive sector and battery development

Several key elements of the support infrastructure for batteries and low or zero emissions vehicles predate FBC. The Advanced Propulsion Centre was established in 2013 and the Office for Zero Emissions Vehicles was established in 2009. Both have historically provided funding to support R&D in batteries and prospects for their commercialisation. Moreover, the government's willingness to provide funding for EVs and related value chains is likely to have led to the creation of other institutions, including the ATF. However, a question that clearly needs to be examined is how far FBC may have contributed to such institutional development (e.g. in terms of scope, focus, speed, resources, etc.). It seems likely that, given the actions taken by partners in recent years to support battery investment and zero emissions vehicles and transport modes, the UK would have also followed suit.

Alternative structures for FBC and its strands may have been envisioned in the counterfactual

FBC follows a particular strand structure, reflecting the fact that there are efficiencies when institutions specialise in specific tasks. Thus, while it is likely that the strand structure would have been retained in a counterfactual world, its characteristics may have differed. This is notably the case for UKBIC, whose structure is recognised as being experimental (i.e. work done on a contractual basis with an ambition to achieve financial self-sufficiency, in the sense of covering operational costs). Alternatives include subscription models or an approach that relies more heavily on government funding.

We assume that domestic and international policy developments would have also taken place in the counterfactual

Neither the external developments nor the non-industrial policy developments can be sensibly said to be linked to FBC. Regarding industrial policy developments, while these largely reflect decisions prior to or independent of FBC, a question that remains to be explored (in line with the first evaluation theme) is how far FBC was able to influence the domestic policy framework. More generally, the issue is whether, given these policy developments and external shocks, FBC has improved the UK's resilience to their effects on battery production and related sectors and is better placed to take advantage of them.

It is relevant to consider trends between the interim evaluation and the final report

While the overall evaluation is against a counterfactual scenario with a baseline in 2017, it is also useful to take advantage of the interim evaluation findings to assess the rate of progress between the interim and final evaluations relative to the counterfactual. This is for two reasons:

- As highlighted in the theory of change, the rationale behind the interventions embodied in FBC is to deliver a big push which would enable technological breakthroughs and industrial transformation. It is therefore relevant to consider the pace of observed change as slippages could point to limitations in the Challenge design, providing that other factors have not changed.
- UKBIC began operations shortly after the interim evaluation, and a specific 2021 baseline was established for it. At the same time, the commencement of UKBIC's operations was intended to give a boost to the Challenge as a whole, given the interdependencies between the strands. It is therefore relevant to consider whether, between the interim and final evaluations, there was a material change to the performance of the Challenge against the counterfactual.

3 Evaluation findings

3.1 Introduction

As already observed, the evaluation is based around seven linked evaluation themes. We specified metrics for each theme. Information and data for these metrics were gathered through three broad sets of approaches:

- **Surveys**, which aimed to provide an overview of the behaviours and perceptions of businesses and academics who had engaged with FBC. The sample included both successful and unsuccessful applicants to the Challenge and covered the FI and CR&D strands. Detailed explanations of the survey methodology and a description of the questions are found in Annex C

- **Case studies**, which involved interviews with senior representatives of battery sector stakeholder entities. The interviews included entities that had not engaged with FBC and those that had. For the latter group, we proposed "what-if" scenarios through interviews with FBC beneficiaries to ascertain what the counterfactual might have been (i.e. self-reported counterfactuals). Detailed explanations of the case study methodology are provided in Annex B .

- The application of survey and case study evidence to the evaluation themes is supported, where relevant, **by analysis of secondary data sources**. These data are sourced from a combination of public and proprietary databases, including – but not exclusive to – SciVal (institutional research performance), the Office for National Statistics (ONS), HM Revenue and Customs (HMRC) (value of exports) and the government's Intellectual Property Office (IPO).

Evidence from all three types of approaches was usually used in each of the evaluation themes. Triangulating between different sources is fairly characteristic of contribution analyses. Any particular evaluation theme usually requires a mix of evidence, as they reflect both quantitative and qualitative assessments.

3.2 Establishment of an enabling policy framework

3.2.1 Overview of metrics

Table 1 Summary of metrics and data sources for "establishment of an enabling policy framework"

Link to logic model	Metric	Data sources and methodology
(1) Cross-government policy frameworks for attracting gigafactories (Challenge Team output)	Qualitative assessments of robustness of policy framework	Horizontal case studies undertaken for this evaluation
(2) Policy community's understanding of value chains (Challenge Team outcome)	Qualitative assessments of understanding	Horizontal case studies and surveys of investor views of policy framework undertaken for this evaluation
(3) Investor interest (Challenge Team outcome)	Investor perceptions and assessment of investor journeys	Horizontal case studies and surveys undertaken for this evaluation. Metrics compiled by government departments and agencies.
(4) Public understanding and acceptance of battery technology and value chains (Challenge Team outcome)	Measures of public opinion	Surveys undertaken for this evaluation

3.2.2 Cross-governmental policy frameworks for attracting gigafactories

FBC is seen to be an influence in government and a driver of collaboration that has made substantial contributions to key frameworks and interventions

The evidence from the case studies and related stakeholder interviews suggests that FBC has succeeded in developing an information base for policymakers that in turn has contributed to shaping policy. For instance, the publication of its report UK Electric Vehicle and Battery Production Potential to 2040 was specifically identified as having informed policy discussions and interventions in relation to the establishment of the ATF (for more details see Section 3.2.2).[8] A foreign investor also reiterated the role that FBC played in demonstrating the need for the ATF and the benefits of this for creating an enabling environment for investment. A stakeholder also mentioned that it was thanks to FBC's work, which increased understanding of the field within the government, that Britishvolt was made a grant offer of £100 million through the ATF in January 2022.[9] Although Britishvolt subsequently entered into administration, the observation is indicative of the catalytic effects on funding that FBC can have.

FBC has also played a key role in strengthening the conditions for the development of skills and markets for these skills. These initiatives are documented in Section 3.6.6. Skills development is essential to attracting investment. Furthermore, processes for training and upskilling are important in order to facilitate the mobility of labour from other sectors (in which the UK may not have a comparative advantage and which may therefore shrink in the future) into automotives and battery sectors. That in turn helps to ensure that the growth benefits from specialisation in batteries and automotives and helps to address some of the distributional issues that arise when some sectors expand and others contract. FBC has also worked closely with the Department of Business and Trade (formerly the Department for International Trade) to improve the policy landscape for battery investment, partly in response to missing the opportunity to attract investment for Tesla in battery production.

Notwithstanding these benefits, interview responses suggest that some of the factors that limit FBC's influence on policy are coming more sharply into view. Some of these relate to weaknesses that would need to be addressed by flanking policies. For example, one stakeholder suggested that there was a lack of policy for building supply chains, resulting in private-mixed companies being left to their own devices to raise financing for capital expenditures, find partners and make the investment case. Others echoed longer-standing concerns about weaknesses in the journey from research to market. Thus, one stakeholder offered the view that the middle ground of development and proof of concept at scale is still incomplete. As a result, this could mean that companies are going elsewhere, for example to Germany, where the development ecosystem and accompanying skills exist. The skills issue is possibly being aggravated by the UK's withdrawal from the single market for labour. If this trend were to persist, the UK could miss out on the major growth and employment opportunities from batteries.

We conducted a survey, based on a range of factors that are influenced by cross-government policy frameworks, to gauge perceptions of the attractiveness of the UK for gigafactory investment. The survey was conducted in 2020 and 2022, and the results reported are those for 2022 (Figure 5). The survey was comparative in nature in that respondents were asked about their assessment of the UK relative to other countries which were potential destinations for battery investment.

The UK academic community's standing in battery-related disciplines was generally viewed favourably, as was the quality of its research output. Similarly, a sizeable majority considered the UK to be ahead of most, if not all, countries in terms of volume of ongoing research. Perceptions in relation

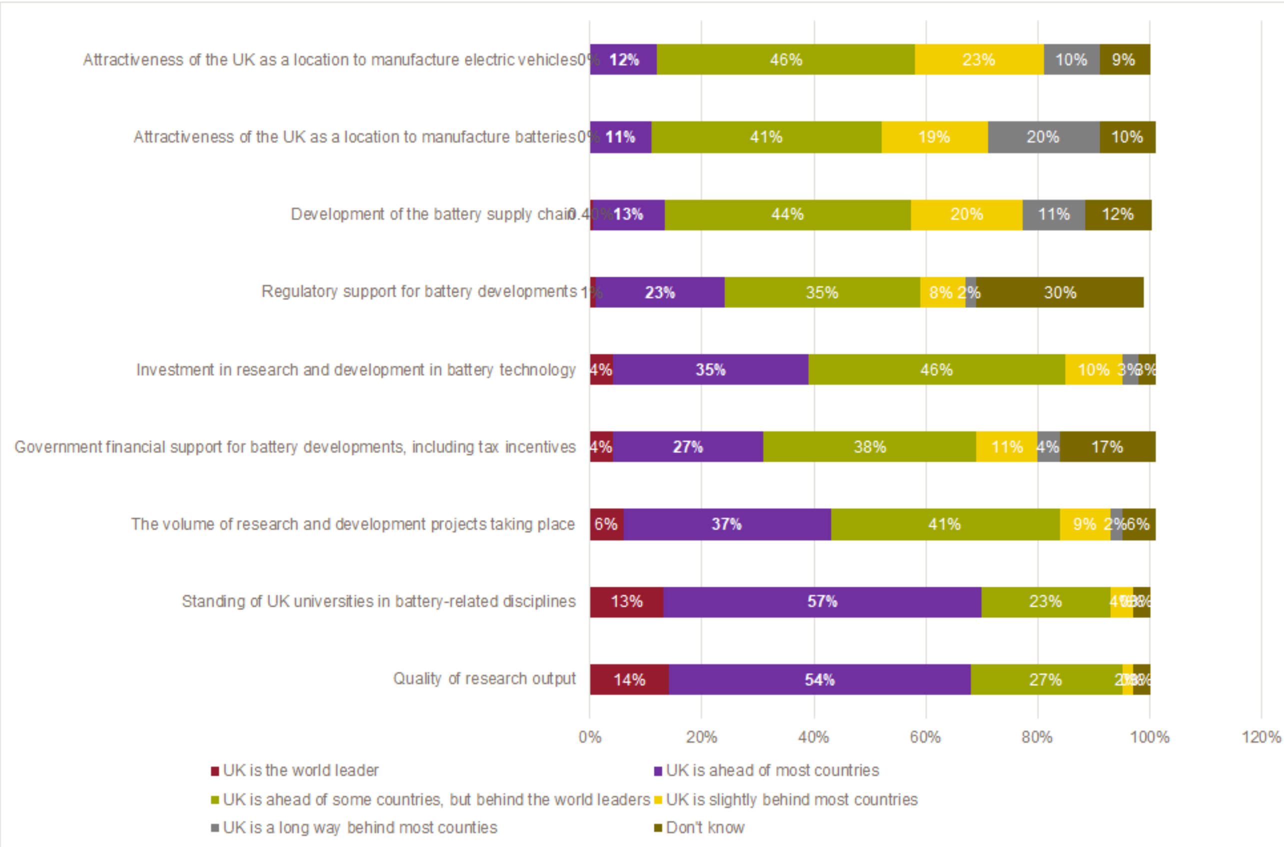
---

8 https://www.faraday.ac.uk/wp-content/uploads/2022/06/2040-Gigafactory-Report_2022_Final_spreads.pdf

9 https://www.gov.uk/government/news/final-grant-offer-provided-to-britishvolt

to other indicators were more mixed, with a larger proportion of respondents saying that the UK was ahead of some countries but behind others, and greater proportions saying that the UK was slightly or significantly behind most countries. This was most noticeably the case for perceptions regarding the attractiveness of the UK as a location to manufacture EVs and batteries and for perceptions regarding the development of battery supply chains.

Figure 5 Survey responses on the UK's performance across aspects of battery development and support



Source: Phase 3 Survey, Question B6

Note: Respondents were asked question B6: "I'm now going to read out some elements of battery technology development and support. For each, please can you tell me how you think the UK is currently performing in comparison to other countries?". The chart is based on data from 112 survey respondents.

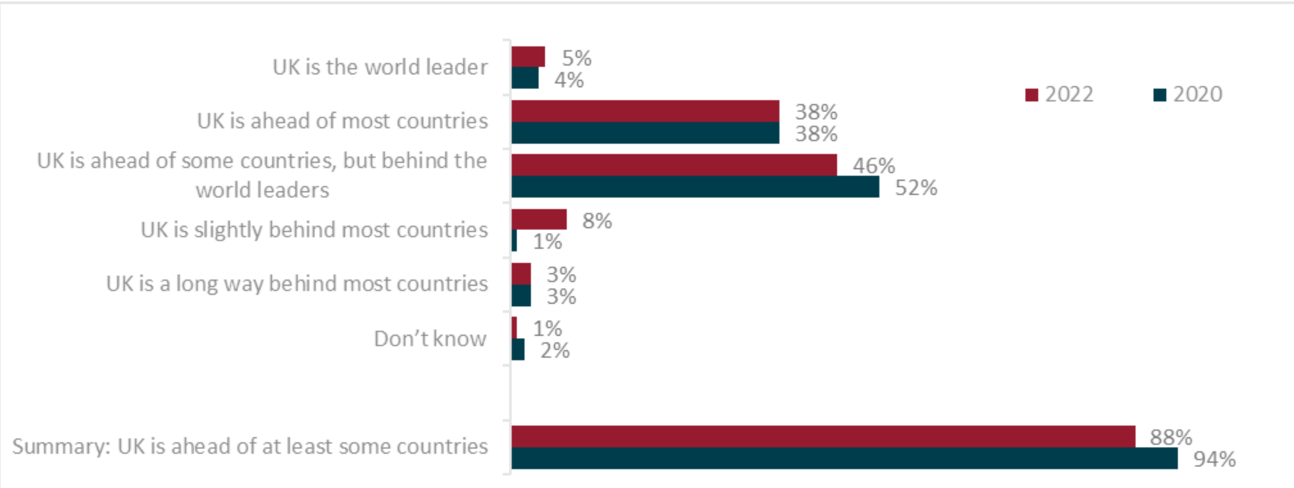
No survey was conducted in 2017, so a formal comparison with the baseline is not possible. However, as already documented in the theory of change, the baseline assessment was that the UK was particularly strong relative to comparator countries in the quality of its research and research institutions, but it faced greater challenges in establishing itself as a global leader in bringing these to market. This view was echoed both by the proponents behind the establishment of FBC and industry respondents.

The findings from the survey responses largely corroborate this view – with favourable perceptions more clearly visible in relation to the research end than the commercialisation end. That in turn suggests that there is still a substantial task left for the UK generally and FBC specifically in responding to the commercialisation challenge, which was one of the major objectives sought through the establishment of FBC. The extent of the task and the need for progress are brought out by the fact that perceptions reported in 2022 had not changed significantly from those reported in surveys in 2020.

The results explain why, while the UK is perceived as internationally competitive as a potential location for battery investment, it is not necessarily seen as a world leader or a battery superpower.

Survey responses to questions regarding the UK's reputation as a centre of innovation suggest a similarly mixed picture (Figure 6). Only 5% of survey respondents perceived the UK to be the world leader as a centre for innovation in battery technology. Overall, nearly 9 in 10 (88%) thought the UK was ahead of at least some countries in this respect.

Figure 6 Survey responses on the UK's current reputation as a centre for innovation in battery technology



Source: Phase 2 and Phase 3 Survey, Question B7

Note: Respondents were asked question B7: "Overall, how would you rate the UK's current reputation as a centre for innovation in battery technology?". The chart is based on the 112 respondents of phase 3 and the 136 respondents of phase 2.

To the extent that policy frameworks are a material element to perceptions relating to these closer-to-market segments, the responses indicate that there is further work to be done to build on the UK's traditional strengths in research into creating market conditions that are optimal for investment. Stakeholder feedback highlights specific ways in which FBC could meet this challenge, while also emphasising the role other institutions would also need to play.

Some challenges in attracting investment may lie beyond FBC's remit

The evaluation process underscored that investment is likely to require a cluster of interventions. Thus the view of stakeholders was that FBC is an attractive element of the UK battery ecosystem. For instance, the role of UKBIC appeared to be seen as key:

- Investing in new, unproven battery technology was deemed risky and contrasts with the traditional automaker approach to investment. A stakeholder considered that UKBIC had helped to lower this hurdle by de-risking these technologies, supported by the APC and FBC.
- The UK holds a strong position on R&D and SMEs in the battery space but has limited experience in scaling up these innovative technologies. The UKBIC interviewees explained that UKBIC plays an important role in developing technologies as a lot of the work UKBIC does is to re-engineer projects coming in such that they reach a maturity level that enables industrialisation.

Stakeholders stressed that, to attract inward battery investment, support and funding was needed at a larger scale than FBC's remit. The government has recognised this: as observed in Section 2.4.1., the government has committed to an in investment envelope of half a billion pounds under the Ten Point Plan announced in 2020. In connection with this, stakeholders also pointed to the ATF's role to fund the development of an end-to-end electrified automotive supply chain to enable large-scale industrialisation in the UK.[10] An example is the ATF Scale Up Readiness Validation specifically aimed at supporting projects with the objective to "produce physical production samples, of a quantity and quality which supports the case for the commercial viability of scale up in the UK".[11] A total of 22 projects related to batteries, battery critical materials, recycling, fuel cells, motors and drives, motor critical materials and power electronics were taken forward by 35 UK-based companies and research organisations which each received up to £2 million of support.

A few external stakeholders mentioned that FBC had helped to lay the groundwork to show the demand for the ATF, which was essential – a point that FBC leadership has also been keen to emphasise. In that sense, FBC can be seen to have contributed to some of the broader funding facilities available to investors over and above those that are available through the three FBC strands.

In addition, stakeholders underscored a range of policy factors that influence investment decisions which are outside of FBC's scope. Even if they believed that FBC had had a positive impact, the general attractiveness of the UK was seen as the main driver for investments. These factors include:

  - Trade policy, particularly conditions of trade with the EU (tariffs, preferential rules of origin, regulations and standards);
  - Energy prices;
  - Local demand for batteries from OEMs; and
  - Capital support and subsidies for manufacturers from government.

In this light some stakeholders expressed caution about the ability of the UK to deal with escalating international competition. For example, one noted that EU-wide mechanisms for industry support made it seem more likely that the EU would reach the volumes and scale required. However, the UK would need to resolve questions around trade and potential friction before the feasibility of large-scale production could be assessed.

---

10 https://www.apcuk.co.uk/automotive-transformation-fund/

11 https://apply-for-innovation-funding.service.gov.uk/competition/1130/overview

3.2.3 Policy community's understanding of value chains

Interviewees reiterated the view that FBC had been able to bring together a team of informed and influential senior leaders, giving it credibility with relevant government departments. FBC engagement with policymakers is therefore valuable as it helps to increase the policy community's understanding of value chains in the sector as well as understanding of the risks and opportunities associated with the sector (i.e. importance of UK auto manufacturing remaining relevant). This is evidenced by the fact that intelligence reports produced by FBC have received a good level of engagement by the public sector.

As mentioned previously, stakeholders recognised that a key contribution of FBC was its role in supporting the foundation of the ATF. The ATF was considered by many stakeholders to be a key attractor for UK battery manufacturing, more so than a UK R&D-linked supply chain, and Automotive Council targets were viewed as providing a basis for global discussions on topics including battery safety, performance and efficiency.[12]

However, findings from case study interviews reiterated the work that remained to be done to ensure that support for moving from concept to production was effective. Several stakeholders felt that FBC had performed well in terms of R&D but that improvements still needed to be made after the R&D stage in relation to the practical steps required to ensure scale-up and put supply chains in place. For instance, a stakeholder in the chemicals value chain acknowledged the support for scale-up of cells provided by UKBIC but reported that more needed to be done to address some of the more regional or local constraints that might affect businesses in the value chain.

3.2.4 Investor interest

Survey results show that overall the UK is not seen as a particularly attractive destination for investments in battery technology: less than a quarter (22%) of survey respondents viewed the UK as such (corresponding to a score of 8, 9 or 10) and nearly two-thirds (65%) gave the UK a neutral rating for attractiveness for investment (a score of 4, 5, 6 or 7) in 2022. This outlook on the UK's attractiveness as a destination for investments in battery technology was broadly consistent across different battery technologies, including both light and heavy vehicles, aerospace and off-highway (see Figure 7).

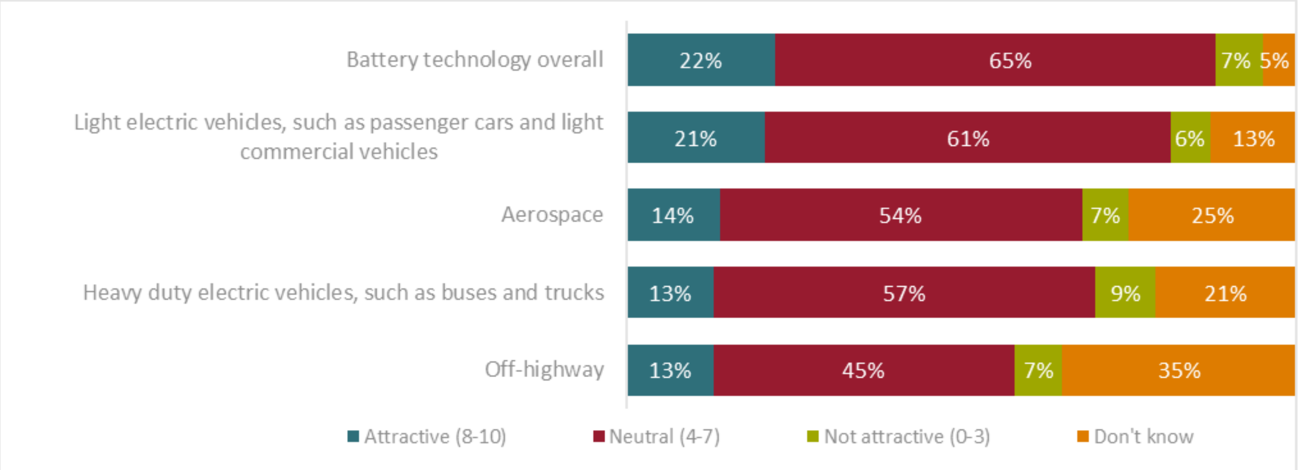
The results should not be taken to mean that the UK is seen as unattractive for investment in batteries – indeed, in Section 3.4.3 we document trends in investment in start-ups that show robust growth. Rather, it is a reflection of whether the UK stands out relative to others, which is relevant to the UK's stated ambitions of becoming a battery superpower, ambitions that FBC is intended to promote. In this sense, it is perfectly possible to see rapid growth in aspects of the battery ecosystem without this carrying implications for the relative status of the UK in the global battery production landscape.

To date, China has been the dominant recipient of foreign direct investment (FDI) in batteries, reflecting in part the operation of value chains controlled by investors in Japan and the Republic of

12 FBC itself was noted by stakeholders to have contributed to the establishment of battery technical standards for the aviation sector.

Korea and the cost advantages relating to production in China (a pattern that is replicated across other manufacturing sectors). According to stakeholder interviews, cost factors may also explain the relative attractiveness of Eastern European jurisdictions.

Figure 7 Survey responses on the attractiveness of the UK as a destination for investment across battery technologies



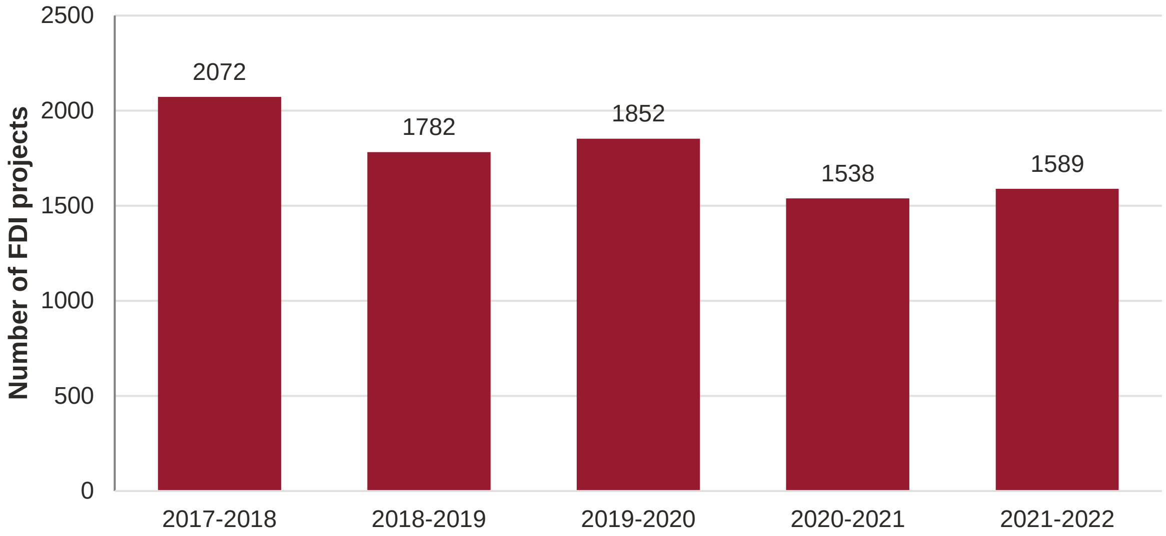
Source: Phase 3 Survey, Question B1

Note: Respondents were asked question B1: "How attractive do you think the UK is as a place to invest in relation to the following types of battery technology? Please use a scale of 0 to 10, where 0 is not at all attractive and 10 is extremely attractive.". The chart is based on the answers of the 112 respondents of phase 3.

Clearly, perceptions of investment attractiveness will be driven by a range of factors outside FBC's control. Indeed, standard economic theories of FDI flows between countries suggest that these are positively related to the size of the countries and negatively related to cost factors, including policy effects. On the latter front, increased costs faced by investors in the UK in terms of access to skills, uncertainties around market access to the EU and macro-economic uncertainties are likely to have affected perceptions. This can be illustrated by comparing the survey results reported above for 2022 with survey results for 2020. This comparison shows a decrease in the proportion of survey respondents who found the UK attractive as a place to invest in battery technology overall (22%, compared to 34% in 2020) and a similar decrease in the proportion of survey respondents who found aerospace investment in the UK attractive (14%, compared to 27% in 2020).

The survey in 2022 was conducted at a time of heightened macro-economic uncertainty in the UK, coupled with uncertainty around the durability of market access arrangements with the EU. It is likely that these factors have influenced FDI trends as a whole. This is supported by the fact that the number of FDI projects has decreased since 2017-18 (Figure 8**Error! Reference source not found.**).

Figure 8 FDI projects in the UK between 2017 and 2018 and between 2021 and 2022



Source: Department for International Trade

The RSM and Make UK report, which surveyed 200 business leaders in the manufacturing sector, reveals that 51% of manufacturers believed that investments in plant and machinery had been held back due to the number of economic shocks that happened over the past two years.[13] That survey identifies inflation as being a barrier to investment, with 37% of respondents saying inflation had decreased investments.[14]

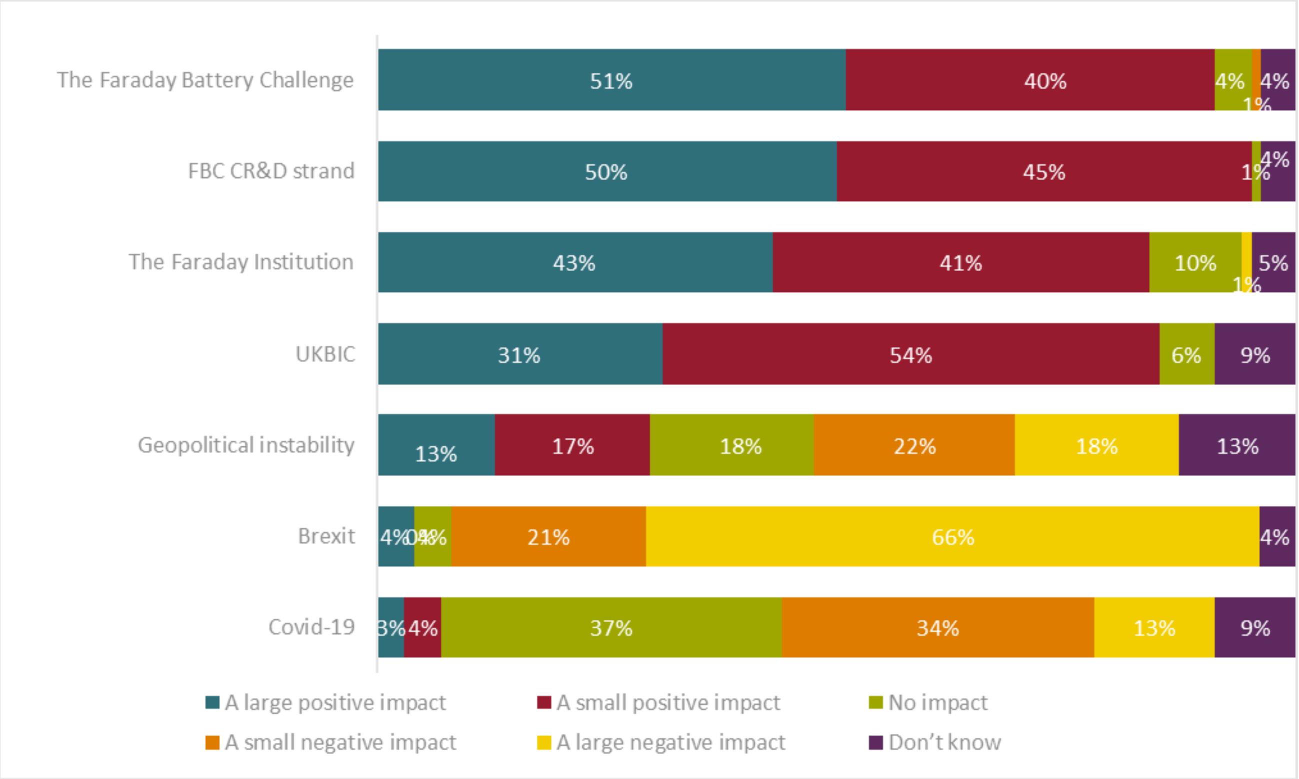
Figure 9 reports respondents' views of the materiality of some of the determinants of investment in relation to batteries. Notably, we find that:

- The continued effects of both Brexit and Covid-19 were seen to have had a negative impact on the attractiveness of the UK as a place to invest in battery technology. Brexit and Covid-19 were seen to have had a marginally more negative impact in 2022 compared to 2020.
- The current geopolitical instability (such as the war in Ukraine and global energy prices) divides opinion in terms of its impact. Thirty percent felt that it had had a positive impact on the attractiveness of the UK as a place to invest, while 40% felt it had had a negative impact. As the question about the geopolitical instability's impact on the attractiveness of the UK as a place to invest in relation to battery technology for EVs was not asked during the interim evaluation, the results cannot be compared.

13 https://rsmuk.pagetiger.com/Investment-Health/1

14 Investment health report 2022, p10.

Figure 9 Survey responses on the impact of FBC and other factors on the attractiveness of the UK as a destination for investment in battery technology for electric vehicles

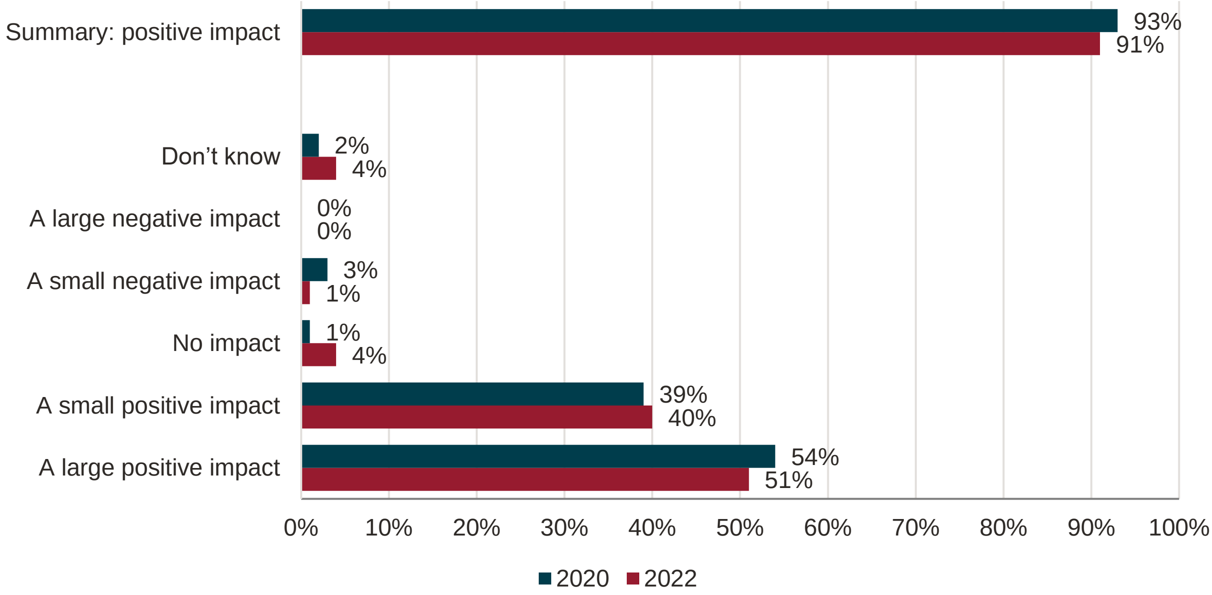


Source: Phase 3 Survey, Question B4

Note: Respondents were asked question: "What impact, if any, do you think the following aspects have had on the attractiveness of the UK as a place to invest in relation to battery technology for electric vehicles?". The chart is based on the answers of the 112 respondents of phase 3.

One of the implications of this analysis for this evaluation is that the primary factors that affect overall investment perceptions would likely also have been observed in the counterfactual case in which FBC had not been implemented. But, while these higher-level factors may dominate investment perceptions, that does not rule out the possibility that FBC can have an impact on investor perceptions, even if this impact may be dominated by other factors. Indeed, as can be observed from Figure 9, respondents pointed to a positive effect of FBC and its strands. This is further brought out in Figure 10, which reports survey respondents' assessments of FBC as a whole. They show robustly positive views across 2020 and 2022, notwithstanding the adverse developments in broader macro conditions documented above.

Figure 10 Survey responses on the impact of FBC on the attractiveness of the UK as a place to invest in relation to battery technology for electric vehicles



Source: Phase 3 Survey, Question B4

Note: Respondents were asked question B4: "What impact, if any, do you think the following aspects have had on the attractiveness of the UK as a place to invest in battery technology for electric vehicles? The Faraday Battery Challenge". The chart is based on the 112 respondents of phase 3 and the 136 respondents of phase 2

Finally, it is important to recognise that the evidence presented here relates to investor perceptions at the aggregate level. It is possible that trends at a more disaggregated level (e.g. by stage of investment) might also generate further evidence of FBC's contribution. We consider this in more detail in Section 3.4.3. where we consider investment activity in start-ups, which has shown robust trends since 2017. Indeed, the views of one CEO point to FBC's effects in creating an enabling framework that is conducive to investment by start-ups

"The biggest strength of the UK Battery ecosystem is perhaps the joint ambition of industry, government and academia. Together, they aim to promote, support and catalyse their interaction to create smooth, funded, efficient pathways from low Technology Readiness Levels through to scalable commercialisation. For instance, the Faraday Battery Challenge with its rather holistic funding portfolio, from Faraday Institution-funded STEM engagement at a pre-university level through to FBC-funded calls for grant funding industry collaborations. This ambition, and the actions that are being taken in line with it, are what I believe make it realistic for UK battery ecosystem players to fight and succeed in securing global leadership positions." (Ian Campbell, CEO and Founder at Breathe Battery Technologies)

This view lends support to the view, also backed up by survey results on the contribution of FBC to the UK's attractiveness as an investment destination, that the UK is better equipped through FBC to deal with adverse developments in the investment climate than it would have been without FBC.

3.2.5 Public understanding and acceptance of battery technology and value chains

Stakeholders and survey respondents primarily addressed the interaction between FBC and government, and the relationship between FBC and the overall investment climate for batteries and EVs. The effects on public sentiment are less easy to discern.

Research conducted by the UK Government found that some 49% of survey respondents had not thought about acquiring an EV in June 2019 compared to 55% in December 2017. The main deterrents to buying a vehicle that were mentioned were recharging (38% of respondents in June 2019), battery range (38%) and the lack of charging points (30%). This further highlights the importance of investing in battery technologies. These data also suggest that the cost of EVs is now slightly less of a concern than it used to be (24% saw the cost to buy, 8% the cost to run/maintain/fix faults and 7% the cost in general as deterrents).[15]

These changes are not unique to the UK and similar changes are observable in other countries, notably France, Germany and China.[16] This suggests that changes in public attitudes may be a function of increased awareness more broadly, and globally, than the result of a specific intervention such as FBC.

3.2.6 Summing up

FBC has made significant contributions to strengthening the enabling policy framework for battery investment and production. This is reflected, notably, in its role in the inception of the ATF and the development of initiatives relating to skills.

The findings suggest that the UK is recognised as a destination for foreign investment in battery technology, even if not the leading destination. There is evidence of robust trends in investment in battery technology start-ups since 2017. The challenges faced by the UK in further enhancing its position relative to competitors reflect broader factors that are beyond the control or influence of FBC, and that indeed seem to have affected foreign investment in the UK as a whole. Several factors were identified as influencing investors' perceptions. These include trade policy, particularly conditions of trade with the EU, as well as energy prices and geopolitical instability. These factors would have applied in the counterfactual case, i.e. if there had been no FBC.

Investor perceptions of FBC's contribution to the investment environment were robustly positive, in line with the observations made above about FBC's role in strengthening the policy framework. Stakeholders also underscored the efforts of FBC to develop public understanding of battery technologies in contributing to a more robust public policy framework and mobilising mechanisms for public support. Taken in combination with the influence of broader macro factors on investment perceptions, the findings suggest that, relative to the counterfactual, the contribution of FBC is positive

[15] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/847653/Summary_Report_of_Wave_4_of_the_Public_Attitudes_Tracker.pdf

[16] https://www2.deloitte.com/uk/en/insights/focus/future-of-mobility/electric-vehicle-trends-2030.html

but is limited by the role played by broader determinants of investment which are not specific to battery technologies. The evidence also suggests that FBC places the UK in a better position to respond to some of these external challenges than the counterfactual case in which FBC did not exist.

Recalling the baseline assessment, which emphasised the requirement to address persistent challenges in translating strengths in applied research and institutional strength into commercial prospects, the findings also suggest that some of these longer-standing constraints about the UK's ability to translate applied research into production still apply. In particular, stakeholders noted missing links relating to proof of concept at scale, although this could be mitigated by UKBIC's activities. One of the challenges to the UK is that the international competition for investment in battery technologies is escalating. This makes it more pressing to address the identified missing links and to supplement these efforts with further flanking policies, notably in the area of skills.

3.3 Systemic change in the conduct of battery R&D

3.3.1 Overview of metrics

Table 2 Summary of metrics and data sources for "systemic change in conduct of battery R&D"

Link to logic model	Metric	Data sources and methodology
(1) Sustained academic collaboration within UK and internationally (Faraday Institution output)	Joint publications Number of research institutions involved Measures of interdisciplinary collaboration	FI data on number of collaborations SciVal
(2) Number of new collaborations, their duration and outputs (CR&D output)	Academic-industry secondments/industry fellowships Use of UK university-generated IP	CR&D data Survey undertaken for this evaluation PAT STAT data for IP
(3) Standing and leadership of UK universities in battery-related disciplines (Faraday Institution outcome)	Quality of research output	SciVal Survey undertaken for this evaluation
(4) Increased probability of breakthrough against eight targets (Faraday Institution and CR&D outcomes)	Progress against eight UK Automotive Council targets	Evaluation of research outcomes drawing on CR&D reports (64 in number at time of writing)

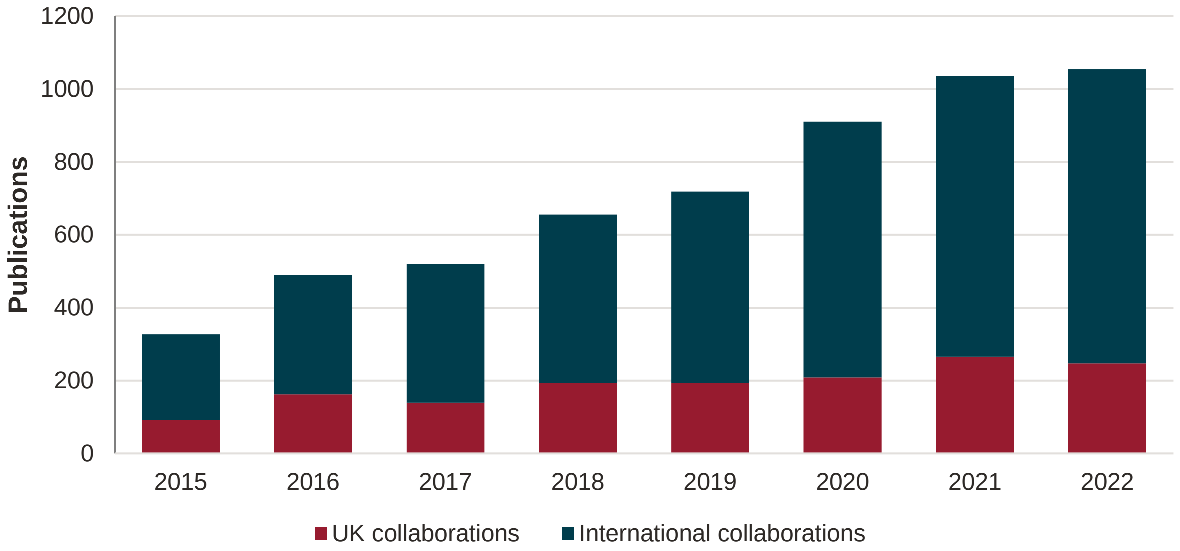
	FI progress towards commercialisation framework Survey data undertaken for this evaluation

3.3.2 Changing academic collaboration patterns within UK and internationally

Collaboration between UK academic institutions on battery-related publications is an indicator of the extent to which the research landscape has been strengthened. While metrics of collaboration can be influenced by a number of factors, FBC (notably via FI) has sought to play a role in this.

Within the UK, collaboration levels on publications have increased to some extent since the inception of the Challenge (see Figure 11). At the same time, international collaborations (between UK institutions and institutions from other countries) on battery-related publications have increased substantially over the last seven years. There appears to have been a step change in international collaborations after 2017 when FI was launched. The number of international collaborations has increased every year since, reaching more than 800 international collaborations in 2022 (approximately 2.5 times the number of international collaborations in 2016).

Figure 11 UK/international collaboration in battery-related publications



Source: Frontier Economics analysis of SciVal data

Note: Data refer only to publications in the Scopus Topic Clusters: Secondary Batteries, Electric Batteries and Lithium Alloys. Collaborations are defined as publications produced by academics from more than one institution. International collaborations are defined as publications produced by academics from institutions in the UK and at least one other country.

It is obviously not possible to formally attribute this increase in international collaborative efforts to FI and, indeed, a variety of factors are likely at play. At a global level, there has been an upswing in research interest in battery technologies in line with the global pursuit of low/zero emissions targets.

Table 3 below tracks UK and FI publications in battery-related domains as a proportion of worldwide publications. It points to a slight increase in publication output both at the UK level and for FI specifically as a share of global publication outputs.

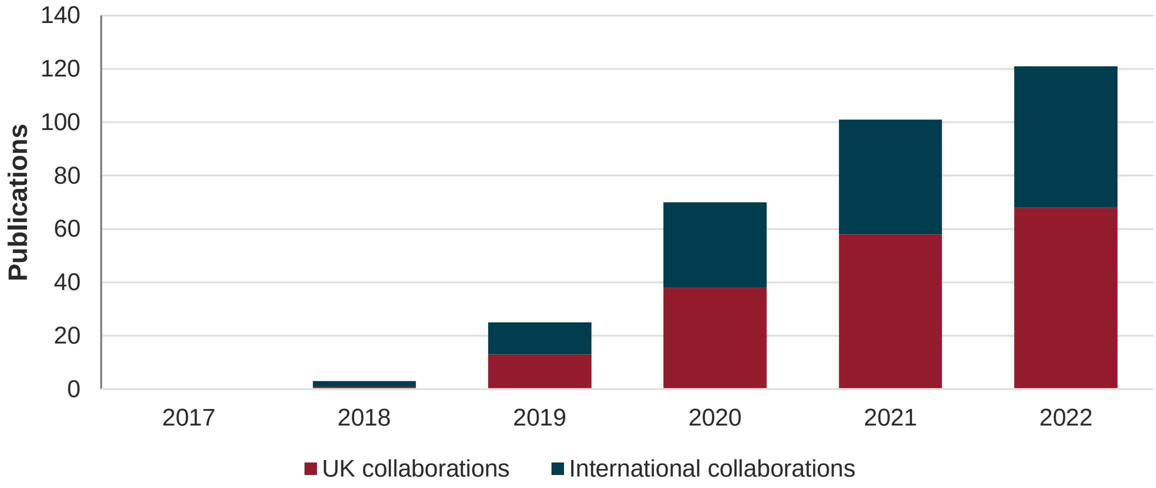
Table 3 UK and FI publications in battery-related domains as percentage of worldwide publications

	2017	2018	2019	2020	2021	2022
Total UK publications	2.6%	2.8%	2.8%	3.2%	3.2%	3.1%
Total FI publications	0.00%	0.02%	0.12%	0.28%	0.34%	0.36%

At a UK level, the increased policy profile and public investment in battery research since the inception of the Challenge may be an attractor for international collaborative efforts. This is consistent with survey findings in which 61% of respondents reported that perceptions of the UK as a centre for innovation in technology had increased by a little or a lot since 2017 (see section 2.3.1). Moreover, as reported in Section 3.3.3, a very large majority (81%) of respondents reported that FBC had slightly or significantly increased collaborative effort. This number is broadly in line with the 85% reported by the survey results in 2020.

If we consider FI's track record in publications since commencement of operations in 2018 (Figure 12), we see a rapid increase in both UK and international collaborations, which is evidence of FI's increasing activity in the field. FI was involved in around 28% of UK collaboration publications in 2022 compared to 18% in 2020 and in around 11% of all publications (UK and international collaborations) in 2022 compared to 8% in 2020.

Figure 12 Faraday Institution UK/international collaborations in battery-related publications



Source: Frontier Economics analysis of SciVal data

Note: Data refer only to publications in the Scopus Topic Clusters: Secondary Batteries, Electric Batteries and Lithium Alloys. Collaborations defined as publications produced by academics from more than one institution. International collaborations defined as publications produced by academics from institutions in the UK and at least one other country.

Data from CR&D provide some initial evidence on how far the collaborative research carried out by the consortia has stimulated academic publications. As at November 2022, 24 of 77 collaborations had already produced publications, with 47 reporting that they planned academic publications. This number significantly increased compared to September 2020, when 14 collaborations planned academic publications. Several planned multiple publications bringing the total to over 80.

Data for rounds 1-4 of CR&D funding show that 23 different academic institutions were involved in funded projects totalling £30.3 million across 86 projects. The large majority of those funded projects had links to FI. Around 75% of this funding envelope was directed at projects involving three institutions: the University of Warwick (which participated in projects that received around £13.4 million in funding), Imperial College London and University College London. These institutions participated in half of the projects for rounds 1-4.

These data can be interpreted in a variety of ways. At one level, the concentration of funding is consistent with efficiencies in research, in the sense that this reflects how economies of scope and scale are harnessed. On the other hand, it may also adversely affect ambitions to distribute R&D efforts on a wider geographical basis. The fact that most projects are linked to FI point to effective feed-through between the strands. But it may also highlight that the catalytic impact of FI (i.e. in stimulating R&D more broadly across the research landscape) may be limited.

3.3.3 Number of new collaborations and their duration

As well as promoting sustained academic collaboration in the battery sphere, FBC aims to promote collaborations within industry and between academia and industry. Currently, FI has more than 85 industry partners that it works with as well as 27 UK university partners.[17] The data for these collaborations since 2018-19 are provided in Table 4 below.

Table 4 FI Collaborations

FI Collaborations by year	**18/19**	**19/20**	**20/21**	**21/22**
Academic	22	21	24	27
Industry	50	50	50+	85
Spin-outs	0	5	8	8

CR&D has undertaken 55 projects with academic collaboration. Data for these are reported below.

Table 5 Mix of collaborations

	Commer-cial partners	**Industrial partners**	**External academic partners**	**All partners (2022)**	**All partners (2020)**	**Change between 2022 and 2020**
Total	0.34	1.77	1.66	3.77	6.15	-39%
Businesses	0.37	1.73	0.77	2.87	4.33	-34%
Academics	0.32	1.79	2.21	4.32	8.16	-47%
1 FBC application	0.26	1.30	1.28	2.84	5.97	-52%
2 or more FBC applications	0.40	2.54	2.28	5.22	6.36	-18%

Source: *Phase 3 Survey, FBC application refers to CR&D projects*

Note: *The table shows the mean number of each type of collaborator across all the projects that survey respondents reported. For this question, respondents were asked to think about up to three different programmes of research activity related to batteries in the previous academic/financial year. If they had more than three, we asked them to think about the largest ones. In total there are data for 162 projects.*

17 Faraday Institution website (https://faraday.ac.uk/research/ accessed: 18/04/2023).

Trends in the intensity of collaboration

We measure intensity of collaboration by the number of organisations that collaborate with each other in any given project. This is an appropriate measure in light of the theory of change, which highlighted the need to reduce fragmentation in the research landscape. At the same time, coordination is costly. Hence, the idea is that by providing funding for collaborative projects, some of these costs can be overcome. Observing trends in collaboration help to gauge to what extent FBC is helping to overcome these costs and strengthen coordination.

The survey focuses on CR&D collaborations, which by definition these did not exist before 2017. The intensity of collaboration reported by respondents, as measured by the average number (unweighted by project value) of collaborating partners in a project, was around 6 in 2020, and around 4 in in 2022. In collaborations led by academics, the average number of partners involved was higher than in those led by businesses (respectively around 8 in 2020 and 4 in 2022, versus 4 in 2020 and 3 in 2022).

There appears to be a greater number of external academic partners when programmes are led by academics compared to businesses (a ratio of around 2 to 1). It also seems that the number of collaborating partners increases with the number of applications; those with only 1 FBC application had on average around 3 collaborating partners, compared to an average of around 5 for those who had 2 or more FBC applications.

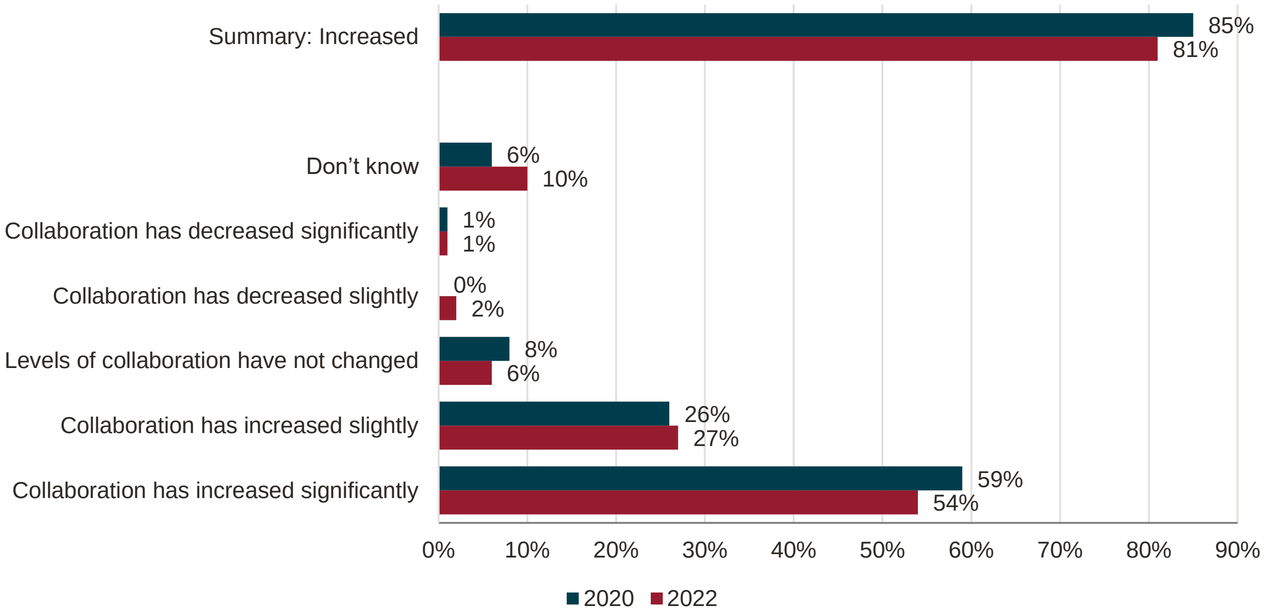
The decline in the average number of partners between 2022 and 2020 does not necessarily suggest a decline in the effectiveness of FBC in promoting collaboration. It more likely reflects differences between CR&D funding rounds in terms of funding and duration.

Survey respondents are recipients of CR&D funding, and a pre-condition of this is a commitment to a collaboration. That imposes some limits on the extent to which we can draw inferences about the effects of the challenge on collaboration relative to the counterfactual case, in the sense that those bidding for funding might have been predisposed to collaboration anyway. At the same time, the fact that the intensity of collaboration increases with the number of FBC applications may suggest that collaboration is reinforced through repeated interaction with the Challenge.

The number of collaborative projects and willingness to collaborate have increased

Progress in reducing fragmentation can also be measured by the number of projects done in collaboration. The data suggest that the number of projects done in collaboration has increased, and therefore that one of the effects of funding via CR&D has been to create an increased interest in collaboration . Indeed, the majority (81%) of survey respondents reported that collaboration on projects or grants concerning batteries had increased since FBC's inception in 2017. This included over half (54%) who felt that collaboration had increased significantly. (See Figure 13 below)

Figure 13 Survey responses on how collaboration in general on projects or grants concerning batteries has changed since 2017

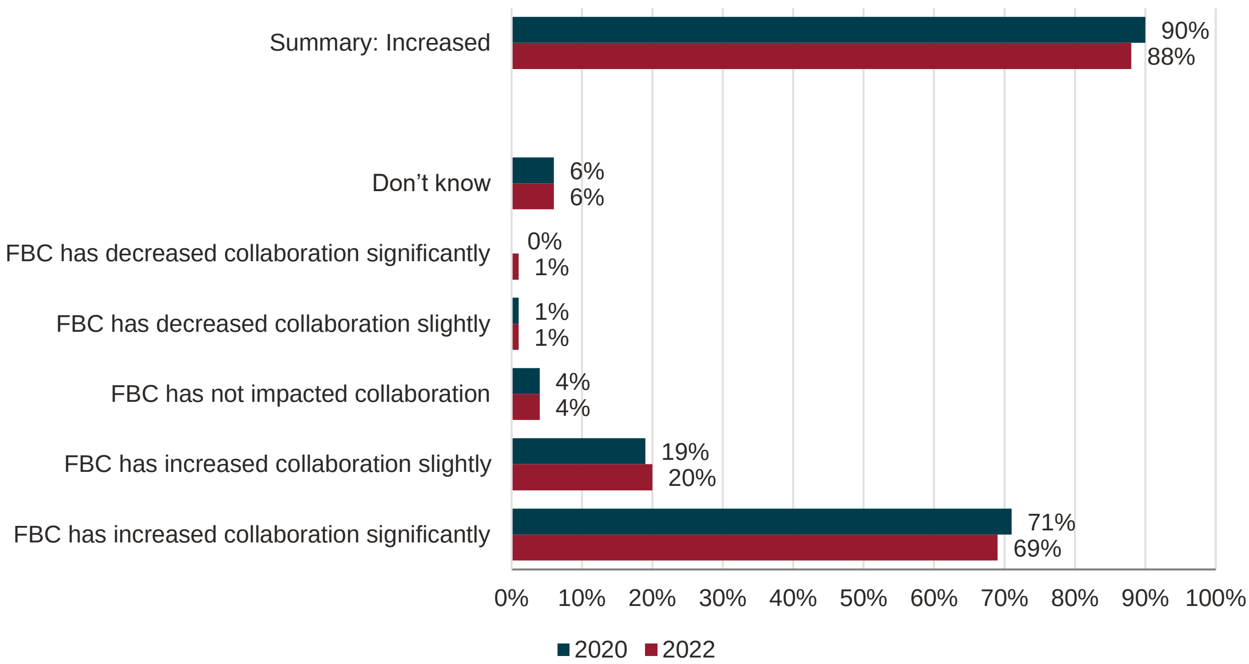


Source: Phase 3 Survey, Question C22

Note: Respondents were asked question C22: "How do you think collaboration in general on projects or grants concerning batteries has changed since 2017?". The chart is based on the 112 respondents of phase 3 and the 136 respondents of phase 2.

Most respondents saw FBC as the driver of this increase in collaboration, as reflected by the number of collaborations. This is illustrated in Figure 14: over two-thirds (69%) felt that FBC had increased collaboration significantly, a similar proportion to when asked in 2020. A further fifth (20%) felt that FBC had increased collaboration slightly.

Figure 14 Survey responses on the impact of FBC on collaboration



Source: Phase 3 Survey, Question C23

Note: Respondents were asked question C23: "How much do you think the Faraday Battery Challenge has impacted collaboration in general on projects or grants concerning battery technology?". The chart is based on the 112 respondents of phase 3 and the 136 respondents of phase 2.

This is supported by the CR&D close-out data: 172 (70%) of the 246 collaborations captured by the CR&D close-out data said that they were considering continuing collaboration with the rest of the participants, 69 (28%) responded that they might consider continuing collaboration with the rest of the participants and only three (1%) said that they would not (the remainder did not provide an answer to that question). Taken together with the survey results reported in Figure 14 on the effects of FBC on collaboration, it is plausible to infer that FBC has generated an increase in collaborative R&D over time which outlasts the impact of the initial support provided, and which is greater than would have been observed in the counterfactual case, i.e. absent the intervention.

3.3.4 Standing and leadership of UK universities in battery-related disciplines

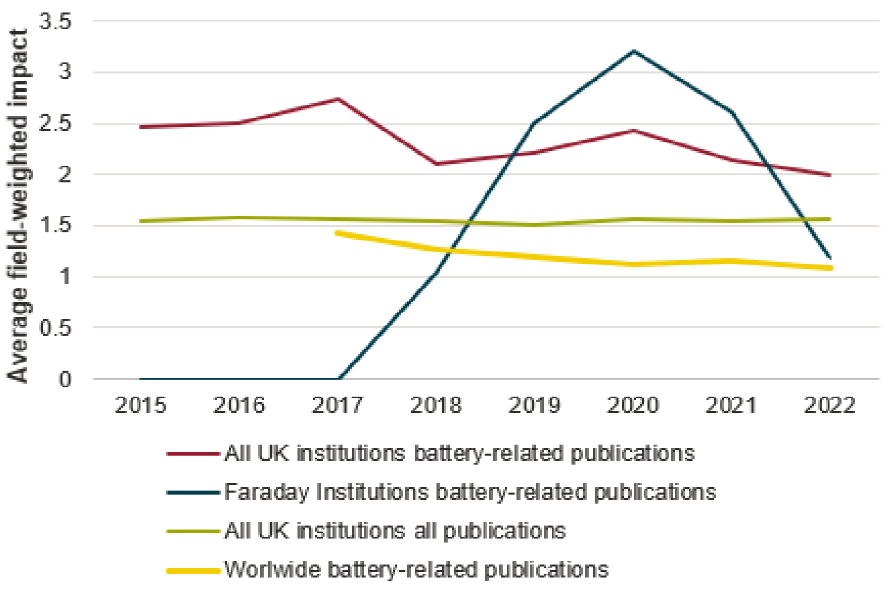
As mentioned above in section **Error! Reference source not found.** perceptions of the quality of research output and the standing of UK universities in battery-related disciplines were positive: the UK was perceived to be at least ahead of most countries for both of these elements. A majority of survey respondents believed that the UK was at least ahead of most countries when it came to the quality of research outputs (92% in 2020, compared to 98% in 2020). Similarly, when it came to views around the standing of UK universities in battery-related disciplines, 90% thought that the UK was at least ahead of most countries (compared to 96% in 2020). Perhaps unsurprisingly, academic respondents were more likely to say that the UK was ahead of most countries in both dimensions (58% and 95% of academics regarding quality of research output and standing of UK universities respectively, compared to 47% and 85% of business respondents).

Data on publications suggest that FI has been capable of generating high-quality publications rapidly since inception. According to FI annual report for 2021/22, FI had produced over 640 publications since inception. Close to 93% of publications appeared in top quartile journals, while nearly 64% appeared in the top 10% of journals. Around 44% appeared in the top 10% most-cited publications.[18]

Figure 15 reports measures of field-weighted citation impact for FI, for UK institutions (for batteries and across all domains) and worldwide battery publications. They show that FI publications achieved higher levels of impact than UK battery-related publications as a whole and than worldwide battery publications. But, the measures of citation impact decreased significantly in 2022. However, it is worth noting that it is normal to observe lower measures of citations for recent years and this phenomenon may have been reinforced by constraints on research imposed by Covid in the years 2020-21, which in turn may have reduced publication rates (and hence citations) in these and in following years. Nevertheless, the drop-off reported appears to be steeper than numbers reported are lower than those of UK institutions as a whole.

The extent to which there have been spillovers between the impact of FI's research and that of UK battery research is not clear on the basis of these data. What is clear is that UK battery research publications have a higher impact than UK publications generally and than worldwide battery publications. This points to the comparative strength of the UK in battery research, trends which pre-dated FI and which do not appear to have materially changed following launch of FI's work.

Figure 15 Average field-weighted citation impact of UK battery-related publications



Source: Frontier Economics analysis of SciVal data

Note: Data refers only to publications in the Scopus Topic Clusters: Secondary Batteries, Electric Batteries and Lithium Alloys. Field-Weighted Citation Impact in SciVal indicates how the number of citations received by an entity's publications compares with the average number of citations received by all other similar publications in the data universe: how do the citations received by this entity's publications compare with the world average? Citation metrics are likely to be lower in more recent years. Data for worldwide battery publications from 2015-17 not available.

[18] Faraday Institution, *Annual Report 2021/22,* p.58.

3.3.5 Increased probability breakthrough against eight targets

The eight automotive targets are presented below.

Table 6 UK automotive targets

Attribute	Status in 2017	Target in 2035
Cost	-$130/kWh (cell) -$280/kWh (pack)	-$50/kWh (cell) -$100/kWh (pack)
Energy density (cell)	-700Wh/l -250Wh/kg	-1.400Wh/l -500Wh/kg
Power density (pack)	3 kW/kg	12 kW/kg
Safety	-	Eliminate thermal runaway at pack level to reduce pack complexity
1st life (pack)	8 years	15 years
Temperature (cell)	-20° to +60°C	-40° to +80°C
Predictability	-	Full predictive models for performance and ageing of battery
Recyclability (pack)	10-50%	95%

Source: Automotive Council UK (2017), UK Automotive Battery Challenge

Progress against these targets is seen as a vital step in enhancing the widespread deployment of battery technology, both in vehicles and other end-uses. Breakthroughs could enhance the possibility of attracting investments in gigafactories. Indeed, from a commercial point of view, stakeholders generally expressed the view that it may be too late for the UK to become competitive in existing technologies. Several stakeholders thought, by contrast, that there was an opportunity for the UK to focus on accelerating the development and commercialisation of next-generation battery technologies.

The targets are central to FI's research programme (see Figure 16 below), with nine research areas collectively addressing these.

Figure 16 Faraday Institution research programmes and automotive targets

	Cost	Density	Power	Safety	First Life	Temp.	Predict-ability	Recycla-bility
Degradation	✓				✓	✓	✓	
Multi-scale Modelling	✓	✓	✓		✓	✓	✓	
ReLiB (Recycle)	✓			✓				✓
SafeBatt (Safety)				✓	✓	✓		
Nextrode (Fabrication)	✓	✓	✓		✓			
CATMAT & FutureCat	✓	✓	✓		✓			
NexGenNa (Na-ion)	✓	✓		✓				✓
LiSTAR (Li-S)	✓	✓						✓
SOLBAT (Solid-State)		✓	✓	✓		✓		

Source: Faraday Institution

Breakthroughs will require more time. Information from FI reports progress across a number of these targets, particularly in relation to energy density, and to some extent power density, lifetime and safety.

Although breakthroughs and their replicability at scale will require more time, survey evidence suggests that funding received from FBC for projects may enhance the prospects of breakthroughs. When asked what impact engagement with FBC had had on their progress in developing more advanced battery systems or components, 93% reported a positive impact. Around half (41%, compared to 51% in 2020) of the respondents stated that their engagement with FBC had had a great impact on their progress. A further 37% said it had had a moderate impact and 15% a small impact (compared, respectively, to 20% and 15% in 2020). Around 2% stated that their engagement with FBC had had no impact at all (compared to 20% in 2020). Overall, a larger proportion of respondents said that FBC had had some impact on their progress in developing more advanced battery systems or components in 2022 (93%) compared to the interim evaluation in 2020 (72%).[19]

CR&D data confirm that FBC support may aid the achievement of breakthroughs. CR&D project collaborators responded as follows when asked how satisfied they were with the effectiveness of the consortium in delivering the project: 99 (41%) reported that they were very satisfied, 90 (37%) that they were satisfied, 29 (12%) that they were neither satisfied nor unsatisfied, six (2%) that they were unsatisfied and 20 (8%) that they were very unsatisfied. The remaining two did not respond to that question. This shows that a significant number of collaborators were satisfied. However, when CR&D

[19] Phase 2 Survey Question D13.

project collaborators were asked whether they had been able to reach the intended project result, only 54 (22%) reported that they had, 19 (8%) that they had done so partially and 173 (70%) did not reply to that question. This may reflect the high-risk, high-reward nature of the projects. Read in conjunction with data regarding assessments of positive impacts and satisfaction, this may also suggest that there were benefits from the project over and above those associated with reaching the intended result.

3.3.6 Summing up

The evidence suggests that, via the activities of FI and CR&D, FBC has contributed to a systemic change in the conduct of battery R&D. FI has generated increased volumes of research outputs since its inception, including via international collaborations. There is evidence that FI has been associated with an observable increase in collaborative effort within the UK and internationally in academic research. The data also point to the high impact of FI's academic research over some of the years of phase 1 relative to UK and global battery publications. The data on publication impact also underscore the UK's general strength in the area of battery research, which predates the launch of FI and does not seem to have materially changed as a result of FI's operations. FI's research programme has also fully integrated the UK Automotive Council targets.

CR&D data point to high levels of satisfaction by consortia regarding their collaborative activities, which is supported by the fact that most CR&D collaborators are willing to continue collaboration. FBC is also perceived to have increased levels of collaboration in terms of numbers of collaborations. While there are a range of academic institutions that receive funding via CR&D for collaborative projects, projects run by three institutions accounted for around 75% of the £30.3 million disbursed through CR&D. This could point to efficiencies via economies of scale and scope but may also raise questions about distributional effects.

Finally, while it is unclear how far progress has been made overall towards achieving breakthroughs against the eight automotive targets, survey evidence suggests that FBC continues to have a significant positive impact on their perceived progress in advanced battery systems and components.

3.4 Attraction of investment in R&D and innovation

3.4.1 Overview of metrics

Table 7 Summary of metrics and data sources for "attraction of investment in R&D and innovation"

Link to logic model	Metric	Data sources and methodology
(1) Attraction of international research and personnel to UK	Measured by people and publications	SciVal Data available for FI projects

(Faraday Institution outcome)	Number of new energy storage research leaders attracted to the UK	This question could be wrapped into case studies undertaken for other themes (e.g. for enabling policy framework)
(2) Increased foreign investment in R&D generating innovation (FI and CR&D impacts)	Increased annual R&D spending Data on investor confidence	FBC project data available Gateway to Research and Innovate UK Grants Database
(3) Increased investor confidence (CR&D impacts)	Perceptions of investors	Link to survey data for "enabling policy framework theme"

3.4.2 Attraction of international research and personnel to UK

Section **Error! Reference source not found.** discussed the evidence that UK universities have a strong reputation internationally in relation to battery-related research, even though they are not always considered to be world leaders. As a vehicle for research funding, FBC aims to attract research and talented personnel to the UK to bolster the UK's stock of battery-related expertise.

We do not have access to reliable data on the inflow of international expertise to the UK in the field of battery research. But as a proxy, we can observe how the proportion of UK publications in battery-related fields that involves institutions from other countries has changed over time. Figure 12 pointed to the number of international collaborations involving FI, and Figure 11 suggested a step increase in the number of international publications in 2018 and a continuous increase thereafter.

3.4.3 Increased foreign investment in R&D generating innovation

Survey results (see Section 3.2) suggest that investors have positive, robust views of the contribution that FBC makes to the UK as a destination for investment in battery technologies.

It is difficult to find evidence to assess whether FBC has led to an increase in foreign R&D investment in the UK. However, it can be noted that the enthusiasm from foreign investors reported by UKBIC interviewees is corroborated by the Electric Vehicle Battery Tech in the UK 2023 report, which shows that the levels of foreign investment (in the form of venture capital) in start-ups reached 81% in 2022. Overall, venture capital-driven investment in start-ups was nearly five times higher in the period 2020-22 compared to 2016-19 ($1.1. billion versus $250 million). Data on the geographic breakdown of investor origin show that the USA and Asia dominate, with shares, respectively, of 43% and 30% from Asia. Investment from within the UK accounted for around 18%, and the EU accounted for 7%.

The share of foreign investment increased from around 45% in 2017, the baseline year for FBC, to 70% in 2018 and 85% in 2019. The share decreased in 2020 (50%), undoubtedly because of the pandemic, before increasing again, respectively, to 75% in 2021 and 81% in 2022.[20] The degree of attribution to FBC is of course uncertain. Evidence from the same source points to a rapid growth in venture capital investments in the UK – around 313% over the five years to 2022, placing it among the leading nations in Europe. It is therefore likely that the growth reported in battery investment was part of the broader trend, reflecting the UK's strengths in attracting venture capital. However, the more rapid growth in batteries suggests that battery sector interventions undoubtedly helped as well. Feedback from start-ups points to the role played by "joined-up" interventions, including FBC, in creating an environment that is likely to stimulate start-up activity.

CR&D data also show that some projects were done in collaboration with foreign organisations based in Japan, the USA, Israel and Australia and other companies with international ties. The data also show that a number of collaborators relied on EU funding (33 out of 246 – the reminder did not answer the question). In addition, a collaborator specifically mentioned relying on overseas funding for financing its R&D. Other collaborators simply mentioned relying on industry investors but did not specify whether those were foreign or not.

The level of collaboration between FI and international collaborators has been increasing since the inception of FBC (see Section 3.3.2).

The stakeholder interviews, the Electric Vehicle Battery Tech in the UK 2023 report, the CR&D and FI data point to it being likely that FBC has had a positive effect on foreign investment levels in R&D generating innovation, although the magnitude of the impact cannot be assessed.

The establishment of UKBIC in September 2021 is a major development which took place since the interim evaluation and which may contribute to this trend. Because the UKBIC model is based on partnerships with investors who commit funds to testing and scaling up, interactions between UKBIC and investors are a metric that can be used to gauge foreign investment in R&D – at least at its later stages close to commercialisation.

As documented in Section 3.6.4, UKBIC revenues are significantly below (around half) those expected, which suggests that original targets in attracting investment in testing at scale have not been met. At the same time, as also documented in Section 3.6.4, UKBIC has developed a substantial portfolio of leads, and feedback from completed projects points to tangible progress in cost reduction, improvements to reliability and learning-by-doing, all of which point to the potential for attracting further customers, and therefore investment. Moreover, stakeholder feedback also highlights some of the mechanisms through which UKBIC could contribute to investment outcomes:

- Stakeholders noted that UKBIC shows that the UK Government is serious about supporting battery development, which increases attractiveness to investors.
- In addition, UKBIC provides a pathway to commercialisation via large-scale testing, which reduces the risks around the development of new battery technologies and hence increases the commercial credibility of these technologies. This view is supported by Kevin Brundish (Director of Strategy, AMTE Power), who publicly stated the following: "Our partnership with UKBIC is a

[20] Dealroom.co and UKRI, Electric Vehicle Battery Tech in the UK 2023, p. 21.

crucial stepping-stone as we scale up our cell production rates to large-scale manufacturing levels. Coupled with testing being done at our existing facility in Thurso, it means we can provide greater certainty on cost and reliability of supply for our customers in the automotive and energy storage sectors. It's fantastic to be doing this work at a UK-based facility, championing home-grown battery IP and supporting the future of British manufacturing jobs".

- Foreign investors are reportedly impressed by the facility and see it as a differentiator for the UK. UKBIC's interviewees also indicated that visitors are impressed with the facility and they shared the following statements from credible, knowledgeable visiting executives:
  - An executive from a major EV company specialised in battery materials said that the UK battery ecosystem was unbelievably good and that nothing of the kind existed in the USA.
  - A car company senior executive and former GAFAM employee specialised in batteries said that he would take this model back to the US Department of Energy as there was a need for such a project. He also mentioned that he would like to collaborate with UKBIC.
  - An executive from an Israeli battery company said that the UKBIC approach was innovatory, especially the scale-up part, which was a very good fit for their needs.
  - A German equipment supplier executive who had visited most European battery plants said that UKBIC was a step forward and enabled progress and learning. He also said that Germany kept reconsidering such a move and was at least three years behind the UK.

3.4.4 Increased investor confidence

The discussion in section **Error! Reference source not found.**. and section 3.4.3 provided evidence on measures that tracked investor confidence. One way of considering the effects of FBC investor confidence in R&D specifically is to consider how far beneficiaries of the intervention were able to raise commitments for additional investments. Information from CR&D close-out reports for funding round four suggests that ten of 42 projects received additional funding, totalling just under £4 million from a range of sources, of which nearly half was in the form of a joint venture and 11% from new investors. This suggests that there is an effect, albeit limited, of the intervention on additional investment in R&D.

3.4.5 Summing up

As observed in Section 3.2, survey evidence suggests that FBC has had a positive impact on perceptions of the UK as a location for investment in battery technology. The evidence also points to FBC's active and increasing participation in research via FI in the UK and internationally. The levels have continuously increased since FBC's inception. The Electric Vehicle Battery Tech in the UK 2023 report shows that the levels of foreign investments in start-ups have increased significantly in the past couple of years. To the extent that start-ups are R&D intensive, and indeed are generally considered prime drivers of innovation, these trends can be interpreted as a sign of increased attractiveness for R&D investment. Clearly, the degree of attribution of these trends to FBC is unclear, if only because the trends in battery investment reflect those, but feedback from stakeholders involved in start-ups suggests that FBC backing has played a significant role.

Given the nature of the UKBIC model, interactions with UKBIC can be seen as one measure of international investor involvement in R&D. These have been significant but more muted than hoped for, with UKBIC revenues and utilisation significantly below what was targeted. Nevertheless, close-out reports from projects undertaken and stakeholder feedback suggest continued investor interest in that model and the services offered by UKBIC.

3.5 Enhanced prospects for commercialisation

3.5.1 Overview

Table 8 Summary of metrics and data sources for "enhanced prospects for commercialisation"

Link to logic model	Metric	Data sources and methodology
(1) UK industry increases its knowledge of the appropriate regulations, standards and testing methods to enable the development of successful cells, modules and packs (Challenge Team impact)	Use of standards	Number of standards downloads
(2) Opportunities for IP patents, licences, prototypes, spin-outs (FI outcomes) (CR&D outputs)	Increase in FI registered spin-outs IP metrics related to FI research (e.g. patent applications and grants) Value of higher TRL projects using FI research Increased total revenue/value as a result of funded projects (years 1-3, 4-7, 8-10) (CR&D)	IPO data Data collected by FI CR&D reports Close-out reports Possibly supplemented by survey data
(3) New SME Tech/IP exploited (CR&D outputs)	IP metrics related to FI research (e.g. patent applications and grants)	IPO

(4) Progression of new technologies towards commercialisation and avoid "valley of death" phenomena/de-risking (UKBIC outcome)	Reports on UKBIC documented Metrics based on documented results of testing and demonstration/scale-up Commercial revenues generated by industry-led testing Technological breakthroughs brought close to commercialisation Number of new R&D collaborations at lower TRLs by investors in UKBIC	UKBIC reports metrics specific to UKBIC Data on commercial revenues available only at aggregate level Progress on technological breakthroughs can draw on survey evidence

3.5.2 UK increases its knowledge of the appropriate regulations, standards and testing methods to enable the development of successful cells, modules and packs

FBC has a direct role to play in the development of the UK's knowledge of the appropriate regulations, standards and testing methods required to develop successful battery technologies. It also has an indirect role to play via its activities in influencing policy and educating policymakers.

FBC, in partnership with the British Standards Institute, has undertaken a number of activities for various stakeholders to enhance knowledge of standards and build capacity in terms of the ability of stakeholders to engage with the standards development process and to implement them. FBC has engaged with over a 100 stakeholders, including leading OEMs. Of these, 22 attended at least one workshop, and eight attended at least two workshops.[21]

On testing, FBC is generally perceived to be developing the right conditions (ecosystem) to aid UK battery production in the long term, including by attracting investment from companies with testing experience. Two of the 36 patent opportunities reported in the next section relate to testing protocols, but further enhancements have not been observed since the commencement of operations at UKBIC.

3.5.3 Opportunities for IP patents, licences, prototypes and spin-outs

Data reported by UKRI suggest that, as of December 2022, research efforts undertaken by FI supported 36 inventions, of which 18 filed for patents across seven projects. Of these 18, six led to official IP disclosures.[22]

---

21 Data provided by FBC.

22 Faraday Institution website (https://faraday.ac.uk/research/ accessed: 04/12/20).

FI has also sought to tackle specific, short-term industry needs for research and innovation that have been identified by companies. The timescales for these projects vary from 4-15 months. To date, there have been 12 examples of such “industrial sprint” projects carried out by FI (compared to four in 2020).[23] The projects cover:

- Predicting the remaining useful life (RUL) of lithium-ion batteries under operating conditions in order to allow for extension of the operational life of EVs/batteries and the stimulation of the second-hand EV market by increasing residual value and incentivisation of repurposing of batteries for second-life applications. This involves collaboration between the Warwick Manufacturing Group (WMG), University of Warwick and Eatron Technologies;
- Reducing the carbon footprint of the coating process of electrode manufacturing to deposit the electrode using a dry printing technology accelerator;
- Cell degradation, involving a major UK-based automotive company. The focus is to develop protocols and strategies that will suppress the potential degradation mechanism(s), for example, by minimising residence time and therefore capacity loss due to these conditions. These should translate into higher performance, longer first life and safer batteries for EVs. This involves the collaboration of WMG, University College London, University of Leicester and the industry partner;
- Developing commercially viable quasi solid-state lithium-sulphur (Li-S) cells. The focus of the project is to significantly enhance the number of times Li-S batteries can be charged before they reach end of life, the energy they can store per unit volume and the temperature range over which they can operate;
- Using greener and more efficient processes based on the development of a lithium-ion conducting fibre material for next-generation batteries;
- Unlocking a path to scale up the type of solid-state batteries. This involves the collaboration of WMG, University of Warwick, Johnson Matthey and Jaguar Land Rover;
- Using oxide ceramics as electrolytes for solid-state batteries to mitigate limited conductivity and optimise performance and cyclability. This involves the collaboration between the University of St Andrews, Morgan Advanced Materials and Ilika;
- Optimising pack design for thermal management. This involves collaboration between Imperial College London researchers and AMTE Power;
- Off gases and detonation behaviour, involving a major supplier to the auto industry that is seeking to establish a better understanding of cell detonation behaviour; and
- Materials for thermal transfer, involving a leading Formula One engineering company that is seeking higher performance thermal materials to improve battery pack performance and longevity.

FI’s entrepreneurial fellowship programme supports researchers who are looking to create new businesses for commercialising battery technologies for the benefit of the UK economy. These fellowships have been set up to facilitate the creation of new business opportunities that have

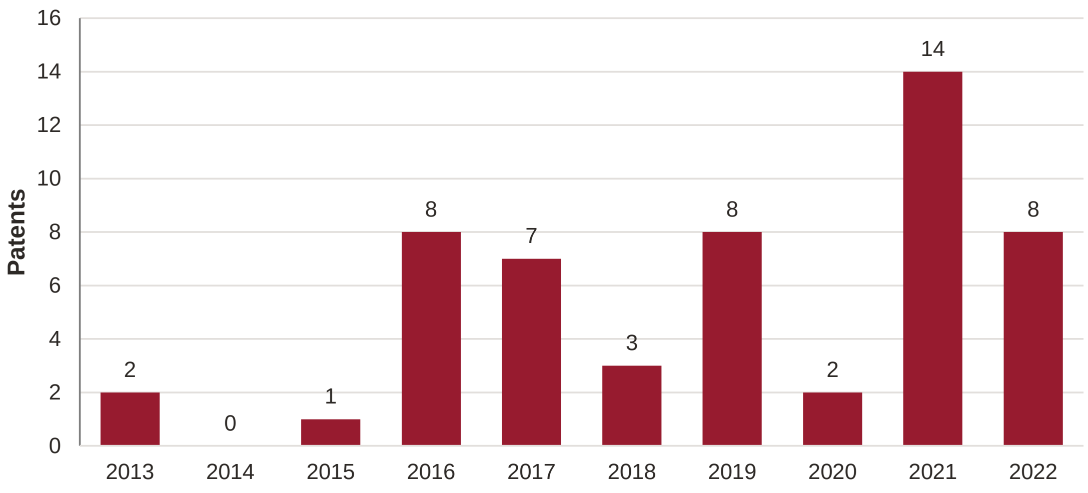
23 According to documents shared with Frontier Economics by UKRI.

emerged from FI research programmes or closely related activities. They provide seed funding, business support and mentoring to maximise the potential for success and accelerate the spin-out process. The goal of the scheme is to give selected entrepreneurs with proven ability in the battery space the best chance of success. So far in FI's lifetime, eight of these spin-outs have emerged (compared to five in 2020).[24] In addition, FI and FBC run the STEPS and FBC investment readiness programme which supports SMEs in the field of battery technologies to bring innovative energy storage products to the market (see Section 3.5.4 for more details).

Data from CR&D close-out reports also offer some insights into the impact of that strand of the Challenge on IP, and on innovation more broadly.[25] Based on data for CR&D collaborations since the inception of the Challenge, we observed that 61 of these collaborations were considering applying for IP protection via patents, 26 had applied for IP protection in this manner and 14 had been granted patents. Fifty-six reported that they were not formally protecting IP rights, mainly because they did not report any relevant IP.

As well as the direct contribution of FBC to various patent opportunities in the UK, there is evidence of a specific increase in R&D outputs relating to EV battery technology in recent years. Data on patents filed with the UK Government's Intellectual Property Office (IPO) lists 53 battery patents specifying EV application filed since 2013. Of these, 11 were filed between 2013 and 2016, 20 between 2017 and 2020, and 22 between 2021 and 2022 (see also Figure 17). This suggests some acceleration in the rate of patent filings in the latter years of the Challenge. Of the 53 patents, vehicle manufacturers are listed as the applicants for 20 (see Figure 18).

Figure 17 Battery-related patent filings which specify electric vehicle application



Source: Frontier Economics analysis of IPO data

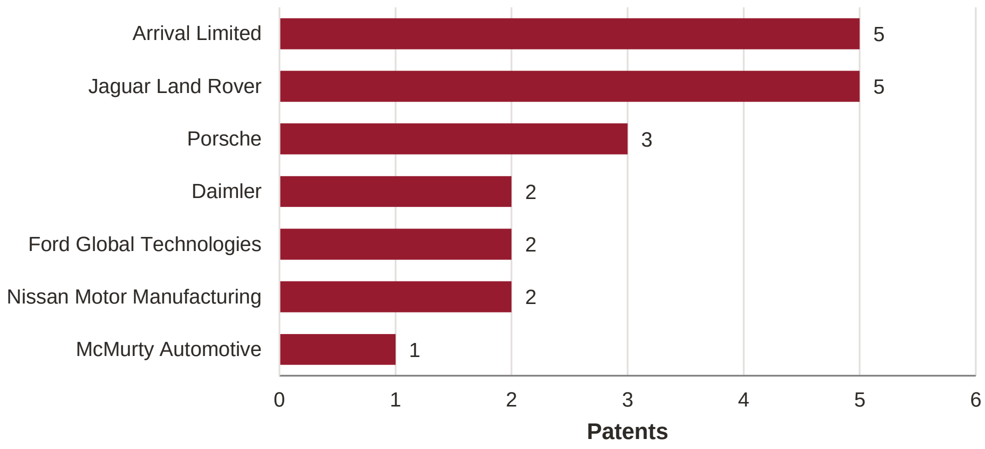
Note: Includes all battery-related patents that specify application or relevance to electric vehicle battery technology.

---

[24] According to documents shared with Frontier Economics by UKRI.

[25] Close-out report project data, as at September 2022, reported by CR&D.

Figure 18 Battery-related patent filings which specify electric vehicle application filed by automotive OEMs



Source: Frontier Economics analysis of IPO data

Note: Includes all battery-related patents that specify application or relevance to electric vehicle battery technology.

3.5.4 New SME tech/IP exploited

FBC supports SMEs through several initiatives:

- FBC Investment Readiness Programme: The Programme tailors SMEs that are at a demonstrator stage of development in the field of EV batteries and helps them prepare to present and connect with potential investors. SMEs need to be UK based and active in either batteries for EV propulsion or the battery value chain. This programme's first round took place in 2021 and because of its success a second round was organised for 2022. Each round supported 15 SMEs. UKRI reports that every SME in the 2021 cohort saw a positive outcome ranging from investment to partnership opportunities.[26]

- STEPS programme: FI together with Cambridge Cleantech launched an initiative to support SMEs in the field of battery technologies to bring innovative energy storage products to the market through their STEPS programme. The application process for SMEs opened in January 2021 and enables support for 40 businesses through a competitive product enhancement voucher programme in which 20 will receive extra support to demonstrate their technology at regional testbeds throughout north-west Europe. The aim is to "offer SMEs a user-centric, demand-driven approach to bring their products closer to the market through tailored testing" and to "support SMEs through its links into the UK's battery research and innovation network and, if

26 https://ktn-uk.org/news/faraday-battery-challenge-investment-programme-2022/#:~:text=The%20deadline%20for%20applications,then%20US%20investors%20in%20June

needed, quickly mobilise resources to address specific technical challenges through Industry Sprint projects".[27]

Aside from the SME-related developments reported in the previous section, the evidence of significant breakthroughs by SMEs in developing and exploiting IP as a consequence of FBC interventions remains limited.

It will be useful to monitor progress against this metric in future evaluations.

3.5.5 Progression of new technologies towards commercialisation

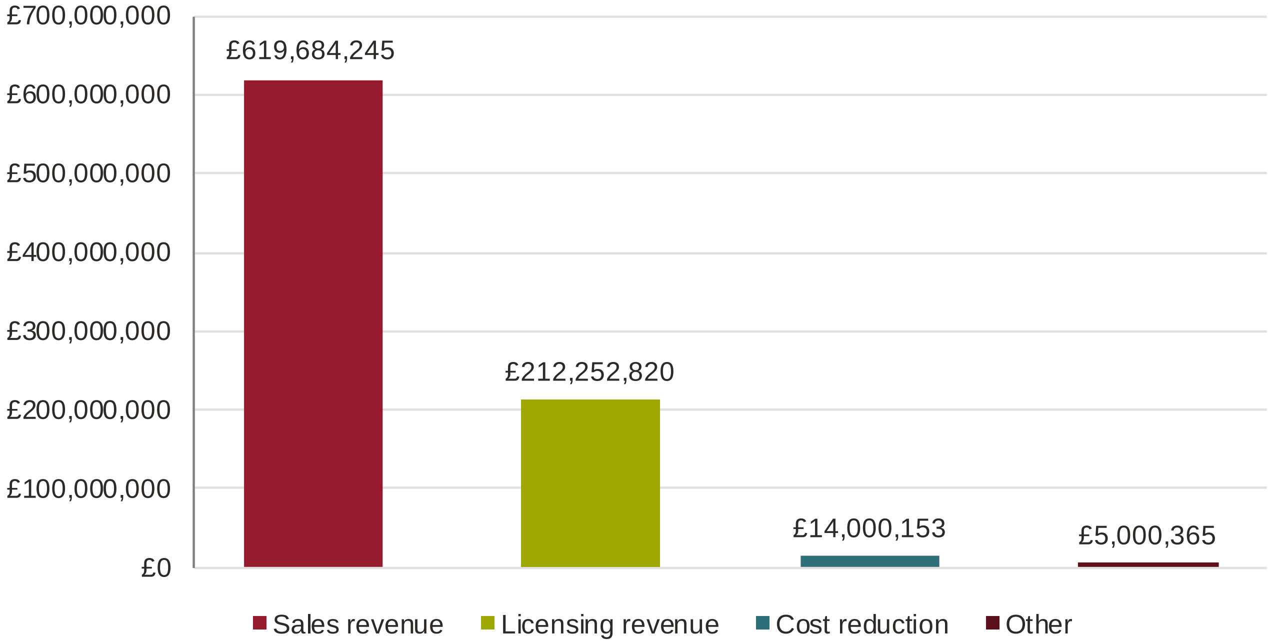
A common point to emerge from stakeholder interviews conducted for the case studies was that the UK is very good at research, including early-stage, next-generation research. As documented above, metrics relating to the generation of IP suggest a relatively positive picture.

Data from CR&D provide further evidence of this. Of the 246 collaborations captured by these reports (as at November 2022), 162 reported that their expectations of commercial opportunity had increased as a result of this project (of these, 71 reported that it had greatly increased). Thirteen reported no change, one a moderate decrease and one a great decrease, and the remainder did not provide an answer. When asked more specifically over what time frames participants expected to introduce new products, services or processes as a result of their collaboration, 18 reported within a year, 55 reported within three years, 36 reported within three to five years and ten in more than five years, while 30 responded never. There were also a large number of non-responses, in line with the question on expectations, probably reflecting the difficulty of answering questions relating to an inherently uncertain process. Sixty-six percent of respondents reported that their expectations of commercial opportunity had increased as a result of their project in collaboration with CR&D, while only 48% reported a time frame of between one year and more than five years, and 12% reported that they did not know about the time it would take. This may reflect uncertainties regarding the actual pathway to commercialisation.

CR&D participants collectively reported expected average annual financial impacts of around £851 million, principally from sales revenue (see Figure 19). This number has significantly increased since the interim evaluation when the expected financial impact was estimated to be at £120 million.

27 https://www.faraday.ac.uk/steps-dec2020/

Figure 19 CR&D participants' expectations of financial impacts



Source: Frontier analysis based on CR&D data

Clearly, if the challenge of commercialisation is to be met, what is required is for these effects to be replicated at scale. That has historically represented a challenge for the UK: there have been longstanding concerns by policymakers and industry alike about weaknesses in what they term the "middle part", i.e. the engineering, development and integration, which is key to bringing new technology to commercialisation. That could lead to UK IP being used overseas. While not in itself a bad thing, the question that is central to FBC as a whole is how to ensure that the generation of UK IP could anchor the production of batteries and EV value chains in the UK.

The extent to which there are weaknesses in the different links that bring new technologies to market can partly be ascertained on the basis of survey data. These are reported in Table 9 and Table 10 below.

Survey respondents who had been successful in securing FBC funding, as well as those who had not secured funding but for whom the project went ahead, were asked to disclose the stage of development their technology had been at at the start of FBC engagement, and the stage that it had currently reached. Table 9 summarises the results. As can be seen, while the majority of projects were between TRLs 1 and 4 at the beginning of FBC engagement, most now sat between TRLs 3 and 6. While 45% were at TRLs 1 and 2 at the beginning of FBC engagement, only 5% were now still at this stage. Meanwhile 4% were at the stage of being fully commercialised and brought to market (TRLs 8 or 9).

Table 9 Stage of technological development reached by survey respondents

Stage of development	At start of FBC engagement	Stage currently reached
Developing basic principles or formulating the concept (TRL 1 and TRL 2)	45%	5%
Developing the proof of concept or testing in laboratory conditions (TRL 3 and TRL 4)	42%	38%
Being validated or tested in a real but controlled environment (TRL 5 and TRL 6)	10%	34%
Being tested and scaled in an operational environment (TRL 7)	1%	14%
Fully commercialised and brought to market (TRL 8 and TRL 9)	0%	4%

Source: Phase 3 Survey, Question C11

Note: Respondents were asked questions C11: "At the start of your engagement with FBC, what stage of development was the technology at?" and C12: " What stage of development has the technology now reached?". This table was produced based on the 92 respondents for whom projects went ahead.

This information can also be looked at in terms of the number of projects that have progressed along the TRL levels and those that have not (see Table 10). As the survey questions grouped TRLs together, this can only be looked at in terms of an increase in stages – which are typically two TRLs each. Fifty had increased by one stage (58%), while 17 had increased by two stages (20%) and three had increased by three stages (3%). Overall, 16 out of the 86 (19%) projects where TRL information was provided had not increased their TRL stage since the start of their FBC engagement.

The survey results suggest that some progress through TRLs has taken place over the lifetime of the Challenge. In comparison to when these questions were asked in the interim impact survey (in 2020), more projects have progressed by at least one stage, although this may also reflect differences in duration across CR&D funding rounds.

Table 10 Numbers of survey respondents by TRL at the start of their engagement vs current status

	At time of survey				
	TRL 1 and TRL 2	TRL 3 and TRL 4	TRL 5 and TRL 6	TRL 7	TRL 8 and TRL 9

At start of the engagement with the Challenge	TRL 1 and TRL 2	4	24	12		
	TRL 3 and TRL 4		11	17	5	3
	TRL 5 and TRL 6			1	8	
	TRL7					1
	TRL 8 and TRL 9					

The bulk of the progress has taken place at lower or mid TRLs rather than from mid to high TRLs, i.e. which are closer to commercialisation. That likely reflects the fact that both FI and CR&D, the two strands of the Challenge that have been operational since 2018, focus on low and mid TRLs. However, compared to the previous stage of the evaluation, there has been a slight increase in the number of survey respondents which show progress at high TRL levels. Indeed, four survey respondents were now at TRL levels 8 and 9 compared to 2 in 2020.

Secondly, the survey results do not establish the *additional* effects of funding on progress against TRLs. In particular, mainly for want of sufficient data, the survey does not allow us to establish any systematic differences between beneficiaries of FBC funding versus those that are not beneficiaries. Narrative information from stakeholder interviews can provide some guidance on this.

Indeed, stakeholders considered that FBC had brought clear benefits to the UK battery research ecosystem by increasing the UK-based battery R&D capability and funding. This was observed in the improved facilities in universities and private companies as well as in the broad portfolio of new technologies being supported. These improvements were yielding battery innovation and emerging new technology options which could then benefit from other FBC support such as collaborative research projects. Some industry stakeholders noted, however, that R&D was not fully linking up with the commercialisation side of industry.

With these considerations in mind, the need to strengthen pathways to commercialisation remains an issue for FBC to address, although UKBIC is a step in the right direction. Case study interviews suggested that some stakeholders were concerned that progress towards the commercialisation of these – and contemporary battery technologies – was not happening fast enough to meet existing policy targets in the UK.

Finally, stakeholders also raised the fact that innovation was being supported at the national scale but that region-specific elements also needed to be taken into account in order to support enhancements in manufacturing. Indeed, when it came to establishing a full supply chain, there were multiple areas that needed addressing that were not within FBC's remit. Stakeholders viewed this as being of particular importance for manufacturing organisations with 100 to 500 employees and which do not have what they describe as an "R&D mindset". The areas that need to be considered to lower the associated barriers include more general manufacturing policy and support, loan schemes and tax exemptions, etc. It was suggested that a further ATF round might assist in developing manufacturing capacity and facilitate investment into the broader supply chain.

3.5.6 Summing up

The activities of FI and CR&D have contributed to stimulating developments at low to mid TRLs. For instance, FI has conducted a number of "industrial sprint" projects which target short-term industry needs for research and innovation that have been identified by companies. This number has significantly increased since the interim evaluation.

Participants in CR&D projects reported significant effects of these on their expectations regarding commercialisation, and close to half specified a timeframe of between one and five years for commercialisation. Reported expectations of profitability rose over seven-fold relative to the interim evaluation. In terms of actual progress through TRLs, while nearly half (45%) were at TRLs 1 and 2 at the beginning of FBC engagement, only 5% were now still at this stage. Only a small proportion (4%) were at the stage of being fully commercialised and brought to market (TRLs 8 or 9). That percentage may serve to moderate findings regarding expectations of commercialisation and profitability.

There is some early evidence of IP generation as a result of these projects. Data for CR&D collaborations show that the number of collaborations that are considering applying for patents has more than tripled since 2020.

As well as the direct contribution of FBC to various patent opportunities in the UK, there is evidence of a specific increase in R&D outputs relating to EV battery technology in recent years. Data on patents filed with the UK Government's IPO lists 53 battery patents that specify EV applications filed since 2013.

The evidence is mixed regarding the key issue of how far FBC has addressed the issue of de-risking scale-up and avoiding a "valley of death" phenomenon. The establishment of UKBIC was considered to constitute a step in the right direction. UKBIC has faced challenges in its early stages of operation. Stakeholders had continuing concerns regarding the pathway to commercialisation and that it was not happening fast enough to meet policy targets. They noted that R&D was not fully linking up with the commercialisation side of industry. Some also observed that innovation had been supported at the national scale but that regional factors – particularly skills – also needed to be taken into account in order to support enhancements in manufacturing.

3.6 Development of battery production capability and supportive ecosystems

3.6.1 Overview

Table 11 Summary of metrics and data sources for "development of battery production capability and supportive ecosystems"

Link to logic model	Metric	Data sources and methodology
(1) New start-up/small-scale battery value chain companies in the UK and increased growth of existing companies (CR&D shorter-term impact)	Cumulative number of new start-ups	ONS
(2) Increased likelihood of attracting gigafactories (UKBIC outcome)	UKBIC leads on gigafactory investors (longer term: FDI in gigafactories)	UKBIC
(3) Growth in commercial battery production and ecosystem including ancillary services (UKBIC shorter-term impact and Challenge Team outcomes)	Data on products and services Number of new commercial battery products from UK companies, annual production of new batteries (MWh, units), annual production capacity within UK companies Number of test houses and engineering services setting up in the UK; magnitude of these Generation of steady supply of UK-based recycled battery material	Case studies undertaken for this evaluation Surveys undertaken for this evaluation
(4) Growth in research ecosystem through spillovers (UKBIC shorter-term impact)	Balance of automotive and other sector batteries	Case studies undertaken for this evaluation

(5) Increased skills in battery force (UKBIC shorter-term impact)	Qualification levels of battery industry workers	Case studies undertaken for this evaluation Surveys undertaken for this evaluation

3.6.2 New start-up/small-scale battery value chain companies in the UK and increased growth of existing companies (CR&D shorter-term impact)

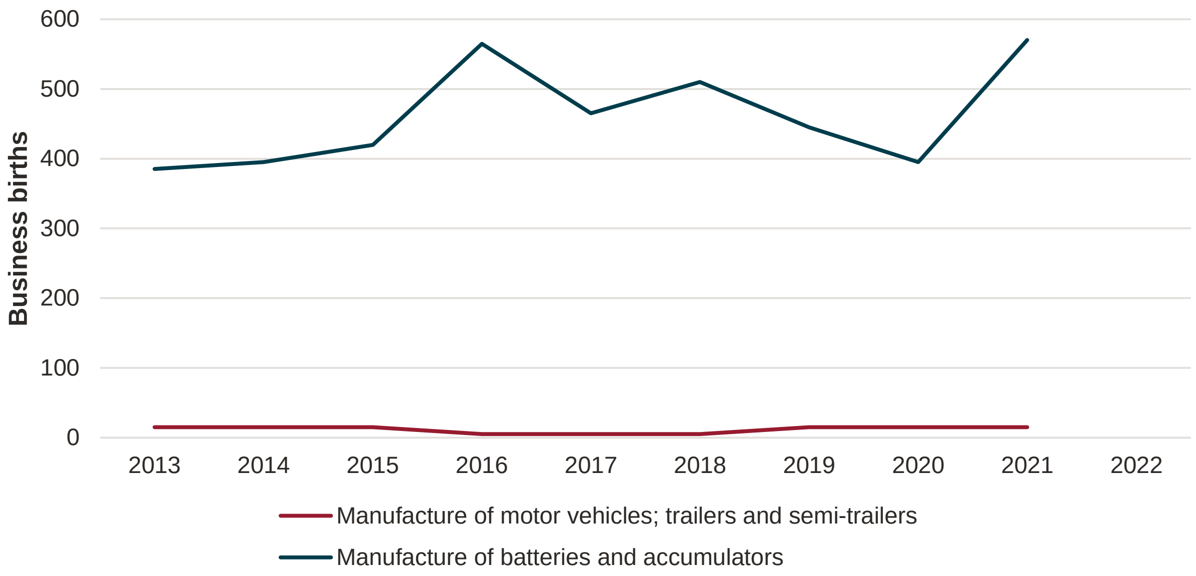
Context

The number of new start-up companies to emerge in the UK battery sector in recent years varies across different stages of the battery value chain.

Figure 20 shows that new start-ups in the manufacturing industry for motor vehicles, including firms responsible for vehicle, chassis and parts manufacturing, are rare. Since 2013, the number of new businesses entering the market each year has remained relatively constant.

In contrast, the number of new businesses in the UK classified as manufacturers of batteries and accumulators has increased significantly since 2013. An average of 460 new firms enter the battery manufacturing stage of the value chain each year. The number of new businesses that classify as manufacturers of batteries entering the market every year decreased between 2018 and 2020 but sharply increased again in 2021.

Figure 20 Births of new enterprises within the UK sectors for manufacture of motor vehicles and of batteries and accumulators



Source: Frontier Economics analysis of ONS data

Evidence from the Electric Vehicle Battery Tech in the UK 2023 provides further information on start-up activity. Indeed, while UK EV battery technology start-ups have undergone a 75% drop in net worth since 2021, the value of private start-ups has increased steadily since 2019. This is even more striking if the valuation of Britishvolt is excluded: the valuation of all other private start-ups doubled between 2021 and 2022. In addition, the evidence shows that 49% of the value is concentrated in companies founded since 2015, which indicates that the battery technology environment in the UK has been quite favourable, enabling the creating of new successful start-ups.[28] UK EV battery technology start-ups raised close to $1.1 billion in the period 2020-22, which is a significant increase over the nearly $230 million reported for the period 2016-19.[29] The extent to which FBC has contributed to this is unclear, but, as noted in Section 2.3.1, feedback from industry participants suggests that FBC is part of a broader enabling environment that facilitates fundraising because it provides a viable pathway from low TRLs to scalable commercialisation.

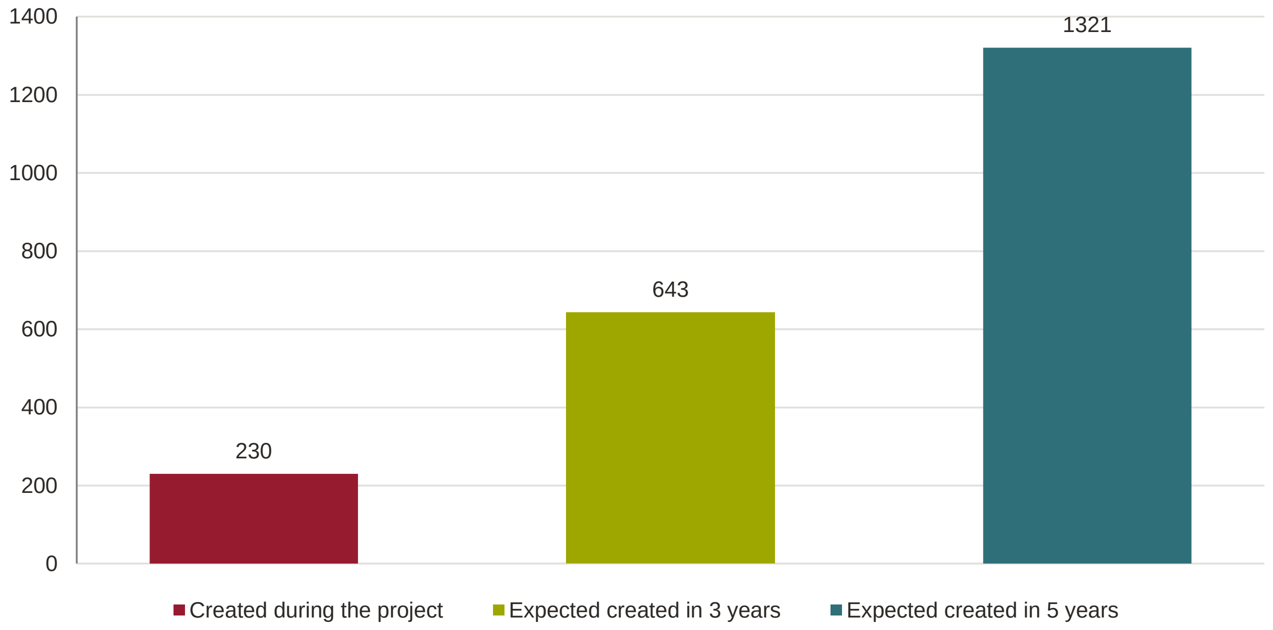
There is some evidence of FBC impacts on growth in battery-related SMEs and start-ups

As already observed in section **Error! Reference source not found.**, there is some evidence of the commercial impacts of CR&D activities on commercial prospects. Close-out reports also signal participants' expectations about jobs growth (Figure 21 below). As these are self-reported expectations, they should be treated with care, but they are nevertheless indicative of the potential impact of commercialisation if replicated at scale. It is relevant to note, in addition, that the participants' expectations about jobs growth have increased over FBC phase 1, with jobs expected to be created during the project, in three years and in five years being four times higher than in 2020. This increase goes hand in hand with the fact that the number of CR&D projects has significantly increased since 2020 (multiplied by eight).

[28] Dealroom.co and UKRI, Electric Vehicle Battery Tech in the UK 2023, p. 8.

[29] Dealroom.co and UKRI, Electric Vehicle Battery Tech in the UK 2023, p. 17.

Figure 21 CR&D participants' expectations regarding jobs growth



Source: Frontier Economics analysis based on CR&D data

Wider effects are harder to detect. The launch of FBC coincided with a continual increase in the number of new manufacturing firms listed under the classification "battery and accumulator" within the UK; more than 2,300 firms have entered the market since 2017 alone. However, it is difficult to ascertain the extent to which FBC actions have contributed to this increase in new start-ups in the sector.

For instance, Figure 20 shows a steady rise in the number of new battery manufacturing start-ups in the UK between 2017 and 2018, over which time FBC was launched as part of the government's Industrial Strategy. But this period was also characterised by a significant jump in the availability of funding for battery-related investment through parallel government initiatives such as the Advanced Propulsion Centre (APC) Technology Developer Accelerator Scheme. While this may limit the extent to which these outcomes are attributable to FBC alone, it highlights the value of complementary government interventions.

3.6.3 Increased likelihood of attracting gigafactories (UKBIC outcome)

As already observed, UKBIC's mission is to enable the scaling of battery-related technology, which in turn is crucial to developing the large-scale production in the UK of batteries using cutting-edge technologies. As already observed, large-scale production typically takes in gigafactories. Research by FBC forecasts that, by 2030, demand for batteries will be equivalent to that supplied by five gigafactories and that this will double by 2040, with most of the expansion required by the early 2030s. (This would be to supply demand stemming from a variety of end-uses and not just the automotive sector).

Progress on the establishment of gigafactories since FBC's inception has been patchy. At the time of writing, the following developments had been observed:

- Envision AESC: The project is to build a gigafactory with 12GWh/yr capacity employing more than 1,000 people located in Sunderland, UK. Envision AESC aims for the gigafactory to be operational from 2025 onwards. This project is part of a wider initiative between Nissan and Sunderland City Council to create an EV hub. The £1 billion partnership intends to support next-generation EV production in line with the transition to net zero carbon mobility.[30]
- Britishvolt/Recharge: The project was initially to build a gigafactory with 30GWh/yr capacity employing more than 3,000 people located in Northumberland. Britishvolt aimed for the plant to be operational by mid-2025, but it announced that it had entered into administration in January 2023. It was subsequently acquired by Australia-based Recharge Industries. At the time of writing, the timelines for gigafactory construction were not clear. Media reports suggest a focus on grid energy storage and the defence industry.[31]
- West Midlands gigafactory: Site permission has been granted, but no investor partner had been found at the time of writing. The consortium behind the initiative aspires to build a gigafactory with a capacity of 60GWhr/yr.

The role of FBC in these developments, and in furthering the potential for further gigafactory plans, is unclear. Foreign investors are reportedly impressed by FBC and see UKBIC as a differentiator for the UK vis-à-vis rival jurisdictions (see Section 3.4.3 for more details). As already reported in Section 3.2.2, between April 2021 and June 2022, the facility had been visited by 236 UK visitors and 47 overseas ones. These included four gigafactory investors, 77 customers, 94 potential customers, 29 interested parties and 11 visitors from the media.

UKBIC has also closely collaborated with Britishvolt over the past two years. Its president of Global Operations of Britishvolt, Graham Hoare, stated: "UKBIC is an essential ingredient in BV's accelerated roadmap to market, providing a platform and environment that delivers high quality development cells in a time period that would be almost impossible in other territories". This suggests that UKBIC had had a substantial impact on Britishvolt. The fact that Britishvolt subsequently entered into administration serves to underscore the multiplicity of factors that affect the journey to gigafactory investment and establishment in the UK. FBC can play a central role in that process, as it did notably by funding three projects in CR&D round four for Britishvolt, which enabled it to explore technologies for later generations of product. The overall narrative around Britishvolt highlights how the impact of FBC also depends on other factors.

Several comments were also made on the need to develop the demand side, which is likely outside the scope of FBC and UKBIC. While there is a general assumption that commitments to phase out internal combustion vehicles will stimulate the demand side, investor feedback suggests that there remain other barriers that need to be addressed to unlock projected battery uptake, particularly for batteries which incorporate new technologies that may initially sell at a premium.

30 https://www.electrive.com/2022/12/12/uk-envision-aesc-lays-foundation-for-sunderland-Gigafactory/

31 https://www.theguardian.com/environment/2023/feb/27/australian-startup-recharge-finalises-deal-to-take-over-uk-battery-maker-britishvolt

Finally, notwithstanding the focus on gigafactories, it is relevant to consider smaller-scale production announcements. Thus AMTE Power has announced plans for a “megafactory” (with a capacity of 0.5GWh/yr) in Dundee. AMTE also signed a contract with UKBIC in late 2022 for the manufacture of 60,000 ultra high power cells in a bid to boost its commercialisation plans.

3.6.4 Growth in commercial battery production and ecosystem including ancillary services (UKBIC shorter-term impact and Challenge Team outcomes)

As already reported in Section 3.2, survey evidence indicates that the UK is not seen as a world leader in the development of its battery production ecosystem. In particular, a significant proportion of survey respondents (c. 31%) suggested that the UK lags behind most other countries in this regard (20% suggested that the UK lags slightly behind and 11% that it is a long way behind most countries).[32] Less than 1% of survey respondents viewed the UK as the world leader in development of the battery supply chain. The results have deteriorated since the interim evaluation in 2020 when 21% of survey respondents suggested that the UK lagged behind most other countries in the development of its battery production ecosystem (15% suggested that the UK lagged slightly behind and 7% that it was a long way behind most countries).

FBC has had a positive impact on battery production and the wider ecosystem

Stakeholders’ views were generally that the work that FBC has done to inform policymakers and industry players about the importance of the growing battery supply chain has been beneficial to the UK battery ecosystem. FBC has helped build the requisite knowledge base amongst UK chemicals companies, which has enabled them to start having serious conversations about the battery supply chain. These points were documented more extensively in Sections 3.2 and 3.3.

The road to large-scale commercialisation is still challenging and highlights the role that UKBIC needs to play

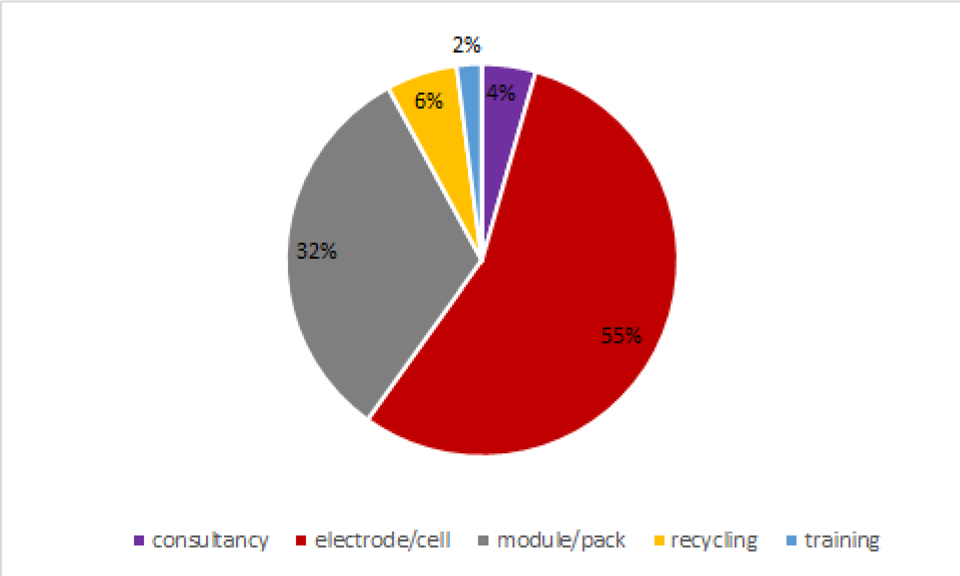
As observed elsewhere in this report, surveys and stakeholder feedback also highlight that the road to large-scale commercialisation, particularly of new technologies, is challenging. UKBIC is called on to play a pivotal role in this regard. Over the course of the first phase of the Challenge and of this evaluation, its ability to play that role has been constrained. To a large extent, this has been attributable to external factors – initially, the effects of the pandemic on the availability of technicians to ensure the commencement of operations on time and, latterly, a volatile investment climate because of input price shocks.

These external factors have meant that utilisation rates for UKBIC have been low (at under 15% of capacity in the first 43 weeks of 2022), while sales between September 2021 and October 2022 were around 55% of budget. As at March 2023, the total value of contracts won by UKBIC amounted to a little under £6.6 million. The chart in Figure 22 provides an overview of the breakdown of that total by type of activity, showing that the projects relating to electrode followed by module and pack account

32 Phase 2 Survey, Question B6. The question asked: “I’m now going to read out some elements of battery technology development and support. For each, please can you tell me how you think the UK is currently performing in comparison to other countries?”.

for the largest shares of contracts won by value. We also note a small share associated with recycling, which at the time of UKBIC's launch was not seen as a core activity but which is likely to rise in prominence in the near future given the importance attached to recycling in terms of the social acceptability of battery value chains

Figure 22 Breakdown of contracts won by UKBIC by activity



Of the overall value of contracts won, nearly a quarter were associated with partners and projects that had received funding from CR&D, providing some evidence of feed-through across the strands, and hence the role of UKBIC in taking technologies from their R&D phase to stages closer to commercialisation at scale. Target revenues for 2023/24 are at £7 million, with an ambition of targeting 10-15 new customers to broaden the customer base.

UKBIC has an active pipeline of leads that in turn generate prospects for future projects. At the time of writing, UKBIC had reported a total of 250 leads. Of these, 174 had advanced to a deeper level of engagement and 84 had reached the final bid stage. In terms of the numbers of leads, the majority were from the automotive sector, but a close number spanned multiple industries. A smaller number were from the aerospace sector. This provides some early evidence of UKBIC's potential to contribute across sectors and, if followed through, may contribute to addressing concerns expressed by some stakeholders that FBC's focus has been too heavy on the automotive sector.

The large majority of leads were from the UK. Of the limited number of non-UK leads, some were from European jurisdictions (Germany being the most frequent, with other EU jurisdictions including France and Slovakia) and the USA. A smaller number of leads were from Asia (Taiwan, India and Korea).

Aside from external constraints, factors that have attenuated customer take-up of UKBIC facilities and contributed to lost bids, include:

- Customers are arriving at UKBIC with cells at a relatively low level of maturity (TRL 5/6). This is likely to continue to be the case in future years and has meant that UKBIC has had to devote resources to adapting facilities that are close to those actually required by the customers.
- These potential customers have found the pricing of existing facilities to be too high.

In order to respond to these issues of scale, UKBIC is developing a facility known as the Flexible Industrial Line (or "Mini-Bic"), which is expected to become operational in the next 18-24 months. The development is expected to extend UKBIC's offer across the different stages of scale (cell design, prototyping, manufacturing at pilot phase and manufacturing at industrial scale).

A consistent message from stakeholder interviews is the value of outreach strategies in stimulating the prospects for large-scale commercialisation. UKBIC has provided some information regarding its outreach strategy. UKBIC has reported 283 visits in total, of which 228 were from potential customers, customers, customers with their investors, interested parties and partnerships, as well as 11 from the media. Table 12 below shows the breakdown of distinct company visits. It indicates that there is diversity in the types of companies visiting the facility (105 distinct companies). The main companies which visited UKBIC were vehicle OEMs, equipment manufacturers, cell (technology) producers and material (technology) producers, who combined represent 60% of the distinct company visitors. In addition, UKBIC held several events and participated in a number of others. This shows that UKBIC is already proactively reaching out to industry players and trying to increase awareness around its capabilities and work in the battery ecosystem.

Table 12 Visits recorded to UKBIC from distinct companies from April 2021 to June 2022

Distinct Company Visits	Number
Vehicle OEMs	11
Motorsport OEMs	4
Off-highway OEMs	3
Aerospace OEMs	5
Rail OEM	1
Electronic appliance OEM	1
Energy storage systems	1
Automotive suppliers	5
Powertrain manufacturers	4
Consultancies	3
Module & pack	2
Equipment manufacturers	17

Distinct Company Visits	Number
Cell (technology) producers	14
Material (technology) producers	21
Industrial/financial investors	6
CR&D consortia	7
Total	**105**

Source: UKBIC data

Numbers relating to contacts, contracts and utilisation are relevant to the public mission of UKBIC, in that the accumulation of project work and client interaction helps to stimulate knowledge transfer and learning-by-doing. These in turn should generate spillover benefits, notably the likelihood that the costs of bringing future technologies to market will decline. It is therefore also relevant to consider the lessons of experience from actual projects. UKBIC shared, on an anonymised basis, some of the lessons learned from the two largest projects that have accounted for the bulk of UKBIC income to date.

Key lessons include those relating to technical performance (yield, failure rates, energy density and unit costs in production) and broader project metrics, notably learning-by-doing key performance indicators, time to completion related to plan and actual cost versus budget. In relation to technical performance measures:

- Yield performance is difficult to discern, given the stage of the project.
- Failure rates tend to be high to begin with, given the nature of the projects, before showing significant improvements.
- Densities are close to or exceed market-leading densities.
- There is mixed evidence in relation to achieving target unit costs.

In relation to technical performance measures:

- Learning-by-doing effects were reported to be significant. They have been enhanced by UKBIC's hosting of customers onsite and pairing key resources so that joint learning occurs on a "day-to-day" basis.
- Projects have tended to overshoot initial timelines, partly because of amendments made during the process (itself an aspect of learning-by-doing), but have generally come in on budget.

UKBIC has also begun to collect data on customer feedback, but this is as yet at too rudimentary a level to permit any inferences. However, over time it could help with identifying the main mechanisms through which learning-by-doing can develop.

3.6.5 Growth in research ecosystem through spillovers

FBC has improved collaboration between academics and OEMs

As evidenced elsewhere in this report, FBC has contributed to the strengthening of academic-industry collaboration. Stakeholder interviews also pointed to the fact that increased funding and opportunities for collaborative research have enhanced the technological capabilities of UK battery stakeholders. Access to the collaborative research and overall ecosystem had led to some OEMs increasing their R&D headcount and capabilities in the UK. For instance, one OEM reported that it could not have grown a team equipped with resources for investigations without FBC. However, stakeholders also felt that FBC's influence on collaborative R&D was felt most strongly by SMEs rather than large automotive OEMs. That may partly be explained by the fact that larger businesses likely already have well-developed R&D facilities and systems. Having a greater influence on SMEs may be a positive thing to the extent that it helps to build a broader ecosystem of businesses within the value chains. At the same time, larger OEMs may be best placed to develop ideas at scale.

Collaboration has also focused on developing projections of cross-sectoral battery performance requirements and future research agendas. An example of such collaboration is FBC's work with the Advanced Propulsion Centre and WMG at Warwick University. This sets out targets for the period 2020-35 across various transport sectors (including marine transport, rail and air) in relation to safety, temperature, predictability and recyclability (see also Section 3.7.3 for further discussion).[33]

FBC and Innovate UK KTN have also established the Cross-Sector Battery Systems (CSBS) Innovation Network, which "aims to create an open and collaborative cross-sectoral community for researchers and innovators in battery manufacturing (including next generation batteries), the related supply chain and end-users". Collaboration extends to international partnerships, as evidenced by a recent US-UK Battery Technology and Innovation Research Summit. Such initiatives are likely to increase in importance given current trends in the USA and other industrialised nations to promote innovation in critical technologies such as batteries on a selective basis with like-minded partners.

FBC's focus on early-stage development stands to benefit broader sectors

While concerns about the future of the automotive sector were a key factor behind the launch of FBC, the broader benefits of innovation in battery technology were always firmly in view. Several key next-generation battery technology projects initiated by FI (for example LISTAR, which focuses on lithium-sulphur technologies, and Nexgenna, which focuses on sodium-ion) were explicit about their potential in relation to applications from aerospace to energy grids.

Stakeholders reported that FBC has had a positive impact in the battery ecosystem beyond auto applications as it has led to an increase in UK-based battery R&D capability and funding. This has resulted in improved facilities in universities and private companies as well as improvements in battery innovation and new technologies. Several stakeholders recognised that FBC has positively impacted

[33] APC, UKRI, WMG (2020), From Research and Manufacturing to Application and End-of-life: Enabling Electrification Across Sectors.

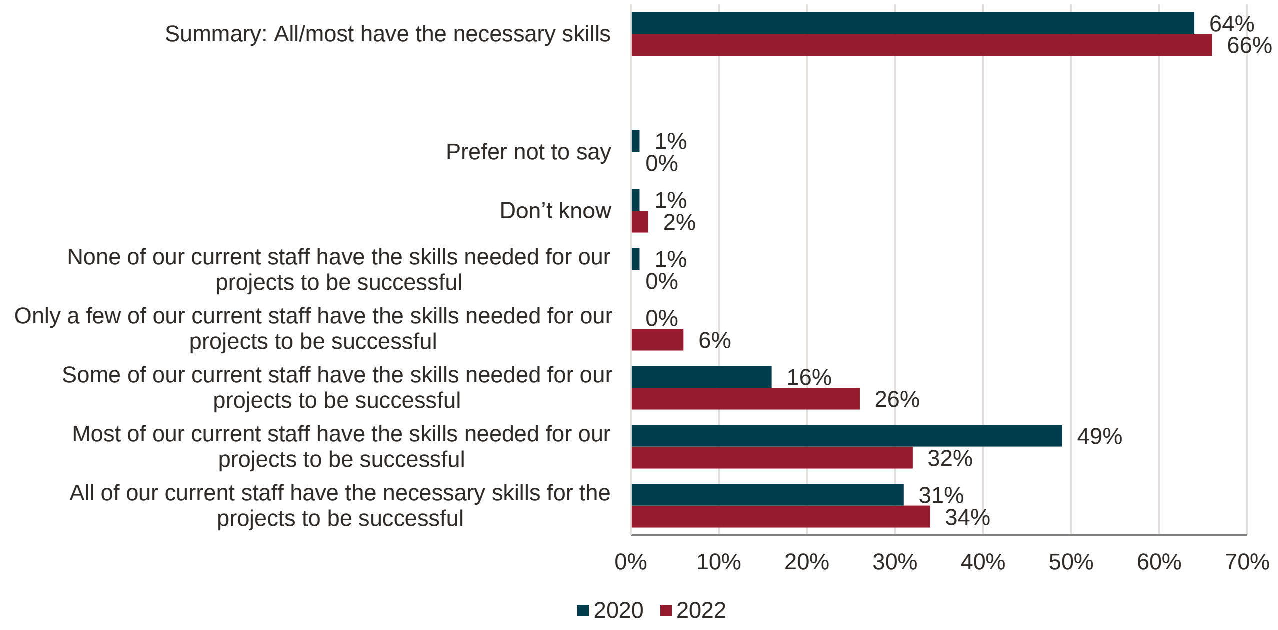
the aerospace industry given that some of the knowledge is transferrable. Some stakeholders even suggested that FBC should widen its scope, for instance, to include technologies considered for the aerospace industry.

3.6.6 Increased skills in battery force

Skills have a critical role in the emergence of a UK battery production ecosystem and the electrification of the automotive sector more generally. A skilled workforce embodies the know-how that any investor requires to operate at scale on a commercial basis. It is therefore a key determinant of investment. Skills are also critical to determining how far investments generate broader benefits over time. This is because the deeper the skills, the more likely it is that there will be spillover effects from an initial investment through domestic value chain linkages. Moreover, the “thicker” that set of skills is in a location, the more likely that location will be to attract further numbers of skilled workers, as workers will typically gravitate to regions where people with similar skillsets gather because this implies a deeper labour market for skills. Hence, the ability to grow a skilled workforce is important, while conversely an inability to retain skills can lead to self-reinforcing declines.

Survey evidence gives a relatively sober picture of the current skills levels of workers in the sector. While around two-thirds (66%) of respondents felt that at least most of their current staff had the necessary skills for projects to be successful, that proportion was considerably lower than at the time of the interim evaluation (Figure 23). However, over three-quarters (81%) felt that there were fewer people with relevant skills than the industry as a whole currently needs. This included three in five (60%) who thought there were significantly fewer people than the industry currently needs (Figure 24). These views have not changed significantly since 2020, suggesting that additional progress on skills in the industry has not been made. As discussed in more detail below, stakeholders considered that FBC has had a positive impact on narrowing the skills gap for high skill levels but that more efforts need to be made regarding lower skill levels.

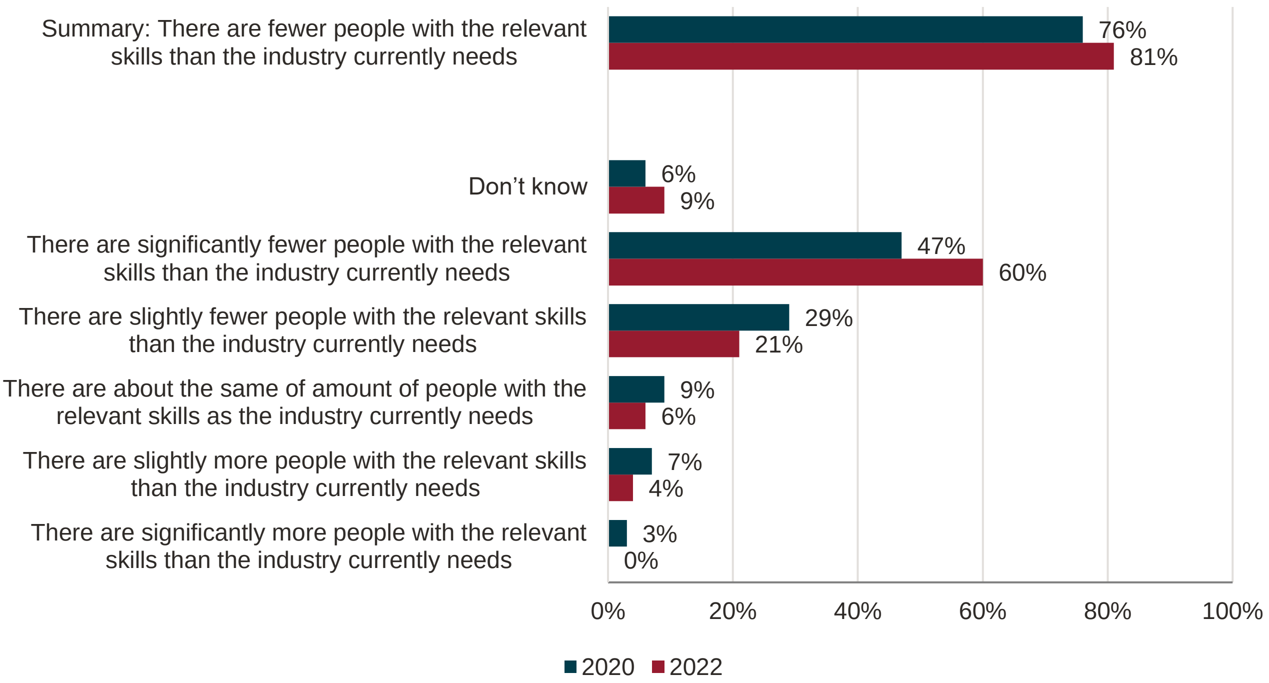
Figure 23 Survey responses on the existing level of skills in the respondent's individual firm



Source: Phase 3 Survey, Question E1

Note: Respondents were asked question E1: "Which of the following best describe the skill levels of your existing staff involved with your battery projects?". This chart is based on the 53 phase 3 business survey respondents and the 70 phase 2 business survey respondents..

Figure 24 Survey responses on the existing level of skills in the battery industry as a whole

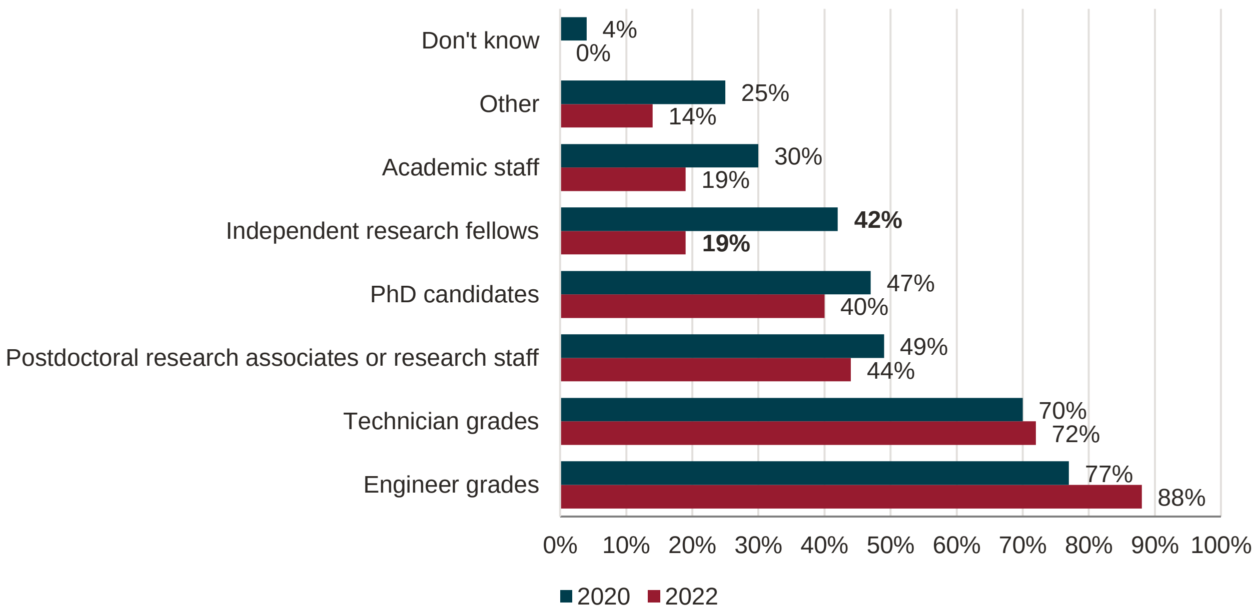


Source: Phase 3 Survey, Question E2

Note: Respondents were asked question E2: "And which of the following best describe your experience of the level of skills in the industry as a whole?". This chart is based on the 53 phase 3 business survey respondents and the 70 phase 2 business survey respondents.

Survey respondents who said that there was a current skills gap were asked what level of skills they felt were currently lacking (Figure 25). They most commonly mentioned engineer grades (88%), followed by technician grades (72%), both of which are areas in which perceptions of gaps have increased relative to the interim evaluation. Postdoctoral research and PhD candidates were also widely seen to be missing skills levels across the industry (44% and 40% respectively). The proportion of respondents who mentioned independent research fellows as a level that was lacking has decreased noticeably since this question was first asked in 2020 (now 19%, down from 42%), suggesting that some gaps may have been filled in this area. This shows that the UK is successful at implementing changes in areas where it already has a comparative advantage (i.e. research) but continues to face difficulties in applied fields relative to needs.

Figure 25 Survey responses on missing skills levels across the industry currently

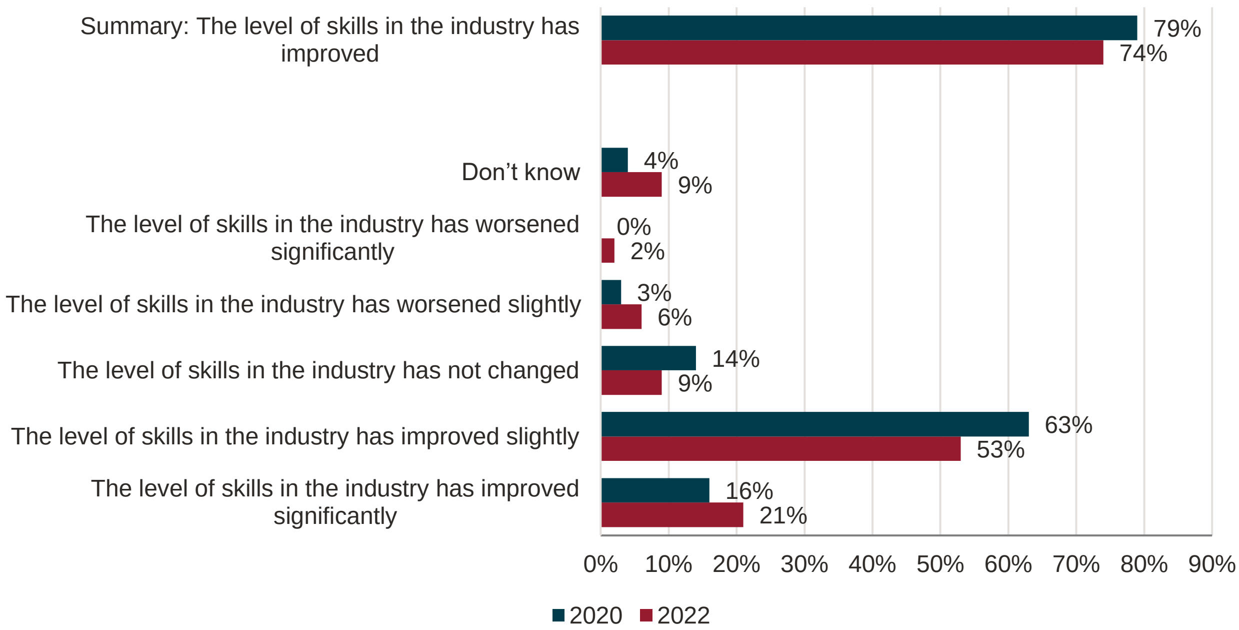


Source: Phase 3 Survey, Question E3

Note: Respondents were asked question E3: "What levels of skills do you think are currently lacking?". This chart is based on the 43 phase 3 and 53 phase 2 business survey respondents who thought there were skill gaps.

Despite the majority perceiving skills gaps in the industry, the levels of skills were generally seen to have improved since the inception of FBC, and FBC was seen to have had a positive impact on skills in the industry (see Figure 26 and Figure 27). Nearly three-quarters (74%) felt that the level of skills in the industry had improved, although the majority (53%) felt that the level had only improved slightly. Just under three-quarters (72%) felt that FBC had had a positive impact on skills levels. This proportion has decreased compared to when asked in 2020 (87%). The plausible inference that may be drawn from these results is that, while FBC continues to help develop skills, the growth in demand for skills outstrips their supply. This likely reflects stronger competition for such skills – indeed, the more successful the UK and FBC in particular are in making the UKBIC attractive to investors in battery technology, the greater the demand for skills.

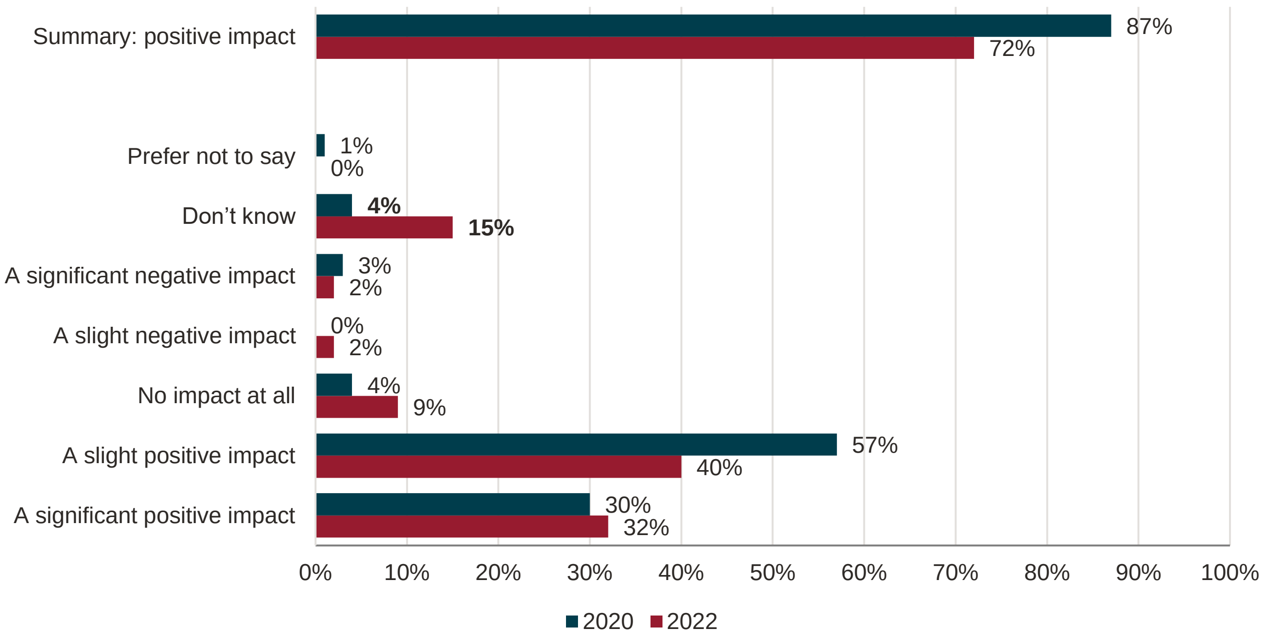
Figure 26 Survey responses on how skills levels have changed since 2017



Source: Phase 3 Survey, Question E4

Note: Respondents were asked question E4: "How do you think skills levels have changed since 2017?". This chart is based on the 53 phase 3 business survey respondents and 70 phase 2 business survey respondents.

Figure 27 Survey responses on the impact of FBC on skills levels



Source: Phase 3 and Phase 2 Survey, Question E5

Note: Respondents were asked question E5: "What impact, if any, do you think FBC has had on skills levels?". This chart is based on the 53 phase 3 business survey respondents and 70 phase 2 business survey respondents..

In addition to survey evidence, CR&D close-out reports present some evidence of effects on skills. The consortia were asked to assess whether the project had had an effect on skills along eight different dimensions: technical skills and knowledge; problem solving; business planning; strategic thinking; project management; fundraising; leadership; and collaboration and partnering. The responses show that 83% (205 of 246) of collaborations reported an improvement or development in skills in at least four of these dimensions. And all but one reported improvement or development in technical skills and knowledge, which is arguably the key focus of CR&D.

The top three dimensions in which collaborations reported improvement or development in skills were (see also Figure 28):

- Technical skills/knowledge (99);
- Collaborating and partnering (92%); and
- Problem solving (84%).

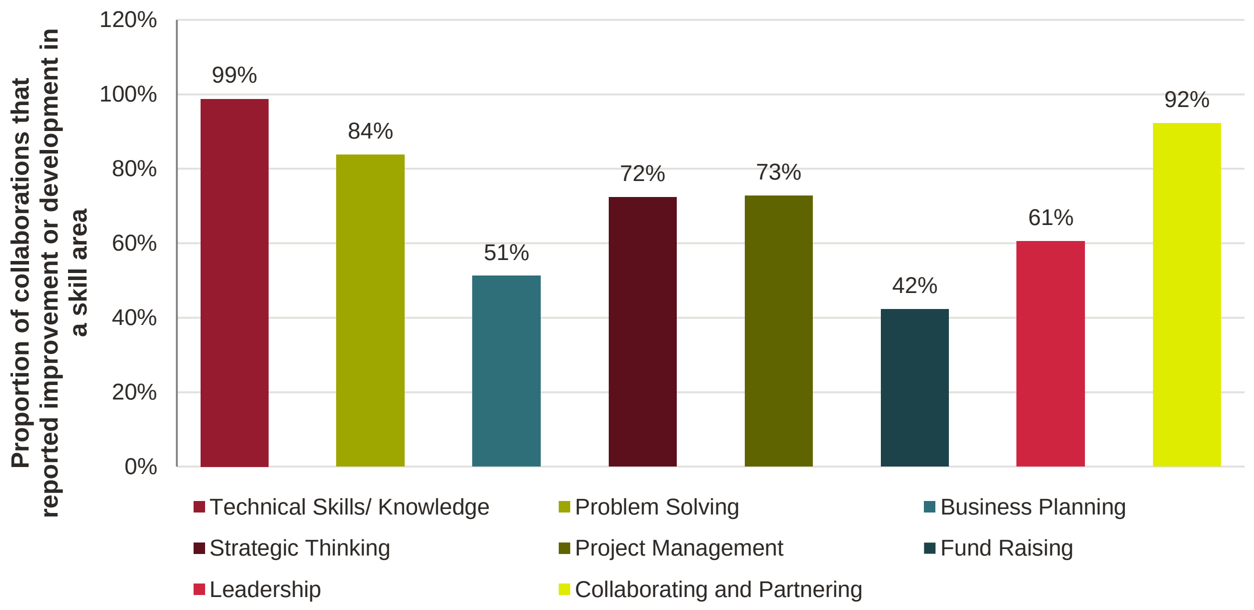
These dimensions are particularly important at initial stages of development.

Dimensions in which collaborations reported less improvement or development were:

- Fund raising (42%);
- Business planning (51%); and
- Leadership (61%).

These dimensions can be considered more commercial than the others.

Figure 28 Dimensions in which collaborations reported improvement



Source: Frontier Economics analysis of CR&D data

Globally, there is a high demand for battery skills that is not being met and hence there is a high level of competition. The general view of stakeholders was that FBC had started to successfully address this skills gap in the UK particularly regarding highly technical people (e.g. PhDs). However, they felt that more needed to be done to support other positions across the supply chain from cell engineers and technicians to getting an EV serviced at a non-specialist dealership and aftermarket repair. Specific training programmes, apprenticeships and collaborative research projects were suggested as good ways to train in these new skills. They also reported that:

- FBC has helped to provide people with the necessary skills to work in the UK industry, which is a positive differentiator for the UK versus other countries considered for investment. Training must remain a focus for FBC as more still needs to be done, particularly around manufacturing and chemical handling;
- FBC funding for equipment has allowed greater opportunity for many people to be trained; and
- FBC should also implement training for somewhat less technical skills. Apprenticeships were suggested as a way of filling some of these gaps. To support this, one stakeholder reported that most employees at fuel cell sites in Germany and in France had done apprenticeships and that this provided a well-trained workforce with skills that matched the needs of the employer. The stakeholder said that this had not been the case in the UK.

Stakeholders considered that narrowing the skills gap across the supply chain should remain a priority for FBC moving forwards. They acknowledged that FBC has played a significant role in skills development. They stated that FBC has been successful in training highly technical people (e.g. PhDs) but more needs to be done to support other positions across the supply chain. This includes cell engineers and technicians as well as beyond FBC to getting an EV serviced at a non-specialist dealership and aftermarket repair. Specific training programmes, apprenticeships, and collaborative research projects have been suggested as good ways to train in these new skills.

FBC is responding to these challenges. In collaboration with WMG and Driving the Electric Revolution, it has established a National Electricity Skills Framework and Forum to meet some of the skills requirements.[34] The initiative includes a "provider network", which aims to facilitate collaborative approaches to developing training and educational programmes, and an "employer network", which aims to stimulate cross-business and cross-sector collaboration in training. These network-based approaches can be seen as ways of capturing some of the spillovers that exist in training and education. In the absence of support for these initiatives via publicly funded institutions such as FBC, it is possible that businesses would underinvest in training because of limitations to their knowledge regarding training gaps, and because they fear that investments in training will be captured by other parties. The implementation of the framework may also be supported by other initiatives, such as the Emerging Skills Project (supported by the High Value Manufacturing Catapult and the Department for Education).

UKBIC, in collaboration with WMG, has developed a UK Battery Skills Framework, which aims to provide employers and employees with a defined set of standardised skills that help businesses with

[34] Faraday Institution, High Value Manufacturing Catapult and WMG (2021), *The Opportunity for a National Electrification Skills Framework and Forum*.

planning and employees with identifying career pathways. The ambition of the framework is to support reskilling workers from other manufacturing sectors that may contract over time, upskilling workers currently in the sector and the development of new skills in line with the technological changes expected in the sector.

UKBIC is working with Cogent Skills and a consortium of employers across the battery industry to develop a level 3 apprenticeship standard for a battery manufacturing technician. The apprenticeship will have four options:

- Electrode assembly;
- Cell assembly;
- Formation, ageing and testing; and
- Module and pack assembly.

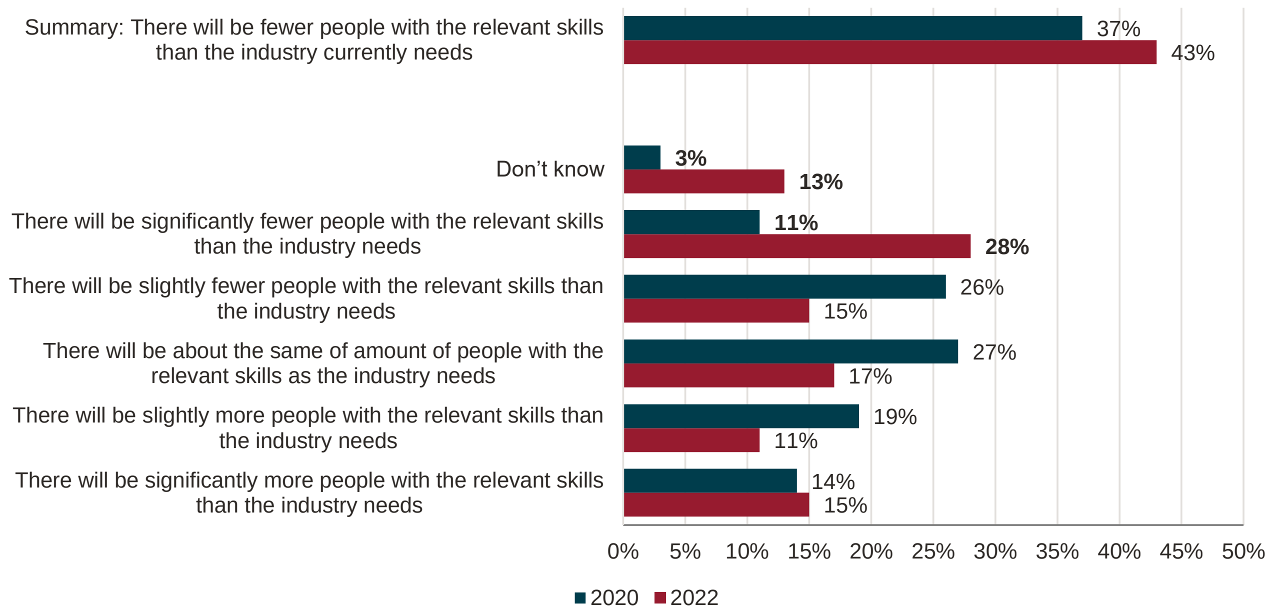
The apprenticeship has been approved by the Engineering Council and Institute for Apprenticeships and Technical Education and is expected to be available for learners from September 2023. The group is currently seeking appropriate providers to deliver the apprenticeship training.

UKBIC participates in closing the skills gap by providing training programmes. Since its inception, UKBIC has delivered three sessions to external organisations: two emerging skills project modules (introduction to battery manufacturing and delivery process training) and training in health and safety process in high voltage to a manufacturing company in the heavy goods vehicle (HGV) sector (providing specialised technology to HGV manufacturers). Those have reportedly received good feedback from the clients. However, training activities only represent 3% of UKBIC’s revenue.

In a sign of the demand for skills, UKBIC has seen a relatively high level of turnover since its inception. UKBIC reports that 48 employees left the company between July 2021 and January 2023: 18 were working in engineering and technology related areas, 11 in manufacturing operations and 19 in business functions. In 2022, there were 31 leavers out of an approximate headcount of 113 people. This indicate that the skills acquired by UKBIC are highly valued in the market. On the basis of exit interviews, UKBIC reported that seven leavers went to new jobs in the battery manufacturing sector. Of these, two moved to jobs overseas (Northvolt in Sweden, Innolith in Switzerland) and five remained in the UK (three went to Britishvolt, one went to Fluence Energy, and one went to Rolls Royce). To the extent that UKBIC builds skills through its operations, such throughflow contributes to developing the skills base of the industry indirectly, although arguably at the expense of UKBIC’s own operational effectiveness and its ability to meet public policy objectives.

Perceptions on what will happen to the skills gap in the industry over the next five years were mixed (Figure 29). While just over a quarter (26%) felt that there would be more people with the relevant skills than the industry needs, over two in five (43%) expected that there would be fewer. This includes over a quarter (28%) who felt there would be significantly fewer people with the relevant skills than the industry needs. This proportion has increased since the question was last asked in 2020 (11%), as has the proportion who were not sure.

Figure 29 Survey responses on whether the UK skills gap will have narrowed in five years' time



Source: Phase 3 and Phase 2 Survey, Question E6

Note: Respondents were asked question E6: "And what do you think the level of skills in the industry will be like in 5 years' time?". This chart is based on the 53 phase 3 business survey respondents and 70 phase 2 business survey respondents.

3.6.7 Summing up

The evidence suggests that FBC has made a substantial contribution to developing battery production capability and pathways for a supporting ecosystem. Key indicators of this are numbers relating to the birth of new businesses in batteries and related fields and evidence relating to start-ups and the role of venture capital. Data from CR&D close-out reports suggest that FBC has had a strong impact on participants' perceptions of commercial prospects.

The activities of UKBIC are expected to provide a pathway to commercialising at scale. Since the commencement of operations in 2021, UKBIC has ramped up its activities. It has also shown the capacity to adapt its offer to market demand and, in particular, to adjust the scale of its operations to suit the specific needs of the range of potential clients. It has an active lead and bid pipeline. Close-out reports from major projects provide early evidence of learning-by-doing effects.

The establishment of large-scale production via gigafactories, which would represent the pinnacle of the ecoysytem, remains a challenge, although data on planned investments suggest some progress. The findings also resonate with those of previous sections which point to the fact that FBC has contributed to enhancing the technological capabilities of UK battery stakeholders, as well as the fact that FBC has had a positive impact on the battery ecosystem beyond auto applications as it has led to an increase in UK-based battery R&D capability and funding.

While the activities of FI and CR&D have generated measurable, positive outcomes, the wider effects on industry at large are still emerging, and there are substantial challenges that need to be met. This is particularly the case in relation to skills, which will play a critical role in anchoring battery and related value chains in the UK and in ensuring that there are wider benefits from investment in these sectors. While the survey evidence and evidence from CR&D close-out reports suggest tangible impacts on skills, there is also evidence from surveys and stakeholders of continuing – and indeed in some cases, increasing – gaps in skills, particularly technologies and skills. That likely reflects the fact that global demand for such skills is escalating. Within the UK, an increase in investment activity – from start-ups to forward plans by gigafactory investors – is also likely to stimulate demand and increase perceptions of gaps. In that sense, the more successful the UK and FBC are in pushing forward the attractiveness of the UK for battery production and related value chains, the greater is the pressure to address skills challenges.

That in turn will depend on broader policy settings beyond the sole remit of FBC. At the same time, FBC has been making substantial contributions to the enabling framework for skills development through its collaboration with other institutions. This in turn can help to address some of the concerns expressed by stakeholders about skills gaps relating to engineers and technicians, and the need to develop apprenticeship programmes.

Of particular relevance are the National Electrification Skills Framework and Forum and UKBIC's work in establishing a Battery Skills Framework. Both these initiatives target market failures that usually affect the development of skills through, respectively, network-based approaches and by developing common standards. They would both also enable the upskilling of workers who could transfer from other sectors as the battery and automotive sectors expand, helping to address some of the labour market adjustment problems that economies face when some sectors expand and others contract. The ability to address market failures and manage adjustment effects are channels through which FBC, through these enabling initiatives, will be able to deliver broader economic benefits that extend beyond those of battery production activities.

3.7 Development of OEMs and other value chains

3.7.1 Overview of metrics

Along with gigafactories, the development of these value chains is the major prize as far as industrial strategy is concerned. As attaining this prize still lies several years in the future, the principle objective at this stage of the evaluation is to develop a base of information that can help to assess the likelihood of this happening and to provide a platform for future evaluations. Recent announcements regarding cell manufacturing ventures fit into this leading indicator category along with assessments of investor contacts by FBC strands, notably UKBIC. Narrative information from case studies is likely to be needed to establish the materiality of FBC's interventions.

Table 13 Summary of metrics and data sources for "development of OEMs and other value chains"

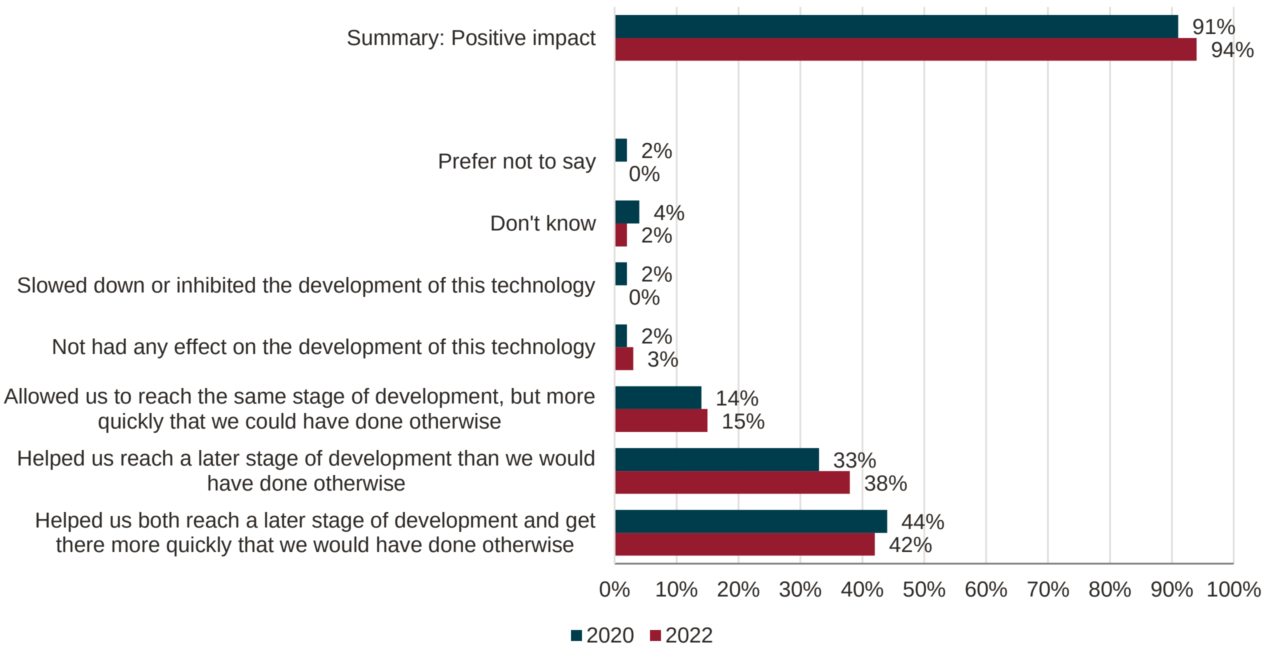
Link to logic model	Metric	Data sources and methodology
(1) Enhanced technological capabilities of UK battery and related businesses (Faraday Institution impacts)	Reported skills shortages UK component production capacity UK cell, module, pack, capacity	Surveys undertaken for this evaluation Case studies undertaken for this evaluation
(2) Emergence of new-generation battery technology options, including for non-auto application, particularly aerospace (industrial and environmental) (CR&D impacts)	Percentage of EV models developed using UK battery designs Chemistry	Case studies undertaken for this evaluation
(3) Flow-through benefits establishing EV value chain and other value chains (e.g. chemicals) (UKBIC impacts)	EV output Value-added data EV exports Chemicals sector output/ value-added data outlook Chemical sector exports Possible leading indicators for UKBIC include: UKBIC activity and project progression through the TRL/MRL grades Number of APC and ATI projects featuring UK battery companies	ABS data on EV output ONS data on value added HMRC data on exports Surveys undertaken for this evaluation

Source: Frontier Economics

3.7.2 Enhanced technological capabilities of UK battery and related businesses

As already explained in this report, the general view of stakeholders was that FBC has had a positive impact on many players in the UK battery space, from early-stage start-ups to OEMs. Survey evidence echoes this and shows that nearly all (94%) respondents who had received FBC funding described the impact that FBC's engagement had had on the development of their technology as positive (see Figure 30). This is highlighted by the fact that FBC's engagement had helped 80% of respondents to reach a later stage of development than they would have reached otherwise. In addition, over half (57%) said that their FBC engagement had allowed them to reach the intended stage of development more quickly than they would have been able to do otherwise.

Figure 30 Effects of FBC on stage of technological development

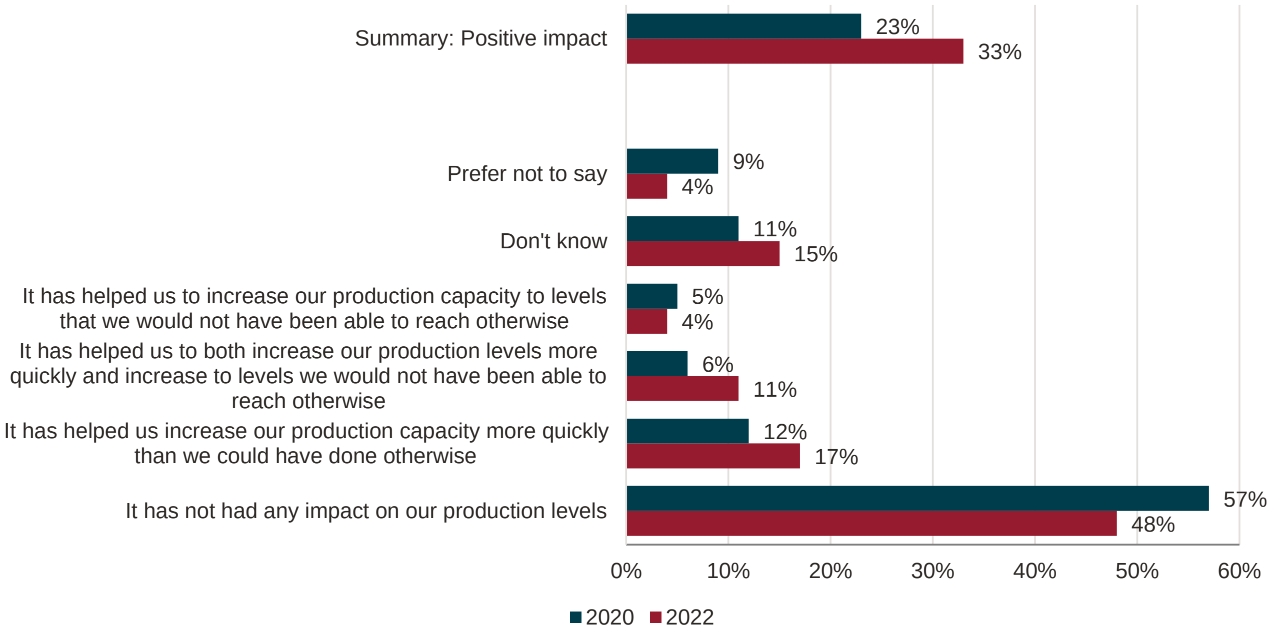


Source: Phase 3 and Phase 2 Survey, Question C13

Note: Respondents were asked question C13: "Which of the following best describes the impact you think engagement with FBC has had on development of the technology?". This chart is based on the 89 phase 3 and 117 phase 2 respondents who received FBC funding.

By contrast, survey data suggest that FBC's impact on production capacity is more limited (see Figure 31). Nearly half (48%) felt that their engagement with FBC had not had any impact on their production levels, while a third (33%) cited a positive impact regarding production levels, by helping to increase production capacity more quickly (28%) or increasing it to levels that would not have otherwise been possible (15%). Regarding impact on production capacity, 33% of respondents reported a positive impact compared to 23% in 2020.

Figure 31 Impacts of FBC on production capacity



Source: Phase 3 and Phase 2 Survey, Question D11

Note: Respondents were asked question D11: "Which of the following best describes how your engagement with FBC has impacted your production capacity?". This chart is based on the 46 phase 3 and 65 phase 2 business respondent who received FBC funding or had used UKBIC..

3.7.3 Emergence of new-generation battery technology options

As explained in Section 3.4.3, the view of stakeholders was that FBC's strong support for research is leading to innovation and new technology development and has thus been successful in increasing UK-based battery R&D capability and funding. This has notably translated into better facilities in universities and companies. These improvements are yielding battery innovation and emerging new technology options which could then benefit from other FBC support such as collaborative research projects.

FBC has also worked to establish enabling frameworks to support the emergence of new technology options. Thus, in order to support the transition from R&D to manufacturing and end-use applications, FBC has worked with the APC and others to establish requirements and research priorities for batteries for a broad range of electrification needs (beyond automotives). The analysis identified that the majority of requirements could be classified into four clusters:

- Energy-focused cost-sensitive applications: applications that fundamentally need energy at the lowest cost – the financial viability is the primary limiting factor for widespread application;
- Energy-focused weight- and power-sensitive applications: applications that fundamentally need energy but need to reach an improved level of energy and power density to work effectively;
- Power-focused cost-sensitive applications: applications needed to handle power at the lowest cost – the financial viability is the primary limiting factor for wider application; and

- Power-focused weight-sensitive applications: applications needed to handle power but also needed to reduce weight to work effectively.

The same research also established targets for safety, predictability, temperature and recyclability.

3.7.4 Flow-through benefits establishing EV value chains and other value chains

Thus far, OEMs have given limited signals regarding significant increases in EV manufacture in the UK. Some OEMs mentioned that they had increased their R&D headcount and capabilities in the UK. This was because increased funding and opportunities for collaborative research have enhanced the technological capabilities of UK battery stakeholders, which has led to benefits in terms of access to collaborative research and the overall ecosystem.

More generally, signals regarding increased investment are limited, and seem mainly to be confined to niche OEMs such as Lotus and Aston Martin, both of which had signed memoranda of understanding with Britishvolt. In light of the latter's commercial failure, it is unclear what the manufacturers' plans will be. A stakeholder believed that the OEMs and car manufacturers would view the UK as the best location to produce supercars but not mass EVs. This is consistent with the view that supercars may be better placed to use premium technologies and draw on brand differentiation, which helps them to overcome some of the cost-increasing factors and constraints that may affect future mass production in the UK. These are related to the external factors documented in Section 3.2.2

Stakeholders also reported that FBC's impact goes beyond batteries for EVs:

- FBC has contributed to an increased understanding of the needs and requirements in non-automotive applications such as stationary storage and aviation regarding batteries. In addition, aviation OEMs had strongly considered the UK for their battery development due to its research capabilities but eventually decided to invest elsewhere. Some stakeholders felt that it could be beneficial for FBC to widen the scope of its activities to include aviation and stationary storage in the second phase given the challenges those sectors are facing. It is important to note that the choice made by aviation OEMs may also be driven by the fact that batteries are likely to only be a relatively small part of the decarbonisation picture for aerospace (with hydrogen and synfuels) and hence constitute less of an investment priority.
- FBC has positively impacted the chemical supply chain by laying the groundwork in increasing companies' knowledge of battery technologies. Stakeholders felt that activity had increased over the past couple of years in the chemical supply space and that this was partially due to FBC's influence.

3.7.5 Summing up

Survey respondents were of the opinion that FBC had had a positive impact on the development of technological capabilities, with a majority of respondents reporting that they had reached a later stage of development than they would have in the absence of the Challenge. They had detected weaker effects on production capability. That result resonates with the broader narrative emerging from this evaluation, namely the difficulties in translating technological progress into commercial prospects.

Stakeholders broadly agreed that FBC has had a positive impact on the development of technological capabilities. However, they expressed the view that SMEs have benefited more from FBC's actions than OEMs. Despite the establishment of UKBIC, concern remained amongst stakeholders regarding the Challenge related to the development of production capability and in bringing research to markets.

Survey respondents and case study interviewees also underscored the importance of multiple external factors outside the direct influence of FBC, notably trade policy and the competing attraction of other jurisdictions, that could impact the development of value chains.

3.8 Economy-wide impacts

Based on the findings to date, the economy-wide impacts of the Challenge can be expected to arise via the following channels:

- The long-term effects of systemic changes to the conduct of R&D. In particular, to the extent that the collaborative model fostered by FBC enables R&D to be conducted more efficiently and increases the probability of innovation, this could have long-term benefits in terms of productivity;
- The increased investment in R&D by businesses, particularly start-ups, and technological progress achieved by businesses generate spillover effects that in turn stimulate further investment and have beneficial impacts on productivity and economic growth; and
- The impacts of gigafactory investment and production on employment and economic activity.

The impacts of these channels on headline indicators of economic performance, including regionalised effects, would typically manifest themselves over a longer time frame than the first phase of FBC. We were therefore not expecting to report any findings in relation to such headline indicators.

What we can report is that the outcomes of phase 1 show positive trends in relation to the three mechanisms set out above. There is strong evidence on systemic changes to the conduct of R&D and on technological progress (including prospects of favourable commercial outcomes) by businesses via interaction with FBC. There is also some evidence that the Challenge has contributed to improving prospects for gigafactory investment.

But these positive trends need to be qualified with the observation of continued difficulties in addressing barriers to commercialisation at scale, which has long been identified as one of the main hurdles the UK needs to overcome. Even though participants in collaborative R&D reported significant expectations of profitability, these would need to materialise at scale. Moreover, self-reported expectations on profitability need to be tempered by findings on the reported effects of FBC on production capabilities.

4 Conclusions

4.1 Findings in the context of the theory of change

The theory of change highlighted the need for a "big push" to enable the transformation of battery technologies and battery manufacturing, and through that the transformation of motor vehicle and related value chains. It also highlighted the broader benefits of improved battery technology to the development of low emissions technologies in transport and energy storage. These transformations are needed to secure overall goals relating to clean (i.e. consistent with net zero objectives) economic growth. Given the pervasive nature of market failures associated with the transformation of industrial processes, a series of coordinated interventions, of which FBC is one, is required, as are enabling policy settings.

To capture how far FBC has contributed to these transformative changes, and the benefits associated with them, we developed a framework based on seven evaluation themes. The metrics associated with these helped to provide guidance on the nature and extent of benefits associated with the implementation of FBC since the baseline year of 2017 compared to a counterfactual case in which FBC had not been established.

The overall evidence suggests that FBC has made a material contribution to these transformations and to increasing the prospects that their associated benefits will be realised. It has done so in a period that has been considerably more challenging than anticipated at the start of the Challenge, due to a series of external shocks. There remain, nevertheless, a number of significant gaps that need to be addressed.

Turning to specific findings against particular evaluation themes, we observe the following.

In an increasingly challenging global environment, FBC has contributed to an improved policy environment and the attractiveness of the UK as a destination for battery investment

Evidence from stakeholders points to several instances in which FBC has strengthened the coherence of policy frameworks and supporting interventions, notably around the inception of the ATF and in communicating battery investment requirements and prospects to industry and authorities. Substantial work undertaken by FBC in collaboration with other institutions has helped to identify research priorities and performance requirements for battery technologies in a range of sectors. FBC has also worked to develop a framework for skills development, which could contribute to remedying skills gaps and therefore strengthen investment. Survey responses show a strong and robust perception of FBC's contribution to the attractiveness of the UK as a destination for battery investment. Trends in foreign investment in battery technology start-ups have also been positive since the inception of the Challenge.

Perceptions of the UK's position internationally relative to competing destinations for battery investment are mixed. Survey evidence suggests that, overall, the UK has not broken through into a position of global leadership on batteries. Indeed, according to both surveys and stakeholder feedback, there have also been some signs of slippage in recent years. These may be related to adverse perceptions about investment in the UK more generally, linked to transient factors. From an evaluative perspective, the combination of favourable views of FBC and its contribution and more mixed perceptions of the UK's general standing as a destination for battery investment suggest that the latter may be more attributable to broader factors that would have been observed in a counterfactual scenario in which FBC had not existed.

FBC has, via the activities of FI and CR&D, contributed to a systemic change in the conduct of battery R&D

There has been a significant effect via FI on increased volumes and quality of research outputs, including via international collaborations. There is also evidence that FI has been associated with an observable increase in collaborative effort, within the UK and internationally in academic research. CR&D data point to high levels of satisfaction by consortia regarding their collaborative activities, and to increased numbers of collaborative efforts. FI research has had a greater impact than UK battery research as a whole and worldwide battery research for parts of phase 1. At the same time, impact has dropped off more recently, and the UK's position vis-à-vis the rest of the world in terms of impactful research predates FI's activities.

The Challenge is making a positive impact on technological progress, although this tails off at closer-to-market levels of technological readiness …

Activities of FI and CR&D have contributed to stimulating developments at low to mid TRLs. For instance, FI has conducted a number of "industrial sprint" projects which target short-term industry needs for research and innovation that have been identified by companies. This number has significantly increased since the interim evaluation. Secondly, participants in CR&D projects reported progress on TRLs – around 60% had progressed at least one level. Progress is significantly more limited at higher TRLs.

…and therefore the effects of the Challenge on technological capabilities in value chains and commercial readiness are mixed

Given the relatively recent launch of FBC, multiple technological breakthroughs were not expected by the time of the evaluation. The aim is to understand effects on capabilities and progress in bringing technologies closer to market as predictors of future breakthroughs. Survey responses suggest that, for a majority of respondents, FBC had helped them to get to a more advanced stage of technological capability and/or get there faster than expected relative to the counterfactual of no engagement with FBC. At the same time, a majority of survey respondents also suggested that FBC had improved their prospects for commercialisation, revenue and job creation. However, the reported effects on production capacity were less positive, with the majority not detecting an effect on production capacity. In conjunction with the evidence of limited impacts at higher TRLs, this serves to moderate expectations regarding commercial success.

UKBIC's activities were constrained by external factors over the course of the evaluation. Project experience to date has enabled it to adapt its product offering, notably by adapting scale to the needs of clients, which is expected in turn to increase its attractiveness to commercial partners. Data on projects to date point to some degree of feed-through from CR&D supported projects. Project feedback also points to significant learning-by-doing effects. If these can be replicated at a larger scale through greater utilisation rates of UKBIC's facilities, the impact of UKBIC on deepening technological capabilities will be enhanced. While there are financial reasons for building up UKBIC's future project pipeline, UKBIC management is conscious of the need to balance commercial imperatives with the broader public mission of seeking projects that are likely to stimulate knowledge transfer and learning-by-doing.

Stakeholders reported that FBC has had a positive impact in the battery ecosystem beyond auto applications as it has led to an increase in UK-based battery R&D capability and funding. This has resulted in improved facilities in universities and private companies as well as improvements in battery innovation and new technologies.

In a challenging environment, there are some positive signs regarding actual and projected investment

Recent evidence suggests significant investment in battery start-ups, driven by venture capital. This may not be directly attributable to FBC. However, based on statements made by investors, it is likely that the broader ecosystem of interventions in favour of battery technologies has helped. After a slow start caused by external factors, UKBIC has developed an active pipeline of projects across a range of activities. It has also adapted its product offering to respond to feedback from potential customers, in particular calibrating its facilities to the varying scales of activities required by potential investors as part of their journey from lab testing products, to prototyping, to production at larger scale. Stakeholder feedback suggests that investors see UKBIC as an important point of differentiation in the UK investment landscape vis-à-vis rivals.

Skills gaps remain and are likely to be a critical issue for the UK's aspirations regarding gigafactories and motor vehicles

The survey evidence and evidence from CR&D close-out reports suggest tangible impacts on skills: skills levels have been increasing. Nevertheless there is also evidence from surveys and stakeholders of continuing – and indeed, in some cases, increasing – gaps in skills. In other words, even as the supply of skills has increased, demand has outstripped it. That is likely to reflect the fact that global demand for such skills is escalating. Within the UK, an increase in investment activity – from start-ups to forward plans by gigafactory investors – is also likely to stimulate demand and increase perceptions of gaps. In that sense, and perhaps paradoxically, the more successful the UK and FBC are in pushing forward the attractiveness of the UK for battery production and related value chains, the greater the pressure to address skills challenges.

Skills are a critical determinant of the UK's ability not only to attract investment but also to absorb the technologies that come with it. Addressing skills gaps will require more than interventions by FBC. It will also rely on broader policy settings, including labour market policies and ones related to the movement of people into the UK. In recognition of this, FI has worked to develop a National Electrification Skills Framework and Forum, while UKBIC has developed a Battery Skills Framework.

Both target market failures related to the development of skills and can also facilitate the reskilling of workers from other sectors that may seek opportunities in the battery sector as it expands.

The window of opportunity is narrowing for FBC and UK policies towards batteries more generally to make a difference

While the evaluation helps to document the progress recorded by the Challenge, a broader issue that arises is the limits to incremental progress in a context of rapid change in the global context for the industry. A fully fledged scramble for dominance and control of green value chains is now under way, and larger jurisdictions are developing their policy arsenal for industry support and seeking to contain the efforts of rivals (e.g. through investment restrictions, anti-subsidy actions, the use of norms, standards and regulations). It is therefore important that the UK establishes itself rapidly within the global battery production ecosystem. While the UK cannot match the scale of subsidies or internal market offered by the likes of the USA and the EU, the global nature of value chains offers the UK the opportunity to specialise in battery production activities that link into the needs of these larger markets.

4.2 Implications of findings for the next phases of FBC

The overarching rationale for FBC was to increase the efficiency of R&D activities and reduce barriers that have traditionally hampered routes to the commercialisation of new technologies. FBC demonstrates strengths in terms of addressing the fragmentation of the R&D landscape, increasing the quality of outputs, and the ability to achieve tangible results at low to medium TRLs. Where the picture is more mixed is in terms of bringing research to market. There have been some clearly positive effects via CR&D, but the picture is more subdued in relation to the major prize of attracting substantial gigafactory investment in the UK. Progress towards the commercialisation at scale of R&D continues to present a challenge.

The declared level of ambition set for phase 2 is high: to become a global battery superpower in order to secure automotive production in the UK and facilitate its transition to low emission technology. This is to be underpinned by value chains that embody leading technologies and that enable an equitable distribution of the benefits from these value chains.

As seen from the results of this evaluation, achieving this will require a considerable step-up over the outcomes and impacts delivered to date.

A few key areas stand out:

- The way in which skills issues can be addressed;
- Whether UKBIC is able to act as a strong attractor for investment and facilitate the diffusion of technology and knowledge through the industry;
- Whether evidence of investment in start-ups leads to a step change in innovation and output; and
- Whether progress in early-stage technologies translates into marketable prospects.

In addition to these, phase 2 will likely need to tackle more fully a range of issues that lay at the periphery of phase 1. These include, notably, recycling and circular economy principles, and sustainability issues more generally. For example, the EU's sustainable batteries initiative establishes norms both for production and processing methods within the EU and across all segments of value chains that interact with the EU single market. This gives the initiative extra-territorial reach – businesses in the UK will need to comply even if they do not sell directly into the EU but supply a business that may in turn sell to the EU.

The evaluation also highlights the extensive interdependencies between FBC and broader supportive interventions in the batteries/automotives space and domestic policy. In particular, it highlights the importance of the availability of large-scale funding, notably of capital costs, to attract investment in an international context in which competing jurisdictions are prepared to spend large amounts of funds to pursue decarbonisation and capture "green value chains" in the process.

The external context has indeed become much more challenging than was anticipated at the launch of FBC. The second phase will need to take account of a "new normal" in terms of the global context for batteries and industrial policy more generally. This "new normal" involves stronger rivalry between countries and a higher level of fragmentation. UK policymakers will need to ensure that the UK and battery and related value chains in the UK are resilient to the shocks that are likely to arise out of this changed context.

Annex A Overview of FBC structure

A.1 The Challenge as a whole

A.1.1 Description

The Faraday Battery Challenge (FBC) is part of the Industrial Strategy Challenge Fund (ISCF). The ISCF is the vehicle through which the UK Government sought to invest £4.7 billion in the period 2017-21 to support the objectives set out in the Industrial Strategy White Paper[35] published in 2017.

The Industrial Strategy includes an Automotive Sector Deal. The Sector Deal aims to deepen the partnership between government and industry, and to set the direction and long-term strategic priorities for the sector. FBC is one of the commitments made under that Sector Deal. Others include £500 million over ten years (to 2023) allocated to the Advanced Propulsion Centre (APC) to support research and development (R&D) and industrial development in low carbon automotive technologies, and a further £225 million for automotive R&D from 2023 to 2026.

FBC is intended to stimulate the high-volume manufacturing of batteries in the UK using leading technologies. This requires innovation in battery technologies and attracting investment from battery manufacturers who operate on a globalised basis. For reasons explained in greater detail in the introduction to this report, battery production is a critical step in securing the manufacturing of low emissions vehicles in the UK.

In addition to industrial policy goals, the emphasis on low carbon technologies reflects the UK Government's legal commitments to achieve net zero emissions by 2050 and its intention to ban the sale of petrol- and diesel-powered vehicles from 2035.[36]

FBC was initially allocated a funding envelope of £246 million over the period 2017-21, divided across three strands:

- Research (£78 million) managed by the Faraday Institution (FI);
- Collaborative R&D (CR&D) (£88 million); and
- £80 million for scaling up under the aegis of the UK Battery Industrialisation Centre (UKBIC). This was to be established in 2020 by a consortium and delivered by the APC.

The funding for UKBIC was subsequently expanded to £108 million, taking the total envelope to £274 million.

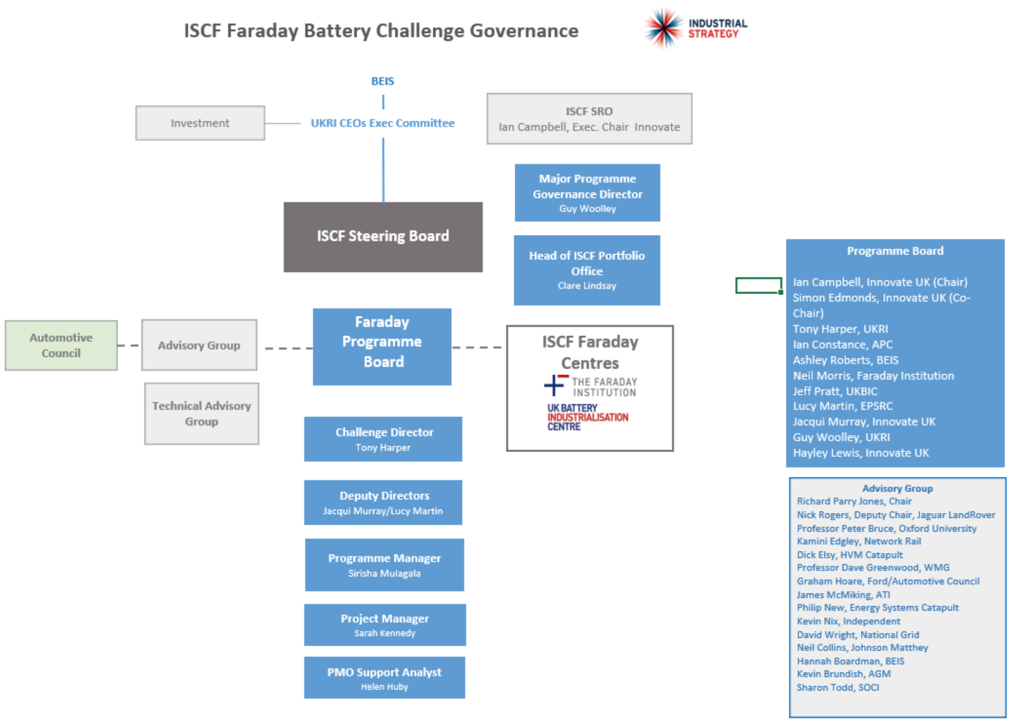
FBC is governed by a board and supported by an advisory group, with higher-level oversight at the overall ISCF level, as depicted in Figure 32.

---

35 The White Paper can be accessed here.

36 Currently under consultation: https://publications.parliament.uk/pa/cm201719/cmselect/cmsctech/1454/145408.htm

Figure 32 Governance structure of the Faraday Battery Challenge



Source: Full Business Case for the Faraday Challenge – Batteries for Britain, 19 May 2017, p. 39

Note: The scale-up programme is now called UKBIC.

One of the key goals of FBC is to induce a step change in battery technologies, rather than simply delivering incremental improvements to existing technologies. This step change is necessary in order to ensure that propulsion systems based on batteries can be deployed on the scale required to replace propulsion systems based on conventional internal combustion.

For this transformation to be successful, FBC needs to integrate development of new battery technologies through all technology readiness levels (TRLs). This means that the three strands of the Challenge need to work collaboratively to succeed. The logical sequencing of this is that research projects conducted at lower TRLs by FI might feed into CR&D projects, which in turn feed into UKBIC's activities that support scaling and testing. This flow can go in the other direction as well. For example, insights from a CR&D project could inform future research projects under FI.

As already observed, FBC is part of a broader Automotive Sector Deal initiated by the government to secure the long-term transformation of motor vehicle manufacturing in the UK. FBC therefore operates in the context of industrial requirements and the Automotive Council has set targets which batteries will be required to meet for their successful adoption (see Table 14 below).

Table 14 UK Automotive Targets

Attribute	Status in 2017	Target in 2035
Cost	-$130/kWh (cell) -$280/kWh (pack)	-$50/kWh (cell) -$100/kWh (pack)
Energy density (cell)	-700Wh/l -250Wh/kg	-1.400Wh/l -500Wh/kg
Power density (pack)	3 kW/kg	12 kW/kg
Safety	-	Eliminate thermal runaway at pack level to reduce pack complexity
1st life (pack)	8 years	15 years
Temperature (cell)	-20° to +60°C	-40° to +80°C
Predictability	-	Full predictive models for performance and ageing of battery
Recyclability (pack)	10-50%	95%

Source: Automotive Council UK (2017), UK Automotive Battery Challenge

The UK is a major developer, manufacturer and integrator of ICEs. To support the transition to electrification, FBC seeks to develop the UK automotive-focused battery supply chain to improve battery performance, cost, lifetime and recycling. This is underpinned by the close collaboration between FBC and the APC, which facilitates UK-based R&D projects featuring later-stage low carbon automotive technologies. Although the automotive sector is initially the main focus, it is intended that the outputs of the Challenge will translate to other sectors such as aerospace and rail. In a manner similar to the APC, the Aerospace Technologies Institute is building close ties with FBC, making it an increasingly significant stakeholder.

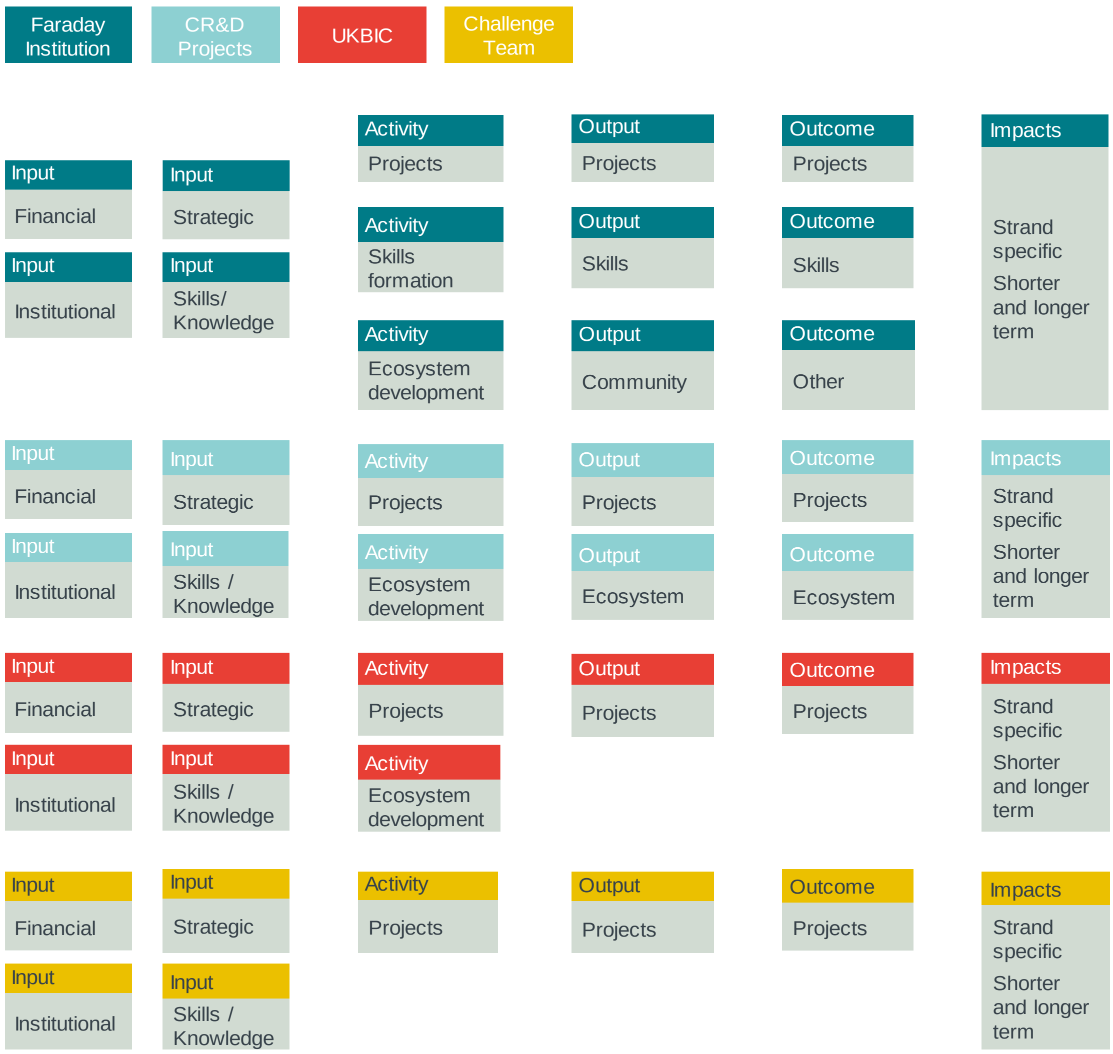
A.1.2 Logic model

Our approach to FBC logic model is as follows. We begin by presenting the overall architecture of the model for the Challenge as a whole. We then present strand-specific logic models for each of FI, CR&D and UKBIC. A separate Challenge Team logic model is also presented.

There are multiple linkages between the individual objects within each strand, as well as between strands. For this reason and to preserve readability, we chose to not highlight each link. Instead we focus on highlighting the most important linkages between individual objects and the feedbacks between the strands.

The figure below shows a schematic overview of the logic model for FBC as a whole.

Figure 33 FBC logic model



The model follows the standard approach to logic models, based on a left-to-right flow from inputs to activities, to outputs, to outcomes, to impacts. In this case, given the dynamic nature of impacts and likely time horizons for them, the model differentiates between shorter- and longer-term impacts.

While there is a general recognition that impacts may reflect the combined activities of all strands, some may be more specific to particular strands.

The layout of the model does not imply that relationships between parts of the model are purely linear and unidirectional. There are various feedback loops that operate within and across strands, resulting in cumulative (non-linear) effects. Indeed, the theory of change that we developed suggests that transformational change requires such self-reinforcing effects, and the Challenge is designed to support their occurrence.

The model is necessarily at a high level, with more detail added in the strand-specific models that follow below. What the high-level model captures is the commonalities between the strands, particularly in terms of outcomes. All strands thus aim to support specific projects, albeit at different parts of the TRL spectrum. They also produce outcomes and impacts over shorter- and longer-term timescales.

In developing the strand-specific logic models, we drew as far as possible on UKRI's work on developing a benefit map and identifying the factors and pathways that underpin benefit realisation.

A.2 The Faraday Institution

A.2.1 Description of the strand

The Faraday Institution (FI) is a registered charity and company limited by guarantee. It was formally established in October 2017 to bring together expertise from universities and industry to support research, training and analysis in battery science and technology. FI is a "virtual" institution. It was originally established around a platform of seven founding partner universities but is independent of these in terms of decision-making.[37]

FI awards funding to university-led consortia to deliver applied research projects that are aligned to industrial needs. In addition, funding for training programmes is provided to grow a talent pipeline for UK energy storage R&D. Training includes provision of a four-year structured support programme for PhD students involving research on battery-related topics, training in work skills and training programmes for undergraduates. The aim is to reduce the fragmentation of research and to foster collaboration and coordination of the UK research landscape across multiple disciplines and institutions.

FI has been active and prominent in the early years of the Challenge. This reflects in part the fact that it has built on a pre-existing research landscape, which in turn reflects the UK's strong academic scientific research base. Stakeholder consultations highlighted that in the initial phase of

[37] University of Oxford, University College London, Warwick University, University of Cambridge, Imperial College London, Newcastle University and the University of Southampton.

the Challenge, FI has been the most noticed component by potential battery and original equipment manufacturers (OEMs) outside the UK.

By harnessing and developing the UK's strengths in basic research, FI seeks to increase the likelihood of achieving major breakthroughs in battery technology which would help to secure the UK's position as a location for battery manufacturing. This in turn would enhance the UK's ability to attract, retain and capture value from electric vehicle (EV) manufacturing.

FI focuses primarily on early-stage research, i.e. at low TRLs. It benefits from a funding commitment of £78 million over the period 2017-21. According to the 2018/19 annual report, it committed £71 million (or 91% of the budget) through to 2021.

FI has three principal research streams:

- Optimising current generation lithium-ion batteries. This consists of five focus areas: extending battery life, multi-scale modelling, recycling and reuse, electrode manufacturing and lithium-ion cathode material;
- Beyond lithium-ion: new-generation battery technologies. This consists of solid-state batteries, sodium-ion batteries and lithium-sulphur batteries; and
- New battery-focused characterisation and analytical techniques intended to provide researchers with the tools to enhance their understanding of battery materials and their performance.

Within these overarching streams, FI launched four fast-start projects in 2018, focused on:

- Extending battery life;
- Multi-scale modelling;
- Battery recycling and reuse; and
- Solid-state batteries.

In the second half of 2019, five further projects were launched covering:

- Electrode manufacturing;
- Lithium-ion cathode materials (2 projects);
- Sodium-ion batteries; and
- Lithium-sulphur batteries.

In addition, three smaller projects, known as "industry sprint projects", to develop battery-focused characterisation and analytical techniques were also launched in the second half of 2019.

Beyond support to specific research programmes and projects, FI sees itself as playing a central role in changing the culture and approaches to how scientific research is done, in order to enhance its impact. For example, FI has sought to develop an approach that is more mission based and milestone focused than has traditionally been the case with academic research. FI considers that the size of the current research community for batteries, specifically, is restricted in the UK. It seeks to deepen this community by attracting research leaders.[38]

Beyond its support of technological innovation and development, a key part of FI's mission lies in developing an understanding amongst both the public and policymakers of industrial policy objectives surrounding batteries and EVs and the environmental benefits associated with these.

A.2.2 Logic model

FI is the first link of FBC. Its activities are intended to generate outputs, outcomes and impacts that flow through the other strands. FI aims to support breakthroughs in battery technology but, to achieve this overarching goal, it seeks to induce systemic changes in how R&D and innovation are done in the UK. These transformations would apply within the research community as well as between research and industry, and between the UK and the international community. This is why the activities column contains a box devoted to ecosystem development. One of the key points here is the transformation of the UK research environment from small competing research teams to a broader community with aligned goals and purposes.

Systemic change depends on the possibility of self-reinforcing effects: as communities are created, these serve as strong attractors for further expansions in skills (for example, academics are attracted to UK institutions or trainees, and students are attracted to study and do research).

The logic model for FI is depicted below.

38 Interview with Lucy Martin.

Figure 34 FI logic model

Input: Strategic
- Appointed leadership
- Existing industrial strategy priorities and UK automotive targets

Input: Skills/ Knowledge
- Existing knowledge based and university programmes
- Researchers with relevant experience
- Research plan

Input: Financial
- £78 million ISCF funding over 4 years for large scale low TRL research

Input: Institutional
- Governance arrangements (internal and cross strand)
- Mechanisms for allocating funding

Activity: Projects
- Establish portfolio of low TRL research projects [specify frequency of calls]
- Sprint projects targeting short term needs
- Monitor implementation and expected returns
- Rescoping of projects as needed

Activity: Skills formation
- Identify research skills gaps
- Support academic training from undergrad to post-grad through internships, secondments and industry fellowships

Activity: Ecosystem development
- Build community of collaborative researchers
- Engage with industry through multiple channels
- Participate in International Battery Research Alliance
- Outreach to policymakers and public on battery research and STEM more generally
- Thought leadership & producing objective analysis for govt, industry and academia

Output: Projects
- Completion of low TRL research projects.
- Dissemination of findings
- Lessons from unsuccessful research
- Commercialisation and IP opportunities identified
- Number of CR&D projects explicitly using FI research*
- Number of completed sprints

Output: Skills
- Cross academic collaborative / multidisciplinary research
- Joint industry / academic publications

Output: Community
- Sustained collaboration within UK and internationally
- Academic industry secondments/ industry fellowships
- Publications for non-specialist audience

Outcome: Projects
- Increased probability of breakthrough against 8 targets
- Increase in FI registered spinouts
- IP metrics related to FI research
- Value of projects using FI research

Outcome: Skills
- Quality of published outputs and correlation with FBC funding
- New energy storage research leaders attracted to the UK
- Standing and leadership of UK universities in battery-related disciplines
- Impact on STEM

Outcome: Other
- Use of UK university generated IP
- Attraction of international research and personnel to UK, measured by people and publications

Impacts: short term

Likely to be influenced by other strands
- Reputation for high quality R&D contributes to attractiveness of UK as location for battery manufacturing

Impacts: Longer term

Likely to be influenced by other strands
- Enhanced technological capabilities of UK businesses
- Enhanced skills and productivity of UK workforce
- Enhanced STEM capabilities

A.3 CR&D

A.3.1 Description of the strand

UK businesses have access to funding of £88 million for feasibility studies and collaborative research and development (CR&D) projects that develop new and improved battery technologies. The CR&D programme is managed by Innovate UK and focuses on mid-TRL projects. The projects so far have been working on improving battery lifespan and range, and the reuse, remanufacture and recycling of batteries at their end of life. The overall aim of CR&D is to ensure that UK battery technology is brought closer to market and that the supporting ecosystem to do this is developed.[39]

CR&D allocates its funding through competitive funding rounds. Four rounds have been held – in July 2017, January 2018, September 2018 and September 2020 respectively. Over 90% of the budget has been committed through these four rounds, covering 63 grant awards.

Projects are largely led by micro/SMEs (small and medium-sized enterprises) (73%), followed by large organisations (16%) and then OEMs (11%). Eighty percent of projects have at least one academic collaborator.

---

39 Interview with Anna Wise.

The CR&D portfolio is balanced between riskier bets on future technology, on one hand, and incremental improvements to existing technology, on the other. The CR&D strand uses research outputs from FI and contributions by private sector partners. The strand engages with industry to align views and goals and reaches out to sectors that were not previously closely engaged with batteries.

The CR&D programme aims to progress technology towards scale-up and commercialisation, which feeds through to UKBIC and may feed back into new research themes to be taken forward by FI. The formal processes for cross-strand collaboration are still under development. The third round of competitions run by CR&D was informed by a feasibility analysis of which FI projects could feed through to CR&D.

A.3.2 Logic model

The CR&D strand of FBC aims to provide proof of concept of new technologies and bring them closer to market. To do this, their goal is to strike a balance between inducing collaboration between projects and teams and running competitive tenders for projects. Further, they are trying to create a balanced portfolio of high-risk, high-reward projects and improvements at the margins of existing technologies. These points are summarised in the activity projects. The eight targets for battery development set by the Automotive Council guide the decisions on what to focus on in their R&D efforts.

The logic model for this strand is depicted below.

Figure 35 CR&D logic model

Input: Strategic

Priorities for each round of competitions

Input: Skills / Knowledge

Internal resources to administer projects and programmes

Skills of collaborating businesses

Inputs from FI research outputs

Input: Financial

£85,4m ISCF allocated over 4 years for collaborative R&D to progress the 8 targets

Contributions by private sector partners, incl. through follow-up

Input: Institutional

Collaborative arrangements with other strands

Activity: Projects

Management of project portfolios

Evaluation (upfront and ex-post) against 8 core objectives and supply chain development

Monitor ratio of transformative and incremental projects to strike balance

Activity: Ecosystem development

Running cohort and cross-strand events

Feasibility studies on use of FI outputs (done in the long run)

Industry monitoring to identify opportunities for market pull-through

Engaging with sectors to align views and goals

Outreach to sectors not previously closely engaged with batteries

Coordination with FI and UKBIC

Output: Projects

Risk balanced portfolio of projects combining technological relevance and commercial returns

Close out reports demonstrate achievements or lessons learnt

Dissemination of findings

Opportunities for IP patents, licences, prototypes, spin-outs

Output: Ecosystem

Number of new collaborations and their duration

Proportion of SMEs funded

Outcome: Projects

Progression of battery technology within CR&D projects towards the 8 targets.

Progression towards scale up and commercialisation

Creation of new products and services

Increased total revenue/value as a result of funded projects (years 1-3, 5-7, 8-10)

New/improved skills from projects

Outcome: Ecosystem

Feed through to UKBIC/ feedback to FI

New SME Tech/IP exploited (metrics of projects, products, services)

Increased £ value of follow up and external funding per year

Impacts: shorter term

Likely to be influenced by other strands

New start-up/small scale battery value chain companies in the UK and increased growth of existing companies (cumulative number of new start ups)

Increased investor confidence and foreign investment in R&D generating innovation (increased annual R&D spending).

Impacts: longer term

Likely to be influenced by other strands

Emergence of new generation battery technology options, including for non-auto application (industrial and environmental)

Development of value chains connected to battery development

A.4 UKBIC

A.4.1 Description of the strand

The UK Battery Industrialisation Centre (UKBIC) is the third strand of the Faraday Battery Challenge, which was launched in 2017 with the ambition of making the UK a world leader in battery technology. UKBIC formally launched its operations in July 2021, later than originally planned, largely reflecting the effects of the Covid-19 pandemic. This made it difficult to mobilise the technical personnel required for the final commissioning of UKBIC facilities and impeded efforts to develop a pipeline of potential customers.

UKBIC is located in Coventry and received an initial investment of £129.1 million. This is higher than the initial budget of £80 million envisioned for the project, which was considered insufficient to provide the required fit-out for the facility given UKBIC's positioning in the battery supply chain (and thus the need to provide the facility with equipment on a scale sufficient for manufacturing). Additional funding of approximately £50 million was provided through a UKRI grant (£30 million) and West Midlands Authority (£18 million), the latter of which was provided as a loan.[40]

The long-term aim is to stimulate investment in large-scale manufacturing through the establishment of "gigafactories". The UK is expected to need between five and eight such gigafactories by 2040 to meet demand. Additional facilities will afford opportunities for the UK to export battery technology abroad; however, insufficient gigafactory investment will leave the UK reliant on imported battery technology.

The thrust of UK policy in relation to batteries goes beyond the establishment of gigafactories. It also aims to deliver breakthroughs in battery technologies. Technological breakthroughs have multiple benefits: they increase battery performance and therefore the likelihood that batteries can play their part in decarbonising various modes of transport. And pushing out the technology frontier could make the UK more attractive to investors in battery technology and original equipment manufacturing (especially EVs) and could help the UK to capture a greater share of value-added from these value chains.

These investments in battery technology are expected to generate broader benefits by anchoring other value chains, notably the manufacturing of EVs and related activities as well as battery materials and chemicals. These are sectors in which the UK has a demonstrable comparative advantage, so securing investment in these activities is expected to generate benefits to the UK in terms of economic growth and employment.

The other two strands of FBC target the development and proof-of-concept phases of new technology. UKBIC thus aims to bridge the gap between the demonstration phase of a new technology and high-volume manufacturing. In particular, it seeks to address the hurdles and market failures associated with scaling up new technologies. Scale-up is crucial for batteries, as

40 UKBIC has noted that Coventry Council (which partnered with UKBIC in approaching West Midlands Authority (WMA) for additional funding) believes that the WMA loan will be converted to a grant following the next round of local authority funding. UKBIC intends to follow this route in negotiating future payments of this funding with WMA.

formulations that work in the laboratory do so under tightly controlled experimental conditions. However, battery scale-up requires flexibility due to the in-batch variability of volume production, which bears little relation to experimental techniques or even to prototype scale.

UKBIC's position in the pathway from R&D to mass production is therefore “tonne-scale” production, providing a facility in which to progress manufacturing beyond “gram scale” (universities) and “kilo scale” (R&D pilot lines, Catapult). UKBIC is thus less a production line and more a commercialisation platform. The idea is that companies bring a proof-of-prototype design, with UKBIC providing the facilities to prove scalability.

The UKBIC concept is itself experimental and a first of its kind globally. Apart from its linkages to the other two strands of FBC, its distinguishing features include the fact that it offers specialist services to support scaling up new battery technologies based on open access principles. In practice this means that customers pay UKBIC for the use of its facilities for activities to support scaling up. Once these activities have been completed, the investor is then responsible for large-scale production through its own facilities.

UKBIC does not enter into large-scale production contracts and does not benefit from any IP rights (e.g. through licensing). The protection of IP generated by customers is seen as a key selling point for UKBIC to customers over alternatives, particularly in Asia.

The main condition currently imposed on customers who contract with UKBIC is that they commit to investing in battery manufacturing in the UK. UKBIC management also conducts due diligence on the potential contracting partners to screen them for financial and technical capacity.

UKBIC is required to attain financial self-sufficiency in the sense that revenues are required to cover operating costs. Aside from being an end in itself, the ability of UKBIC to earn net revenues and become self-sufficient in line with its business plan is an indicator that it is on track to meet the overall objectives set for it and the Challenge as a whole, namely to attract a high level of interest in battery manufacturing in the UK.

A.4.2 Logic model

The logic model was developed as part of a specific baseline study undertaken in relation to UKBIC in autumn 2021, reflecting the fact that UKBIC operations commenced at that time.

Figure 36 UKBIC logic model

Input: Strategic
- Internal business plans
- Assessments of industry needs

Input: Technical and knowledge
- Workforce skills
- Equipment and machinery for six areas.
- Knowledge and skills from investors
- Inputs from other FBC strands
- Utilities and maintenance costs

Input: Financial
- Initial investment of 129.1 million. Additional investment in £50 million

Input: Institutional
- Investment and trade promotion activities by HMG
- FBC governance inputs

Activity: Projects
- Operation and maintenance of equipment across six areas
- Training of personnel
- Skills development through learning by doing
- Monitoring of skills gaps
- Monitoring project and product performance
- IP generation and transfer

Activity: Business and ecosystem development
- Project pipeline and outreach activities
- Coordination with HMG to target investors
- Benchmarking against rivals
- Assessment of industry technology needs and skills gaps
- Standards development

Outputs:
- Utilisation rates of facilities
- Number and value of projects across each of 6 areas
- Number of products brought to TRL 8
- Number of new and repeat collaborations
- IP development
- Skills levels of personnel
- Future contract leads
- Number of Standards developed

Outcome: Projects and ecosystem
- Performance characteristics of products relative to industry benchmarks and current technology
- Cost competitive pathway to commercialisation (unit costs of production)
- Progress against internal KPI
- Efficiency of service provision actual versus achieved times*
- Transfer of skills to UKBIC and increase in capabilities
- Internal financial sustainability
- Alignment between services provided and industry needs
- Measures of client satisfaction and investor perception of UKBIC

Impacts shorter term
- Evidence of upskilling in Closing of skills gaps
- Commercialisation of new technologies
- Increase probability of attracting Gigafactory investment using UK generated technology
- Investor perception of UK as location for battery and EV manufacture
- Spillovers to broader ecosystem

Impacts longer term
- Battery and EV ,manufacture
- Growth in sector economy-wide GVA
- Productivity and employment effects
- Environmental benefits of battery utilisation across transport sectors
- Technologies usable more broadly than automotive

Annex B Information on case studies

The case studies were based on interviews with industry stakeholders (automotive OEMs, chemical supply chain businesses, large-scale cell manufacturers, testing and recycling providers), industry representative bodies, and government departments and agencies including FBC delivery partners.

The interviews took place at two different points in time: September to November 2020 and September to November 2022.

Each case study is built on the basis of questions that stem from the theory of change, although interviews yielded other findings thanks to a semi-structured approach.

Case study 1: Enabling policy framework

a. To what extent is FBC influencing policy that could drive inward investment for battery production in the UK?

b. Does the policy community understand the importance of battery value chains and to what extent can this be attributed to FBC?

c. What is the level of battery inward investor interest in the UK and to what extent can this be attributed to FBC?

Case study 2: Development of battery production capacity and supportive ecosystem

a. How has FBC contributed to the emergence of new-generation battery technology options, including for non-auto applications?

b. How has BIC increased the likelihood of attracting gigafactories?

c. Has FBC (especially BIC) had a discernible impact on the growth in commercial battery production and its ecosystem including ancillary services?

d. Has FBC (especially BIC) influenced growth in the research ecosystem?

e. Has BIC increased skills in the battery production labour force?

Case study 3: Development of UK OEMs

a. How has FBC (especially FI) enhanced technological capabilities of UK battery and related businesses such as OEMs?

b. Is there evidence that FBC has resulted in the emergence of new-generation battery technology options, including for non-auto application – particularly aerospace?

c. What early indications are there that FBC (especially BIC) has led to UK OEM activity in EV manufacturing?

d. How has FBC (especially BIC) influenced the establishment of supporting value chains such as chemical supply?

Case study 4: Development of skills

a. To what extent has FBC helped to fill battery sector skills gaps in UK?

Interviews took place between 28 September and 4 November. The list of interviewees is produced below.

Category	**Organisation**
Automotive OEMs	WAE
Automotive OEMs	Cummins
Automotive OEMs	BMW/Mini
Chemical supply chain	Johnson Matthey
Chemical supply chain	BASF
Chemical supply chain	Synthomer
Industry or government bodies	APC
Industry or government bodies	SMMT
Industry or government bodies	ATI
Industry or government bodies	DIT
Large-scale cell manufacturers	AESC Envision (Nissan)
Testing and recycling providers	AVL

Annex C Information on surveys

C.1 Overview of survey process

The surveys aimed to provide an overview of the behaviours and perceptions of businesses and academics that had engaged with FBC. The sample mainly consisted of successful and unsuccessful applicants to the Challenge from FI and CR&D strands. For the final impact survey, a small number of UKBIC contacts were also included. These contacts had not made any applications for funding from FI or CR&D but had interacted with UKBIC regarding potentially accessing UKBIC services. Some contacts had engaged with both FI and CR&D.

The contact file for the final survey consisted of 507 individuals. Of these, 253 were from businesses (50%) and the remaining 254 were from academic institutions (50%). The majority of the contacts had only been involved in one application for FBC funding (67%), a little over a quarter (28%) had been involved in between two and four applications for funding, and 3% had been involved in five or more applications. A small number of contacts had only interacted with UKBIC and so had made no applications for funding (1%).

Where email addresses were available for individuals, they were initially approached via email with an invite to complete the survey. Telephone chasing was then employed, where telephone numbers were available, to encourage individuals to take part. If they preferred, respondents could complete the survey over the phone with a specially trained telephone interviewer. Telephone numbers were available for 143 individuals, with the remaining 364 having an email address only.

In total, 112 individuals completed the final survey. This compares to 136 individuals who completed the interim survey. Twenty-seven of the final surveys were completed over the phone and 87 were completed online. The overall response rate to the final survey, across both methods, was 22%. This compares to a response rate of 24% for the interim survey.

Just under half (47%) of the respondents to the survey were business contacts, with the remaining 53% being academics. Some questions within the survey asked respondents to discuss a specific application for FBC funding: 79% of respondents discussed a successful application (i.e. one where FBC funding had been granted), 17% discussed an unsuccessful application and the remaining 4% were not asked the questions about individual projects as they had not made an application for funding.

Survey respondents were asked which areas their organisation or research group focused on in relation to the design and development of batteries. The most common area selected was materials. The other areas were selected by roughly between a fifth and a third of respondents, as shown in Table 15.

Table 15: Areas of battery design and development that survey respondent’s organisation or research group focus on

Area	Number selected	% selected
Materials e.g. electrode, electrolyte, separator, binder	70	63%
Thermal management of modules	38	34%
Diagnostics	37	33%
Battery management systems for modules	35	31%
Battery management systems for packs	32	29%
Thermal management of packs	32	29%
Cell manufacture	30	27%
Vehicle application	29	26%
Recycling	27	24%
Second life	22	20%
Other	24	21%

Two in five (40%) of the business contacts that completed the survey described their organisation as a technology developer, focused primarily on research and development rather than production. Table 16 below shows the breakdown of business respondents in terms of how they would best describe their organisation's involvement in the battery supply chain.

Table 16: How business respondents describe their organisation's involvement in the battery supply chain

Description	Number selected	% selected
An OEM / prime producer designing, assembling and marketing vehicles to end users	7	13%
A tier one producer supplying automotive grade systems directly to OEMs	6	11%
A tier two producer selling components to tier one producers but also other firms outside the automotive industry	9	17%
A tier three producer supplying raw materials to OEMs and tier one and two producers	6	11%
A technology developer focused primarily on research and development rather than production	21	40%
Other	4	8%

While the survey collected a range of useful data and inputs from FBC participants, it should be noted that there are some limitations to the achieved sample for this impact evaluation. Some questions were only asked of businesses as they referred to aspects such as production capacity and the characteristics of batteries being produced. As such, data from these questions are based on 53 responses or fewer. While this number is large enough to draw conclusions at a total level, it is not sufficient to allow for sub-group analysis, for example by aspects such as company size.

Furthermore, as only a minority of respondents discussed unsuccessful FBC applications, there is limited scope to use the survey data for counterfactual analysis. As such, insights from survey data mostly rely on the stated impacts provided by the respondents.

C.2 Detailed survey questions

2046: FARADAY CHALLENGE EVALUATION

Introduction

Good morning/afternoon/evening, my name is ……. from BMG Research, an independent research agency.

We are conducting a survey on behalf of UK Research and Innovation. UKRI has commissioned an impact evaluation of the Faraday Battery Challenge.

UKRI wants your help in evaluating the value for money generated by the activities and interventions supported by FBC, by assessing their effectiveness in light of the objectives set for FBC.

Your time and input will help the ongoing development and improvement of FBC, and the programmes and funds that may be available to you or that you may have accessed, and to help demonstrate their value.

You may have already completed a survey in 2020. We'd very much appreciate your time again. It's important that we can see how experiences and impacts of FBC have changed over time.

IF NECESSARY: FBC is part of the UK's Industrial Strategy and Automotive Sector Deal. The overall purpose of FBC is to stimulate innovation in battery technology, in order to support investment of large-scale battery manufacturing in the UK, and through that to secure the production in the UK of electric vehicles.

[IF UNSUCCESSFUL APPLICANT] We're looking to speak to a mix of successful and unsuccessful applicants, and so would really value your time. This is your chance to help provide feedback on the Challenge and its processes, and to help it improve for future rounds of applications.

IF ASKED The survey will take around 15 minutes to complete.

Just to confirm, your responses will be treated in the strictest confidence. BMG Research abides by the Market Research Society Code of Conduct and data protection laws at all times.

You can find out more information about our surveys and what we do with the information we collect in our Privacy Notice which is on our website
INTERVIEWER TO DETERMINE IF RESPONDENT WANTS WEBSITE ADDRESS BEFORE PROVIDING IT OR IF IT IS TO BE SENT VIA EMAIL.
TO BE INCORPORATED INTO THE SCRIPT IF EMAIL REQUIRED.
(www.bmgresearch.co.uk/privacy)

Please note that this call may be monitored or recorded for training purposes.

ASK Can I confirm that you are happy to participate in the survey?
Record on script 'YES'

Scripting notes

Data to be pulled from sample:

- OUTCOME – either SUCCESSFUL or UNSUCCESSFUL
- PROJECT NAME
- TYPE – either BUSINESS or ACADEMIC
- STRAND – UKBIC, FI and/or CR&D
- D12_ASK

Screener

ASK ALL WITH 1 PROJECT

S1. Before we begin can I check that you [IF TYPE=BUSINESS:or your organisation] were involved in the application for funding for [PROJECT NAME] from the Faraday Battery Challenge?

SINGLE CODE

1. Yes – CONTINUE WITH INTERVIEW
2. No – THANK AND CLOSE

ASK ALL WITH MORE THAN 1 PROJECT [DEFINED BY COUNT_PROJECT SAMPLE VARIABLE]

S1a. Before we begin, can I check that you [IF TYPE=BUSINESS:or your organisation] were involved in the application for funding for the following projects from the Faraday Battery Challenge?

[INSERT PROJECT 1 NAME, PROJECT 2 NAME, PROJECT 3 NAME, PROJECT 4 NAME, PROJECT 5 NAME, PROJECT 6 NAME]

1. **Yes – CONTINUE WITH INTERVIEW**
2. **No – THANK AND CLOSE**

ASK ALL WITH 1 PROJECT

S2. And can I check that this application for funding for [PROJECT NAME] was [OUTCOME]?

SINGLE CODE

1. Yes
2. No

SCRIPTING: IF S2=2 CHANGE OUTCOME FROM SAMPLE, E.G. IF OUTCOME IS 1 (SUCCESSFUL) AND RESPONDENT SAYS 'No' AT S2, RECODE AS UNSUCCESSFUL AND VICE VERSA.

ASK ALL WITH 1 PROJECT

S3. And are you able to answer questions about this application and work that has been undertaken in this area following your application?

SINGLE CODE

1. Yes
2. No

IF S3=2

S4. Please can you tell me who is the best person to speak to regarding the application and the work that has been undertaken in this area following the application.

COLLECT NAME AND TELEPHONE NUMBER FOR CORRECT CONTACT

ASK ALL UKBIC ONLY

S5. Has your organisation had some interaction with the UK Battery Industrialisation Centre? This could include conversations about opportunities to use the centre, even if your organisation didn't actually go on to use the centre.

SINGLE CODE

1. Yes**– CONTINUE WITH INTERVIEW**
2. No **– THANK AND CLOSE**

Background

ASK IF TYPE = BUSINESS

A1. Which of the following best describes your organisation's involvement in the battery supply chain?

SINGLE CODE, READ OUT

1. An OEM / Prime producer, that is designing, assembling and marketing vehicles to end users
2. A tier one producer, supplying automotive grade systems directly to OEMs
3. A tier two producer, selling components to tier one producers but also other firms outside the automotive industry
4. A tier three producer, supplying raw materials to OEMs and tier one and two producers
5. A technology developer, focussed primarily on research and development rather than production
6. Other (specify) EXCLUSIVE
7. Don't know EXCLUSIVE

ASK ALL

A2. Which of the following areas does you organisation or research group focus on in relation to the design and development of batteries? Please say yes to all that apply.

MULTICODE, READ OUT

1. Materials e.g. electrode, electrolyte, separator, binder
2. Cell manufacture
3. Battery Management Systems for modules
4. Battery Management Systems for packs
5. Thermal management of modules
6. Thermal management of packs
7. Vehicle application
8. Second life
9. Recycling
10. Diagnostics
11. Other (specify)

IF TYPE=BUSINESS

A3A. In which region of the world is the headquarters of your business located? If a subsidiary, please choose the location of the ultimate parent company, that is the highest level organisations within your global corporate groups.

SINGLE CODE, READ OUT

1. UK
2. European Union (excluding UK)
3. Rest of Europe (excluding EU)
4. Middle East
5. Asia
6. North America
7. South America
8. Africa
9. Australasia
10. DO NOT READ OUT Don't know
11. DO NOT READ OUT Prefer not to say

IF TYPE=BUSINESS

A3B. And which other regions, other than the UK is your organisation located in?

MULTICODE, READ OUT

1. No other regions

2. European Union (excluding UK)
3. Rest of Europe (excluding EU)
4. Middle East
5. Asia
6. North America
7. South America
8. Africa
9. Australasia
10. DO NOT READ OUT Don't know
11. DO NOT READ OUT Prefer not to say

IF TYPE=BUSINESS AND A3B=2-9

A4A. How many members of staff does your organisation currently employ globally? Please think about the number of full-time equivalent employees.

IF NECESSARY: If you don't know the exact number please give an estimate.

NUMERIC RESPONSE WITH DK OPTION

VALIDATION – WHOLE NUMBERS ONLY. MIN 1, MAX 99,999

IF A4A=DK

A4B. Which of these bands would best describe the number of full-time equivalent employees at your organisation?

SINGLE CODE, READ OUT

1. 1-9
2. 10-19
3. 20-49
4. 50-99
5. 100-249
6. 250-499
7. 500-999
8. 1000-4,999
9. 5,000-9,999
10. 10,000 plus
11. Don't know

IF TYPE=BUSINESS

A5A. And how many members of staff does your organisation currently employ in the UK? Please think about the number of full-time equivalent employees.

IF NECESSARY: If you don't know the exact number please give an estimate.

NUMERIC RESPONSE WITH DK OPTION

VALIDATION – WHOLE NUMBERS ONLY. MIN 1, MAX 99,999

IF A5A=DK

A5B. Which of these bands would best describe the number of full-time equivalent employees at your organisation?

SINGLE CODE, READ OUT

1. 1-9
2. 10-19
3. 20-49
4. 50-99
5. 100-249
6. 250-499
7. 500-999
8. 1000-4,999
9. 5,000-9,999
10. 10,000 plus
11. Don't know

IF TYPE=BUSINESS AND A3B=2-9

A6A. What proportion of your global employees currently work in Research and Development? By Research and Development I mean people who work in research in lab environments as well as people who work in application, for example TRL6 and below.

IF NECESSARY: If you don't know the exact number please give an estimate.

NUMERIC RESPONSE WITH DK OPTION

VALIDATION – WHOLE PERCENTAGES ONLY. MIN 0%, MAX 100%

IF A6A=DK

A6B. Which of these bands would best describe the proportion of employees that currently work in Research and Development?

SINGLE CODE, READ OUT

1. 0%
2. 1% - 10%
3. 11% - 25%
4. 26% - 50%
5. 51% - 75%
6. 76% - 99%
7. 100%
8. Don't know

IF TYPE=BUSINESS

A7A. What proportion of your UK employees currently work in Research and Development?

IF NECESSARY: If you don't know the exact number please give an estimate.

NUMERIC RESPONSE WITH DK OPTION

VALIDATION – WHOLE PERCENTAGES ONLY. MIN 0%, MAX 100%

IF A7A=DK

A7B. Which of these bands would best describe the proportion of employees that currently work in Research and Development?

SINGLE CODE, READ OUT

1. 0%
2. 1% - 10%
3. 11% - 25%
4. 26% - 50%
5. 51% - 75%
6. 76% - 99%
7. 100%
8. Don't know

SHOW/READ OUT TO ALL

The Faraday Battery Challenge is made up of three strands;

- Collaborative Research and Development, also known as CR&D, where applicants bid for funding for projects
- The Faraday Institution, which awards funding to university-led consortia to deliver applied research projects

- UK Battery Industrialisation Centre, also known as UKBIC, which provides open access to manufacturing knowledge and capability

ASK ALL

A8. Before today, were you aware of each of these strands?

SINGLE CODE PER ROW

ROWS

a) Collaborative Research and Development (CR&D)
b) Faraday Institution
c) UK Battery Industrialisation Centre (UKBIC)

SCALE

1. Yes
2. No

Perceptions of UK progress

READ OUT: I'm now going to ask you some questions about your perceptions of the UK's progress regarding battery production. There are no right or wrong answers to these questions, we are after your opinions.

ASK ALL

B1. How attractive do you think the UK is as a place to invest in relation to the following types of battery technology? Please use a scale of 0 to 10, where 0 is not at all attractive and 10 is extremely attractive.

SINGLE CODE PER ROW

ROWS

d) Battery technology overall
e) Light electric vehicles, such as passenger cars and light commercial vehicles
f) Heavy duty electric vehicles, such as buses and trucks
g) Aerospace
h) Off-highway

SCALE

3. 0 – Not at all attractive
4. 1
5. 2
6. 3
7. 4
8. 5
9. 6
10. 7
11. 8
12. 9
13. 10 – Extremely attractive
14. Don't know

ASK ALL

B2. And how do you think the attractiveness of the UK as a place to invest in battery technology overall has changed since 2017?

SINGLE CODE, READ OUT AS NECESSARY

1. A lot more attractive
2. A little more attractive
3. About the same
4. A little less attractive
5. A lot less attractive
6. Don't know

ASK IF B2=1-5

B3. Why do you say that?

OPEN, PROBE.

ASK ALL

B4. What impact, if any, do you think the following aspects have had on the attractiveness of the UK as a place to invest in relation to battery technology for electric vehicles?

SINGLE CODE PER ROW, RANDOMISE ROWS, READ OUT AS NECESSARY

ROWS

a) The Faraday Battery Challenge overall
b) The Faraday Battery Challenge Collaborative Research and Development strand [ONLY ASK IF A8A=1]
c) The Faraday Institution [ONLY ASK IF A8B=1]
d) The UK Battery Industrialisation Centre [ONLY ASK IF A8C=1]
e) Brexit

f) COVID-19
g) Geopolitical instability, such as the war in Ukraine and global energy prices

COLUMNS

1. A large positive impact
2. A small positive impact
3. No impact
4. A small negative impact
5. A large negative impact
6. Don't know

ASK ALL

B6. I'm now going to read out some elements of battery technology development and support. For each, please can you tell me how you think the UK is currently performing in comparison to other countries?

SINGLE CODE PER ROW, RANDOMISE ROWS, READ OUT FULL SCALE ON FIRST ROW, READ OUT STATEMENTS IN FULL

ROWS

a) Government financial support for battery developments, including tax incentives
b) Regulatory support for battery developments
c) Investment in research and development in battery technology
d) The volume of research and development projects taking place
e) Quality of research output
f) Standing of UK universities in battery-related disciplines
g) Development of the battery supply chain
h) Attractiveness of the UK as a location to manufacture batteries
i) Attractiveness of the UK as a location to manufacture electric vehicles

SCALE

1. UK is the world leader
2. UK is ahead of most countries
3. UK is ahead of some countries, but behind the world leaders
4. UK is slightly behind most countries
5. UK is a long way behind most counties
6. Don't know

ASK ALL

B7. Overall, how would you rate the UK's current reputation as a centre for innovation in battery technology? Please use the same scale.

SINGLE CODE

1. UK is the world leader

2. UK is ahead of most countries
3. UK is ahead of some countries, but behind the world leaders
4. UK is slightly behind most countries
5. UK is a long way behind most counties
6. Don't know

ASK ALL

B8. And how do you think this reputation has changed since 2017?

SINGLE CODE, READ OUT AS NECESSARY

1. Increased a lot
2. Increased a little
3. About the same
4. Decreased a little
5. Decreased a lot
6. Don't know

Current project progress

IF MORE THAN 1 PROJECT [DEFINED BY COUNT_PROJECT IN SAMPLE]

C1A. Our records show that [IF TYPE=BUSINESS:you or your organisation] is, or has been, involved in more than one project within the Faraday Battery Challenge. Which project are you most able to answer questions about regarding the projects progress?

INSERT AS APPLICABLE, SINGLE CODE [NOTE THE MAX NUMBER OF PROJECTS IS 11, BUT I DON'T RECOMMEND READING 11 OUT]

- PROJECT 1 NAME
- PROJECT 2 NAME
- PROJECT 3 NAME
- PROJECT 4 NAME
- PROJECT 5 NAME
- PROJECT 6 NAME

IF MORE THAN 1 PROJECT [DEFINED BY COUNT_PROJECT IN SAMPLE]

For the following questions please think about [INSERT RESPONSE FROM C1A] only.

IF OUTCOME=SUCCESSFUL

C1. Thinking about your project: [PROJECT NAME], what year did your organisation begin working on this project?

YEAR RESPONSE, ALLOW DK, VALIDATION MIN 2000, MAX 2020

IF OUTCOME=SUCCESSFUL

C2. And at the time of your application, what year was the project due to end?

YEAR RESPONSE, ALLOW DK, VALIDATION MIN 2017, MAX 2050

IF OUTCOME=SUCCESSFUL

C3. Has your project been delayed at all by COVID-19?

SINGLE CODE

1. Yes
2. No
3. Don't know

IF C3=1

C4. How long do you expect this delay to your project to be?

SINGLE CODE, READ OUT

1. Less than 3 months
2. Between 3 months and up to 6 months
3. Between 6 month and up to a year
4. Between 1 year and up to 2 years
5. More than 2 years
6. Don't know

ASK ALL APPLICANTS

C5.

IF OUTCOME=SUCCESSFUL: If your application for funding had been declined, would you have taken the project forward in any form?

IF OUTCOME=UNSUCCESSFUL: After your application for funding was declined, did you take the project forward in any form?

SINGLE CODE

1. Yes
2. No – ROUTE TO C9
3. Don't know
4. Refused

IF C5=1

C6

IF OUTCOME=SUCCESSFUL: If your application for funding had been declined, would the project have gone ahead…

IF OUTCOME=UNSUCCESSFUL: Did the project go ahead…

MULTICODE, READ OUT

1. Unchanged
2. At a later date
3. In a different country
4. At a reduced scale of investment
5. With reduced scope (e.g. met fewer objectives)
6. Over a longer timescale
7. DO NOT READ OUT Don't know EXCLUSIVE
8. DO NOT READ OUT Refused EXCLUSIVE

IF C6=6

C7

IF OUTCOME=SUCCESSFUL: What would have been the changes in timescale?

IF OUTCOME=UNSUCCESSFUL: What has been the impact on timescales?

SINGLE CODE, PROMPT AS NECESSARY

1. Delay of up to a year
2. Delay of around 1 to 2 years
3. Delay of around 3 to 5 years
4. Delay of more than 5 years
5. Don't know
6. Refused

IF OUTCOME = SUCCESSFUL OR [OUTCOME = UNSUCCESSFUL AND C5=1 (UNSUCCESSFUL BUT PROJECT WENT AHEAD)]

C8. Which of the following best describes the current status of your project? Would you say the project currently…?

SHOW PROJECT NAME

INTERVIEWER CAN REFER TO PROJECT NAME IF NEEDED

SINGLE CODE, READ OUT

1. Is at an initial stage
2. Is mid-way through delivery
3. Is at a later stage but not yet completed
4. Has been completed
5. Has been abandoned before completion
6. Has been postponed
7. DO NOT READ OUT Don't know
8. DO NOT READ OUT Refused

IF C8=5 (ABANDONED) OR [OUTCOME=UNSUCCESSFUL AND C5=2 (UNSUCCESSFUL AND PROJECT NOT TAKEN FORWARD)]

C9. Why was the project [IF C8=5: abandoned, IF OUTCOME=UNSUCCESSFUL AND C5=2: not taken forward]?

DO NOT PROMPT, PROBE FULLY

MULTICODE

1. Difficulties securing finance
2. Failure to meet key technical milestones
3. Failure to meet key non-technical milestones
4. Concerns over costs of further research and development
5. Concerns over potential returns / revenue / likely take-up by users
6. Change in government policy affected market expectations
7. Project staff left our organisation
8. Partner with essential skills or assets pulled out
9. Initial stages suggested project was not going to lead to outcomes planned so was not worth continuing
10. Challenges due to COVID-19
11. Other (specify)
12. Don't know
13. Refused

IF OUTCOME = SUCCESSFUL OR [OUTCOME = UNSUCCESSFUL AND C5=1 (UNSUCCESSFUL BUT PROJECT WENT AHEAD)]

C10. How would you describe the extent to which the project [IF C8=4: has met, IF C8=1-3,6: will meet] its original intended objectives?

SINGLE CODE, READ OUT

1. The project [IF C8=4: has fully met, IF C8=1-3,6: will fully meet] its intended objectives
2. The project [IF C8=4: has partially met, IF C8=1-3,6: will partially meet] its intended objectives
3. The project [IF C8=4: has not met, IF C8=1-3,6: will not meet] its intended objectives
4. DO NOT READ OUT Don't know
5. DO NOT READ OUT Refused

IF OUTCOME = SUCCESSFUL OR [OUTCOME = UNSUCCESSFUL AND C5=1 (UNSUCCESSFUL BUT PROJECT WENT AHEAD)]

C11. At the start of your engagement with FBC, what stage of development was the technology at?

SINGLE CODE, READ OUT

1. Developing basic principles or formulating the concept IF NECESSARY: TRL 1 or TRL 2
2. Developing the proof of concept or testing in laboratory conditions IF NECESSARY: TRL 3 and TRL 4
3. Being validated or tested in a real but controlled environment IF NECESSARY: TRL 5 and TRL 6
4. Being tested and scaled in an operational environment IF NECESSARY: TRL 7
5. Don't know

IF OUTCOME = SUCCESSFUL OR [OUTCOME = UNSUCCESSFUL AND C5=1 (UNSUCCESSFUL BUT PROJECT WENT AHEAD)]

C12. What stage of development has the technology now reached?

SINGLE CODE, READ OUT

1. Developing basic principles or formulating the concept IF NECESSARY: TRL 1 or TRL 2
2. Developing the proof of concept or testing in laboratory conditions IF NECESSARY: TRL 3 and TRL 4
3. Being validated or tested in a real but controlled environment IF NECESSARY: TRL 5 and TRL 6
4. Being tested and scaled in an operational environment IF NECESSARY: TRL 7
5. Fully commercialised and brought to market IF NECESSARY: TRL 8 and TRL 9
6. Don't know

IF OUTCOME = SUCCESSFUL

C13. Which of the following best describes the impact you think engagement with FBC has had on development of the technology?

SINGLE CODE, READ OUT

1. Helped us reach a later stage of development than we would have done otherwise
2. Allowed us to reach the same stage of development, but more quickly that we could have done otherwise
3. Helped us both reach a later stage of development and get there more quickly that we would have done otherwise
4. Not had any effect on the development of this technology
5. Slowed down or inhibited the development of this technology
6. Don't know
7. Refused

IF OUTCOME=UNSUCCESSFUL AND C5=1 (UNSUCCESSFUL BUT PROJECT WENT AHEAD)

C14. What stage of development do you think the technology would now be at if you had been successful in your FBC funding or grant application?

1. Developing basic principles or formulating the concept IF NECESSARY: TRL 1 or TRL 2
2. Developing the proof of concept or testing in laboratory conditions IF NECESSARY: TRL 3 and TRL 4
3. Being validated or tested in a real but controlled environment IF NECESSARY: TRL 5 and TRL 6
4. Being tested and scaled in an operational environment IF NECESSARY: TRL 7
5. Fully commercialised and brought to market IF NECESSARY: TRL 8 and TRL 9
6. Don't know

IF OUTCOME=SUCCESSFUL

C15. Have you secured any follow-on funding or investment as a result of FBC grant?

SINGLE CODE

1. Yes
2. No
3. Don't know
4. Prefer not to say

IF C15=1

C16A. Please estimate the value of this follow-on funding or investment.

ENTER VALUE IN £s

ALLOW DK AND REFUSED

VALIDATION, MIN £0, MAX £100,000,000, NO DECIMAL PLACES

IF C16A=DK

C16B. Would you say it was…?

SINGLE CODE, READ OUT

1. Less than £50,000
2. £50,000 to less than £100,000
3. £100,000 to less than £500,000
4. £500,000 to less than £2 million
5. £2 million to less than £10 million
6. £10 million to less than £50 million
7. £50 million or more
8. DO NOT READ OUT Don't know
9. DO NOT READ OUT Refused

ASK ALL

C17A. In the previous [IF TYPE=BUSINESS: financial, IF TYPE =ACADEMIC: academic] year how much did your [IF TYPE=BUSINESS: company spend on research and development activities, IF TYPE =ACADEMIC: research group spend in grant income]?

INTERVIEWER NOTE:

- RESEARCH AND DEVELOPMENT (R&D) REFERS TO ALL R&D UNDERTAKEN IN THE REPORTING PERIOD EITHER FOR THE BUSINESS/RESEARCH GROUP OR FOR A CUSTOMER. THIS IS THE TOTAL COST OF R&D CONDUCTED BY THE BUSINESS, REGARDLESS OF THE SOURCE OF FUNDS OR THEIR TREATMENT
- WITHIN THE ACCOUNTS THIS INCLUDES ALL PURCHASED SERVICES AND MATERIALS WHICH SUPPORTS THE R&D THAT THE BUSINESS/RESEARCH GROUP PERFORMS

ENTER NUMBER IN £, ALLOW BEST ESTIMATE

ALLOW DK AND REFUSED, MIN 0, MAX, £100,000,000, NO DECIMAL PLACES

IF C17A=DK

C17B. Would you say it was..?

1. Less than £50,000, but not zero
2. £50,000 to less than £100,000
3. £100,000 to less than £500,000
4. £500,000 to less than £2 million
5. £2 million to less than £10 million
6. £10 million to less than £50 million
7. £50 million or more
8. Zero – no spend on R&D/grant income spent
9. DO NOT READ OUT Don't know
10. DO NOT READ OUT Refused

IF C17A>0 OR C17B=1-7

C18A. And what proportion of this spend was related to batteries?

ENTER % ALLOW BEST ESTIMATE

ALLOW DK AND REFUSED, MIN 0, MAX, 100, NO DECIMAL PLACES

IF C18A=DK

C18B. Would you say it was..?

1. 1-10%
2. 11-25%
3. 61-50%
4. 51-75%
5. 76-90%
6. 91-99%
7. 100%
8. Zero – no spend on battery R&D/grant income spent on batteries
9. DO NOT READ OUT Don't know
10. DO NOT READ OUT Refused

ASK ALL

C19. Thinking again about all of your research activity in the last [IF TYPE=BUSINESS: financial, IF TYPE=ACADEMIC: academic] year, how many [IF TYPE=BUSINESS: distinct managed programmes of R&D activity, IF TYPE=ACADEMIC: grants] were your team involved in?

IF TYPE=BUSINESS: By distinct managed programmes of R&D activity we mean R&D projects focused on the development of a defined product, process, service or business model

IF NECESSARY: Please include the application for Faraday Battery Challenge funding.

NUMERICAL RESPONSE, WHOLE NUMBERS ONLY, MIN 1, MAX 50. ALLOW DK AND REF

IF GREATER THAN 25 SOFT CHECK.

IF C19>1

C20. And how many of these grants of applications related to batteries?

IF NECESSARY: Please include the application for Faraday Battery Challenge funding.

NUMERICAL RESPONSE, WHOLE NUMBERS ONLY, MIN 1, MAX IS NUMBER GIVEN AT C14. ALLOW DK AND REF

IF C20>3: I'm now going to ask you about three of your grants or projects. Please think about the three largest grants or projects in terms of total funding

IF C20=2,3: I'm now going to ask you about each battery or grant project, starting with the largest in terms of total funding.

SCRIPTING: C21 TO BE REPEATED UP TO 3 TIMES, DEPENDING ON RESPONSES TO C20.

IF C20=1,2,3

C21. Thinking about your [largest / second largest / third largest AS RELEVANT] grant or project. How many of each of the following partners were involved?

NUMERICAL BOX FOR EACH ROW, WHOLE NUMBERS ONLY, MIN 0, MAX 50

INCLUDE DK AND REF OPTIONS

1. Commercial partners
2. Industrial partners
3. External academic partners [IF TYPE=ACADEMIC: by this I mean and academic partner outside of your institution]

ASK ALL

C22. How do you think collaboration in general on projects or grants concerning batteries has changed since 2017? Please think about collaboration between academia and industry and also within academia, such as cross-institutional and cross-departmental. Please think about collaboration that you are aware of outside your organisation or research group and well as the collaboration of your own organisation or research group.

SINGLE CODE, READ OUT

1. Collaboration has increased significantly
2. Collaboration has increased slightly
3. Levels of collaboration have not changed
4. Collaboration has decreased slightly
5. Collaboration has decreased significantly
6. Don't know

C23. How much do you think the Faraday Battery Challenge has impacted collaboration in general on projects or grants concerning battery technology?

SINGLE CODE, READ OUT

1. FBC has increased collaboration significantly
2. FBC has increased collaboration slightly
3. FBC has not impacted collaboration
4. FBC has decreased collaboration slightly
5. FBC has decreased collaboration significantly
6. Don't know

Progress against targets

IF TYPE=BUSINESS

READ OUT: I would now like to ask you about your oganisation's capacity to produce battery cells, modules and packs for vehicles and other applications.

IF TYPE=BUSINESS

D1. Does your organisation currently produce any of the following?

MULTICODE

1. Battery cells
2. Battery modules

3. Battery packs
4. None – GO TO D11

IF D1=1

D2. What is your organisation's current maximum annual production capacity for battery cells for use in vehicles and other applications?

IF NECESSARY: **Please think about the most advanced type of battery cells that your organisation produces for this question and the two that follow.**

SHOW ONE BOX FOR UNITS AND ONE FOR GWh

ALLOW DK AND NA FOR BOTH

IF D1=1

D3. How many battery cells for use in vehicles or other applications did you organisation produce last year?

SHOW ONE BOX FOR UNITS AND ONE FOR GWh

ALLOW DK AND NA FOR BOTH

IF D1=1

D4. And what is the current unit cost per cell of production for use in vehicle or other applications?

ENTER NUMBER IN £, ALLOW UP TO 2 DECIMALS, ALLOW DK AND NA

IF D1=2

D5. What is your organisation's current maximum annual production capacity for battery modules for use in vehicles and other applications?

IF NECESSARY: **Please think about the most advanced type of battery modules that your organisation produces for this question and the two that follow.**

SHOW ONE BOX FOR UNITS AND ONE FOR GWh

ALLOW DK AND NA FOR BOTH

IF D1=2

D6. How many battery modules for use in vehicles or other applications did your organisation produce last year?

SHOW ONE BOX FOR UNITS AND ONE FOR GWh

ALLOW DK AND NA FOR BOTH

IF D1=2

D7. And what is the current unit cost per module of production for use in vehicle or other applications?

ENTER NUMBER IN £, ALLOW UP TO 2 DECIMALS, ALLOW DK AND NA

IF D1=3

D8. What is your organisation's current maximum annual production capacity for battery packs for use in vehicles and other applications?

IF NECESSARY: **Please think about the most advanced type of battery packs that your organisation produces for this question and the two that follow.**

SHOW ONE BOX FOR UNITS AND ONE FOR GWh

ALLOW DK AND NA FOR BOTH

IF D1=3

D9. How many battery packs for use in vehicles or other applications did you organisation produce last year?

SHOW ONE BOX FOR UNITS AND ONE FOR GWh

ALLOW DK AND NA FOR BOTH

IF D1=3

D10. And what is the current unit cost per pack of production for use in vehicle or other applications?

ENTER NUMBER IN £, ALLOW UP TO 2 DECIMALS, ALLOW DK AND NA

IF (TYPE=BUSINESS AND OUTCOME=SUCCESSFUL) OR (UKBIC AND USED UKBIC)

D11. Which of the following best describes how your engagement with FBC has impacted your production capacity?

SINGLE CODE, READ OUT

1. It has helped us increase our production capacity more quickly than we could have done otherwise
2. It has helped us to increase our production capacity to levels that we would not have been able to reach otherwise
3. It has helped us to both increase our production levels more quickly and increase to levels we would not have been able to reach otherwise
4. It has not had any impact on our production levels
5. It has reduced our production capacity
6. Don't know
7. Refused

IF TYPE=BUSINESS AND OUTCOME=UNSUCCESSFUL AND C5=1 (UNSUCCESSFUL BUT PROJECT WENT AHEAD)

D11. If your FBC funding application had been successful, what impact do you think this would have had on your production capacity?

SINGLE CODE, READ OUT

1. It would have been significantly higher
2. It would have been slightly higher
3. It would have been the same
4. It would have been slightly lower
5. It would have been significantly lower
6. Don't know
7. Refused

IF (TYPE=BUSINESS AND OUTCOME=SUCCESSFUL) OR (UKBIC AND USED UKBIC)

D12. Thinking about the most advanced battery system into which your components are integrated, what is the current…?

WRITE IN THE VALUE FOR EACH, ALLOW DK AND NA

1. Cost in US dollars per kilowatt hour for a battery cell
2. Cost in US dollars per kilowatt hours for a battery pack
3. Energy density in Watt hours per litre [IF DK ALLOW IN WATT HOURS PER KILOGRAM AND RECORD UNITS] [RECORD IF REFERRING TO ANODE, CATHODE, CELL, MODULE OR PACK LEVEL]
4. Power density in kilowatts per kilogram [RECORD IF REFERRING TO CELL OR PACK LEVEL]
5. First Life, in years
6. Minimum operating temperature, in degrees centigrade
7. Maximum operating temperature, in degrees centigrade
8. Recyclability, in percent of the weight of the battery

IF (TYPE=BUSINESS AND OUTCOME=SUCCESSFUL) OR (UKBIC AND USED UKBIC)

D13. Which of the following best describes how your engagement with FBC has impacted your progress in developing more advanced battery systems or components?

SINGLE CODE, READ OUT

1. It has had a great impact
2. It has had a moderate impact
3. It has had a small impact
4. It has had no impact at all
5. Don't know
6. Refused

Skills and recruitment

IF TYPE=BUSINESS

E1. Which of the following best describe the skill levels of your existing staff involved with your battery projects?

SINGLE CODE, READ OUT

1. All of our current staff have the necessary skills for the projects to be successful
2. Most of our current staff have the skills needed for our project to be successful
3. Some of our current staff have the skills needed for our projects to be successful
4. Only a few of our current staff have the skills needed for our projects to be successful
5. None of our current staff have the skills needed for our projects to be successful
6. Don't know
7. Prefer not to say

IF TYPE=BUSINESS

E2. And which of the following best describe your experience of the level of skills in the industry as a whole?

SINGLE CODE, READ OUT

1. There are significantly more people with the relevant skills than the industry currently needs
2. There are slightly more people with the relevant skills than the industry currently needs
3. There are about the same of amount of people with the relevant skills as the industry currently needs
4. There are slightly fewer people with the relevant skills than the industry currently needs
5. There are significantly fewer people with the relevant skills than the industry currently needs
6. Don't know
7. Prefer not to say

IF E2=4 OR 5

E3. What levels of skills do you think are currently lacking?

MULTICODE, READ OUT

1. PhD candidates
2. Postdoctoral research associates or research staff
3. Independent research fellows
4. Academic staff
5. Technician grades
6. Engineer grades
7. Other (specify)
8. Don't know

IF TYPE=BUSINESS

E4. How do you think skills levels have changed since 2017?

SINGLE CODE, READ OUT

1. The level of skills in the industry has improved significantly
2. The level of skills in the industry has improved slightly
3. The level of skills in the industry has not changed
4. The level of skills in the industry has worsened slightly
5. The level of skills in the industry has worsened significantly
6. Don't know

IF TYPE=BUSINESS

E5A. What impact, if any, do you think FBC has had on skills levels?

SINGLE CODE, READ OUT

1. A significant positive impact
2. A slight positive impact
3. No impact at all
4. A slight negative impact
5. A significant negative impact
6. Don't know
7. Refused

IF TYPE=BUSINESS AND AWARE OF UKBIC (A8C=1]

E5B. What impact, if any, do you think the UK Battery Industrialisation Centre has had on skills levels?

SINGLE CODE, READ OUT

1. A significant positive impact
2. A slight positive impact
3. No impact at all
4. A slight negative impact
5. A significant negative impact
6. Don't know
7. Refused

IF TYPE=BUSINESS

E6. And what do you think the level of skills in the industry will be like in 5 years' time?

SINGLE CODE, READ OUT

1. There will be significantly more people with the relevant skills than the industry needs
2. There will be slightly more people with the relevant skills than the industry needs
3. There will be about the same of amount of people with the relevant skills as the industry needs
4. There will be slightly fewer people with the relevant skills than the industry needs
5. There will be significantly fewer people with the relevant skills than the industry needs
6. Don't know
7. Prefer not to say

Wrap up

ASK ALL

F1. Thinking about all of the interaction you have had so far with the Faraday Battery Challenge to date, how satisfied or dissatisfied have you been with the interaction?

SINGLE CODE

1. Very satisfied
2. Fairly satisfied
3. Neither satisfied not dissatisfied
4. Fairly dissatisfied
5. Very dissatisfied
6. Don't know
7. Prefer not to say

IF BUSINESS, AWARE OF UKBIC, BUT NOT USED [TYPE=BUSINESS AND A8C=1 AND NOT UKBIC FROM SAMPLE]

F1A. You previously mentioned that you are aware of the UK Battery Industrialisation Centre, but our records show your organisation has not used the Centre. Why has your organisation not used the Centre?

MULTICODE

1. We have used the Centre
2. We plan to use the Centre in the near future
3. The price is too high
4. We do not need any support with scaling up
5. We do not plan to invest in battery manufacturing in the UK
6. We did not pass the financial and technical due diligence
7. We have been in talks with UKBIC, but have not yet come to an agreement
8. We have our own facilities for development and validation
9. We are using another facility
10. We have the skills required in house
11. It is not relevant to what we do
12. Don't know
13. Prefer not to say

IF AWARE OF UKBIC [A8C=1]

F1B. Which of the following best describes how effective you think the open access, contract-based model of the UK Battery Industrialisation Centre (UKBIC) is in meeting current industry needs?

The UKBIC model involves customers paying UKBIC for the use of its facilities for activities to support scaling up. The customer is then responsible for large scale production through its own facilities. UKBIC does not enter into large scale production contracts and does not benefit from an IP rights.

SINGLE CODE

1. UKBIC meets all of the current industry needs
2. UKBIC meets most of the current industry needs
3. UKBIC meets some of the current industry needs
4. UKBIC meets a few of the current industry needs
5. UKBIC doesn't meet any of the current industry needs
6. Don't know

IF USED UKBIC [FROM SAMPLE]

F1C. Thinking about all of the interaction you have had with the UK Battery Industrialisation Centre to date, how satisfied or dissatisfied have you been with the interaction?

SINGLE CODE

1. Very satisfied
2. Fairly satisfied
3. Neither satisfied not dissatisfied
4. Fairly dissatisfied
5. Very dissatisfied
6. Don't know
7. Prefer not to say

ASK ALL

F2. Is there anything you want to mention about your experience so far with the Faraday Battery Challenge that has gone particularly well?

OPEN

ASK ALL

F3. Is there anything you want to mention about your experience so far with the Faraday Battery Challenge that has not gone well?

OPEN

Body Text