National Physical Laboratory

NPL REPORT IEA 8

# A META-ANALYSIS OF NPL'S IMPACT CASE STUDIES: CHARTING NPL'S ECONOMIC AND SOCIETAL BENEFIT MECHANISMS

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FEBRUARY 2022

# A Meta-Analysis of NPL's Impact Case Studies; Charting NPL's Economic and Societal Benefit Mechanisms

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## ABSTRACT

Using a large sample of case studies generated by NPL over the last 20 years as a dataset, a "meta-synthesis" was used by NPL for the first time, in which these case studies were linked to one of NPL's four sectors; and then coded with regards to a range of indicators, according to common criteria, which included three distinct types of impact. This analysis has generated three main results:

1. Identification of impact profiles for each of NPL's sectors.
2. Evidence of marked differences in the orientation of such impact profiles among NPL's sectors.
3. Provision of better qualitative evidence to inform and guide future programme management.

The location of each of NPL's sector was evidenced within a three-dimensional impact space, whose dimensions are: 'direct impacts'; 'indirect impacts'; and 'future impacts'. Moreover, a sector's orientation in this impact-space gives an indication of its phase of development within the conventional technology lifecycle. From the analysis conducted, we see the following orientations for each of NPL's sectors: *Advanced Manufacturing* is a more mature sector compared its counterparts, with high levels of direct impact; whilst *Digital & Quantum* is still at a youthful phase of the lifecycle, with high levels of future impacts. The two remaining sectors - *Health & Life Sciences* and *Energy & Environment* - are each producing high current impacts, as well as, high future impacts.

ISSN 2633-4194

https://doi.org/10.47120/npl.IEA8

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## Executive Summary

The allocation of NMS funding occurs every 3-4 years, driven by expert opinion of leading stakeholders with panel of expert advisors along with the judgement of NPL's senior management, backed up by 100 years of accrued experience running the NMS programme.

Future formulations are likely to benefit from complementing such expert opinion with greater reference to published evidence (quantitative or qualitative). This would increase the transparency of the process, further demonstrating NPL's commitment to the principles of HMT's Green Book[1]. Moreover, previous approaches to formulation involved ranking individual projects using a common set of criteria, but the current method can be improved upon by introducing a more systematic consideration of where such projects are with respect to the technological lifecycle. The ability to locate projects with regards to their position in the lifecycle would allow for longer-term, dynamic considerations when selecting and composing the portfolio of funded projects.

NPL's position as a leader in programme evaluation has been evidenced by the positive feedback from our SR submissions, our Maryland scale-rated, peer-reviewed analysis and our position as a reviewer of analysis conducted by BEIS and other government departments. We have contributed to the strategy of NPL and improved NPL's ability to win additional funding, by adopting evermore fully the appraisal and evaluation cycle stipulated in HMT's Green Book (the ROAMEF cycle). Despite NPL's position as a leader in evaluative work among its international comparators, there remains an opportunity to further strengthen the link between the evidence being generated and the approach taken in portfolio rebalancing; the opportunity extends to strengthening the final link in the cycle by boosting the "signal quality" of evidence produced by the analysts, as well as increasing their engagement with staff involved in the formulation process. This can be done by producing the kind of evidence needed to inform a long-term portfolio approach to future formulations.

To produce such evidence for future formulation exercises, NPL's extensive case study database was analysed on the basis of a kind of "survey". This is based on the belief that the sectors have pre-set "personalities" (Impact Profiles), which are quasi-fixed and can only be changed through evolution of the respective sector. Each impact profile is unique and there is no preference between them from the perspective of Analysis & Evaluation. In order to reveal this "personality", each case study underwent a standardised coding procedure, where it was 'asked' a set of questions by reviewers and coded according to its 'answers'. Every case study was analysed independently of each other, and then segmented according to sector and activity. Within the context of this "survey" exercise - and using personality surveys as an analogy - the 'Sectors', 'Activities', and 'Impact Themes' discussed in this report can be characterised as follows:

- ***Sectors***: Subjects who are undertake a kind of personality test through the "meta-analysis" detailed in this report, with behaviours that become apparent from reviewing the relevant case studies. These are the four sectors of NPL, whose impact profiles are presented and detailed.
- ***Activities***: The observable behaviours seen in the sample of case studies, that correspond to a limited set of scientific activities or technical tasks referred to in the case studies.
- ***Impact Themes***: The latent (or hidden) factors corresponding to underlying personality types which can nonetheless by inferred from certain patterns of observable behaviour.

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1 The Green Book is guidance issued by HM Treasury on how to appraise policies, programmes and projects. It also provides guidance on the design and use of monitoring and evaluation before, during and after implementation.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/938046/The_Green_Book_2020.pdf

NPL isn't a homogenous institution, hence the approach should better consider each subpart of NPL. All four of NPL's significant subparts focus on differing areas of research and technology, from a metrological perspective. This study focuses on the impact themes with regards the following four constituent sectors.

- Advanced Manufacturing
- Life Sciences and Health
- Digital & Quantum technologies
- Energy & Environment

Not only do these sectors focus on different research areas, they are qualitatively different with regards to maturity and impact themes.

Greater understanding of this complexity can be developed by generating visualisation of the interrelationships of the sectors/activities along the dimensions detailed below. Hence, this study plots these sectors within a three-dimensional space, with the following impact themes comprising the axes:

- Future Impact – Where work NPL conducts has the potential to produce benefit, often in the future with an uncertain probability of occurring.
- Indirect Impact – Where the work NPL conducts producing impacts for third parties, who don't work with NPL directly but impact via positive externality effects.
- Direct Impact– Where the work NPL conducts impact our customers and collaborators, along with their customers and collaborators.

Lifecycles can be used to show the movement of a range of different entities from their start/birth to their end/death. In this report, the lifecycle model has been applied to technology. The technological lifecycle details the evolution of NPL's sectors. Within this model, the lifecycle of a technology is analogous to the phases of person's life, with future impact of a person/technology decreasing with age while current impact (direct or indirect) increases. The aging process of technology does lead to a loss in current impact, keeping in step with the four phases of life (Infancy - Adolescence – Adulthood – Seniority). This suggests a sector's orientation with regards to the impact themes will change throughout its lifecycle. This allows for each sector/activity to be described with regards to their impact profiles as detailed within the Pen Pictures at the end of the report.

Using the great number of case studies generated by NPL over the last 20 years as a dataset, a "meta-synthesis" was performed. Through this:

1. The case studies were linked to the sectors
2. After which, the case studies were coded with regards to a range of indicator within the database following a common criterion, which included several types of impact

This analysis of the case studies was used to evidence the locations of the sector with regards the three-dimensional impact space as detailed above. Moreover, a sector's orientation gives an indication of where it resides within the lifecycle. As seen from the analysis on the case studies, the following orientations have been drawn out by sector:

- Advanced Manufacturing as a more mature sector when compared its counterparts. This could require refocusing on more youthful activities (e.g. In-House R&D) in order for the sector as a whole to endure, potentially coupled with divestment of certain functions.
    - This maturity is derived from the prevalence of direct impact for this sector. Advanced Manufacturing has significantly higher-than-average results for every direct impact indicator used in this analysis.
    - Despite its strength lying in direct impact, its relative weakness with regards to indirect impact weakens its current impact overall, with lower-than-average levels of externalities and consumer benefit case studies as much of the work is conducted with customers and are focused on improving a firm's productive capabilities.
    - Similar to indirect impact, this sector performs poorly with regards to future impact, due

to low levels of R&D case studies and Breadth of Impact.

- Conversely, Digital & Quantum is very youthful at this point in time, with an emphasis on future impact, which should be invested in further if future impact is the aim for NPL. Furthermore, it would be beneficial to see this sector converting the potential, future impact into current impact in the near future, be it through direct or indirect impact (Details of how one would move around the technological lifecycle will be detailed in the section 8.2 – Activities).
    - The youthful nature of this sector does damage its ability to provide impact now. This is seen in both the direct and indirect impact themes being weak.
    - Instead, the youthful nature is derived from the innovative work conducted, as seen by the strength of its future impact theme. Notably, this sector has high breadth of impact, driven by the scale of many of the research areas focused on, such as 5G, Quantum technology and IoT.
- Energy & Environment and Health & Life Sciences exist within the sweet spot, where they are both producing current and future impacts. However, their make-up with regards to the three impact measures are slightly different. Concerning Energy & Environment:
    - Energy and Environment follow the NPL average concerning direct impact, due to the work conducted with the Energy industry, providing measurement services and working in a customer-supplier relationship.
    - Indirect impact arises from the work to improve traceability and measurement of greenhouse gas emissions, working with the Energy industry in a myriad of ways, such as the Heavy Metals network.
    - Much of the future impact for this sector comes from the work concerning the environment. Helping to reduce the impact on the environment has clear impact into the future, with the development of hydrogen cars an obvious example of technology that could be impact moving forward.

  Concerning Health & Life Sciences

    - Unlike Energy & Environment, this sector has little direct impact. This is due to the nature of the industry it works in, as the NHS has a limited mechanism to pay for things in a customer-supplier relationship, with a small exception being the calibration of Radiotherapy equipment. This £500,000 a year contract is a rare example of paid work with the NHS. Instead, it would look to work alongside NPL on projects such as the Breast Cancer scanner.
    - As much of the work conducted is tailored for the Health industry, there is clear evidence of the indirect impact of this sector, which drives its current impact theme. As with health-related innovations generally, the impact will affect third parties rather than the direct users of the products/research developed, providing externality benefits.
    - With an aging populations and general need for healthcare innovations, as seen with the COVID-19 pandemic, this sector is clearly suited for future impact. This is seen by several research projects in the case study database, such as the “Google Earth of Cancers” project[2]

In order to change the impact profiles of the sectors, their activities would have to be adjusted. The differences between the sectors are reflections of differences in the weighting of the activities that they do. These activities are as follows:

- Collaborative R&D and Instruments
- In-House R&D
- Delivering Infrastructure
- Developing Infrastructure
- Consultancy and Training

The activities can be viewed as securities, with constant returns which can’t be changed. Sectors can be assessed as portfolios, which can change its weightings to produce different returns. However, unlike financial portfolios, the research and services that underlies each sector ages over time, with all forms of impact decreasing eventually. In order to adjust the impact profile of the sectors, their respective distribution of activities have to be adjusted,

2 https://www.npl.co.uk/grand-challenge

leading to the change in direction as wanted. The following shows which activities lend towards direct and indirect impact.

- Collaborative R&D and Instruments and In-House R&D allow for a sector to shift towards future impacts
    - With regards to direct impact, these activities are both weak but with one caveat. As the findings developed in research take time to be converted to products, there is limited scope for impact now. The caveat is the high levels of process innovation for Collaborative R&D and Instruments, which likely ties in with contract R&D work with firms.
    - Research generally has high indirect impacts, as often it can be utilised by other researchers to further their own projects. This is particularly true for In-House R&D, whose output is often research papers, which can be cited by other scientists.
    - Research is done with the expectation that the knowledge developed can be utilised moving forward, either as a product/service or in the work of other researchers, clearly showing future impacts.
- Delivering & Maintaining Infrastructure and Consultancy & Training leads to greater levels of current impact.
    - This is driven by direct impact for both indicators. Most notably the customer-supplier relationship and the measurement services and consultancy indicators are both significant. These directly link to the activities as seen in their respective definitions.
    - As much of this work is conducted with customers, the scope for externality impacts are limited. However, there is significance with regards to transaction costs reduction, likely by improving traceability and by reducing measurement uncertainty through consultancy (and theoretically, Measurement services, though this isn't seen in the data)
    - There is very little, if any impact for the future developed by this indicator. This is likely due to the nature of the work being sales of products/services rather than research.
- Developing Infrastructure appears to impact both current and future impact (though this is determined by a small sample size).
    - Direct impact is limited by this activity. This is due to much of the output of this area being internally focused, with little scope for impacts for our customers directly.
    - Investment in infrastructure does impact our customers (and collaborators) indirectly, allowing us to align better with our customers' needs, enabling the provision of better services.
    - As infrastructure lasts a long period of time, we see future impact increasing as well, often down to the research needed to develop infrastructure, the time period the infrastructure is used and the broad capabilities that infrastructure developed by the NMS has.

Through the adjustment of weightings of activities, it can be hypothesized that the sectors' impact profiles can be shifted in beneficial ways for each respective sector for greater balance. Information of this nature is key for the development of a strategy to decide the direction of NPL's subparts and for a dynamic portfolio approach. By conducting this analysis, we are able to draw three important benefits:

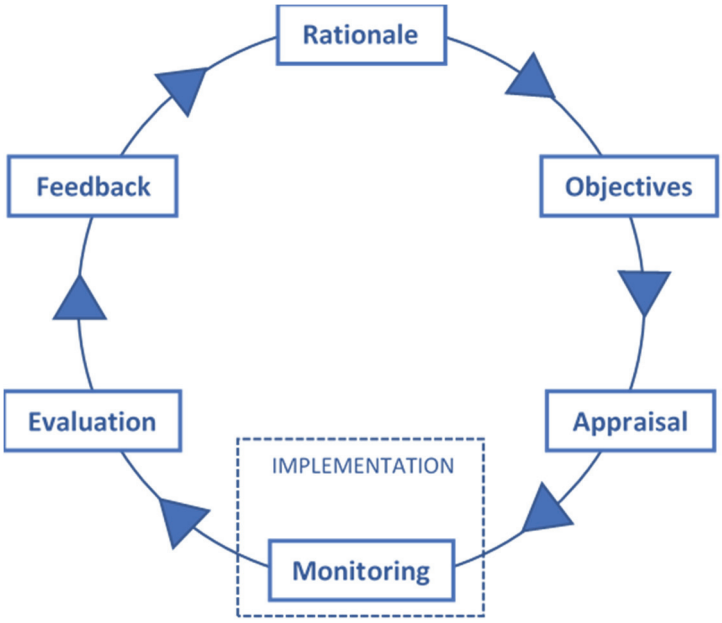
1. Identification of impact profiles for each sector at NPL,
2. Assessment of the differences in orientation between the sectors
3. Provision of better qualitative evidence for management

Once its limitations, as detailed in section 2.1, this analysis has a range of uses. It can feed into the formulation process, the importance of divestment and the potential need for long-term public money for areas with indirect benefits with little scope for future research.

# 1 INTRODUCTION

NMS formulation concerns the re-allocation of the NMS budget. Common factors considered included need, delivery confidence and affordability, with expert opinion of stakeholders and NPL's management being the driving force of the re-allocation. In future formulations, benefits could arise from greater use of published evidence or frameworks to aid with guiding the conversations concerning formulation. Greater emphasis could be placed on an overarching framework guiding the decisions for NPL generally, rather than a focus on certain aspect of NPL[3]. Furthermore, formulation as a process has been based on expert opinion and internal views, built on 100 years of accrued experience managing the NMS programme. This input isn't to be demeaned, but greater use of evidence and frameworks would improve codification of the process. The use of the analysis in this report would provide a baseline for the sectors, from which the sectors can be assessed in a repeat version of this analysis, likely in another 5-10 years. Despite the inability to track changes in the moment, the conceptual framework helps to guide the development of appropriate metrics, reducing the use of one-size-fits-all metrics for each unique sector.

During a potential independent review, the Appraisal & Evaluation (ROAMEF) cycle, as set out within the HMT's Green Book[4], will likely be used to analyse NPL current funding method. It is as follows:




Stages of the ROAMEF cycle are meant to feedback on themselves in a perpetual cycle, with evidence developed during the evaluative process providing outputs to inform the allocation of government funding across projects and programmes. At this point in time, NPL's position as a leader in evaluative work can be strengthened by adopting more elements of the cycle through the greater use of evidence. In particular, the link between evidence produced by analysts and those involved with formulation is one which can always be improved (as seen in section 9 Conclusion). An important caveat is that **frameworks and evidence cannot be the only input into the process**, as this would effectively mechanise formulation. The greater use of evidence and frameworks developed cannot overlook the input of internal and

3 This can be compared to a Premier League manager only developing tactics to win games, rather than a strategy to achieve a greater goal like winning a league or staving off relegation.

4 The Green Book is the rules/expectations concerning the monitoring of and accountability for public expenditure, with the onus of those in receipt of public funding to assure they meet the guidelines as detailed within the book.

external stakeholders currently involved with formulation. Rather it should enhance the process as it currently exists and would be noted as a positive in a future independent review of BEIS, that the NMS may be rolled into.

Furthermore, as detailed within the Evaluation Framework of the NMS[5], a mixed-methods approach was proposed, requiring both Qualitative and Quantitative methods. Currently, the balance of evidence swings heavily in favour of Quantitative analysis, with strong econometric papers. The work as detailed within this paper would help to address this imbalance, as Case studies make up an important role within the Qualitative methods section, along with logic models and theories of change. Qualitative analysis as seen in this document allows for an assessment concerning the mechanisms through which NPL provides impact, rather than the level of impact which can be found through empirical analysis. This allows for greater insight by evidencing the internal functions of NPL that lead to impact, through the provision of analysis into a range of different indicators such as levels of spillover effect and types of products produced by sector.

The document is broken down into the following sections:

- Section Two details the data source itself, the case study database; where it comes from, how it was constructed and its limits.
- Section Three goes through the three axes used to assess impact.
- Section Four details the theories behind the frameworks through which we can assess impact on a range of axis.
- Section Five details how the theoretical frameworks are computed to produce results.
- Section Six and Seven detail the analysis by NPL Sector and Activity respectively.
- Section Eight details the links between the Sectors and Activities.
- Section Nine go through the pen pictures, a short description of each sector/activity according to the Impact themes as detailed in section Four.

## 2 CASE STUDY DATABASE

The data used for this analysis is the Case Study Database, a repository of Qualitative impact statements ranging from Customer testimonials to formal case studies for ISR submission. For simplicity, case studies refer to all Qualitative Impact Statements. The analysis team undertook an assessment of the content in the case studies stored in the database. However, the analysis team have no influence over the style of case study generated by the science team, nor the content they include.

To undertake analysis, the case studies have been quantified in the database in order to account for the lack of qualitative information on how or why things occurred. In order to do this, the factual text has been coded to into a range of binary and categorical variables. The coding system mirrored those which are used in well-respected internal surveys. This is equivalent to each case study being interview with responses coded-up, with the responses used to assess the corpus of case studies, after segmenting for sector and activity.

This process is similar to a “qualitative meta-synthesis”, as coined by Stern & Harris (1985), where qualitative data is brought together and analysed as a single body of evidence, rather than looking at the individual data points (i.e. each case study/qualitative impact statement). Normally, qualitative meta-synthesis would involve a topic analysis on the corpus of case studies to assess themes, but for our purposes that wouldn’t allow for the depth of analysis

5 The Evaluation Framework of the NMS is “based on the themes of the NMS strategy to ensure accountability for the public investment and to enable future funding to be allocated based on evidence of what worked well. The purpose of the framework is to provide evidence that NMS activities are generating the expected outputs and on course to deliver the intended impacts.”

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/712629/uk-measurement-strategy-delivery-plan-2017-2020.pdf

we wanted. Therefore, we "surveyed" all 365 case studies using a range of indicators, allowing for inferences on the basis of different categorical variables (Sectors, Activities, etc). The indicators are:

- Logic Model groupings – These indicators account for the logic model within the Evaluation Framework for the NMS.
    - Trade & Regulation – This is where NPL has helped ensure good policy and standards. This is done through verifying the claims of businesses, maintaining UK standards, providing traceability and producing new measurement capabilities.
    - Innovation – This is when we have worked with our end-users to produce impact. This is done when new or improved measurement capabilities have adopted by our end-users, helping them to innovate.
    - Skills – This is where we improve the UK's measurement skills, done through training, secondments, PhD supervision and outreach activities in schools.
    - Research – This is when investment in measurement infrastructure has been conducted. This would be to improve our knowledge surrounding metrology, sometimes conducted with foreign NMIs and academics.

- Product groupings – This indicator details the "products" NPL produces:
    - Licence transfer – this entails case studies where our IP and know-how has been passed to a beneficiary, for the beneficiary to exploit the resource.
    - Consultancy – this involves case studies where the beneficiary sought expert information or advice from us for an external project. (E.g. Standards consultation).
    - Measurement services – this are for case studies where we performed a measurement service such as calibrations for a beneficiary.
    - Training – this includes case study where our educational product/service was used by the beneficiary.
    - R&D:
        - In-House R&D – This includes case studies where work was conducted by our scientists without direction from outside commercial influence.
        - Collaborative R&D – where NPL works alongside a commercial organisation to find an innovative solution to a problem
        - Contract R&D – This includes case studies where NPL was tasked with finding an innovative solution to a problem for a commercial customer

- Swann Mechanisms – Developed by Prof Peter Swann[6], these mechanisms detail the channels through which measurement delivers impact. Swann detailed 13 mechanisms, which have been distilled into four mechanisms.
    - Product Innovation – where NPL has enabled/assisted the beneficiary to create a new product or NPL has created a new product.
    - Process Innovation – where NPL have influenced how the product /service of the beneficiary is made/delivered.
    - Consumer Benefit – where NPL works towards improving the Quality of life of the consumer, implementing Health & Safety standards in the workplace and civic benefits (benefits to the citizens of the state)
    - Transaction Costs – where NPL's product or service has reduce the transaction costs (cost associated with trading a good or service) our beneficiaries would incur due to trade.

6 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/297870/prof-swann-report-econ-measurement-revisited-oct-09.pdf

- Externalities – Where NPL's engagement has not only affected the party we are directly involved with but also affects unrelated third parties who were not involved in the market transaction i.e. would/did the outcome benefit a group of individuals who did not pay NPL for its work or the beneficiary for their product or service.

- Time Profile of impact – This indicator assesses the time period an impact NPL's work has generated can be expected to last
    - One-off impact – Case studies where the impact is felt by a firm for a short time, with little outside scope
    - Short-term impact – Case studies where the impact is felt for a short time, often by a number of firms, which may be providing benefits to this day
    - Long-term impact – Case studies where the impact is felt for a significant duration, often by a large number of firms across an industry, helping a great number for organisations
    - No Impact yet - Case studies where there is no current economic impact, however there is potential for impact in the future
- Working Relationship – What type of relationship did NPL have within the other parties within the case study:
    - Customers – NPL was paid for services in a Customer-Supplier relationship
    - Collaborators – NPL worked alongside other parties
    - No Outside Influence – NPL worked alone on the work detailed in a case study

The data was segmented in two main ways:

- Activity Parameters:
    - In-House R&D
    - Developing Infrastructure
    - Delivering & Maintaining Infrastructure
    - Collaborative R&D & Instruments
    - Consultancy & Training
- Sectors:
    - Advanced Manufacturing
    - Life Sciences & Health
    - Energy & Environment
    - Digital & Quantum Technologies

As the surveying was subjective, steps were taken to standardise the approach, such as a common guidance document and a comparison of results between the two surveyors. The Indicators used were

## 2.1 LIMITATIONS

In spite of this, there are some limitations to the data. There is an underrepresentation and overrepresentation of certain projects, topics and outcomes. There's no mention of case studies where there was no impact, where NPL had to learn from its mistakes and evaluate its processes. Furthermore, the focus on the case studies are on outputs with notable features (e.g. scale, innovative nature) rather than assessing all potential impacts being produced at NPL, underrepresenting some of the "day job" of NPL (such as measurement services). Following on from this point, there is a non-uniform template of the case studies, leading to information being omitted. Another issue is the lack of timestamping on many of the case studies, particularly the customer testimonials. The approximate time-period of the case studies is from 2001-2020, but no further information is available. Future customer testimonials will be time stamped to allow for a repeat analysis in 5-10 years, assessing where the sectors have gone. Customer testimonials also have far less detail and more focus on direct impact than those detailing Metrology Research for ISR. The ISR case studies have an unknown bias due to the nature of prioritising case studies that are likely high science and longer-term impact, but this is speculation and is a fundamental unknown. If one was to look

at each individual case study, the information gathered would be limited, which is why the database was developed make up for the lack of individual detail.

## 3 METHODOLOGICAL FRAMEWORK

Once this categorisation was done, results were tabulated, and graphs were produced in order to compare the sectors/activities to one another and the NPL-wide average. Using our case studies as observable data points, a set of generic questions were drawn up concerning the results from the analysis. These questions, linked to several categories within the database, were then asked of the sectors/activities themselves, with the results computed using quotients[7].

This allows for a comparison of the sectors to the NPL-average. This allows for comparisons to be made concerning the impact themes but doesn't assess the magnitude of the impact. Using the quotient scores, the observable categories can be viewed as behaviours, the manner with which they each act in order to provide impact. By using a manual version of factor analysis/PCA[8], these observable behaviours can be grouped together in order to find the underlying/latent behaviours of the sectors. In order for this to work, the latent behaviours had to be developed prior to the analysis. The three latent behaviours developed were as follows:

### 3.1 DIRECT IMPACT

- ➔ Where NPL provides impact for customers/collaborators who work closely with us. The indicators used for this impact theme were:
    a. Process innovation – If a sector is particularly strong at this mechanism, it would suggest that the work conducted within this sector is likely to be focused on production lines, increasing efficiency of production, and reducing cost. This tends to be for large-scale, well-established manufacturers with developed products in little need of further innovation. Due to the target audience for this mechanism, it is likely to have direct impact for our users.
    b. Customers – If the case study in question involves another firm paying for NPL's goods or services, it's indicative of the impact that NPL would have on that firm. The fact the good/services is monetizable further proves that the firm in question is receiving direct impact from NPL.
    c. Measurement Services/Consultancy – out of the 7 main product types NPL has, these two are the most commercial. Similar to the previous point, by using (i.e. paying) these services, direct impact is clearly evidenced.

### 3.2 INDIRECT IMPACT

- ➔ Where NPL provides impact for third parties, not involved with the transactions. Two main types of indirect impacts are:
    I. **Knowledge spillovers**, where third parties gain access to knowledge from NPL without paying
    II. **Market failures**, where NPL supports **public goods** such as Health, Environment and Education.

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7 The Quotients used are similar to location quotients used for "quantifying how concentrated a particular industry, cluster, occupation, or demographic group is in a region as compared to the nation". In the NPL context, there are used to assess how each sector/activity is concentrated in a particular question.

https://www.economicmodeling.com/wp-content/uploads/2007/10/emsi_understandinglq.pdf

8 Factor Analysis and PCA are statistical methods used to describe variability among observed, correlated variables, producing a lower number of unobserved variables which account for a greater amount of variance than the individual variables.

https://stats.idre.ucla.edu/spss/seminars/introduction-to-factor-analysis/a-practical-introduction-to-factor-analysis/

The indicators used were:

d. Externalities – This is where a transaction between two entities leads to impact being generated for a 3rd party, who receives the aforementioned impact without having to pay for it. If many third parties were to impact, there would be little reason to pay for the knowledge producing the impact in the first place. Externalities and indirect impacts are the same in this instance, as NPL is a positive externality (the private sector would underfund NPL as it wouldn't account for the social benefits, the rationale for government funding).
e. Consumer Benefits – This mechanism is purely focused on improved consumer welfare, through a variety of means, such as improving safety of goods or healthcare. For NPL, this predominantly comes through healthcare benefits, such as the work conducted in Medical Physics.
f. Transaction Costs – These are the expenses incurred as part of being in a market, whether you are a producer or consumer. These vary from financial ones, such as the cost of enforcing agreements and transactions, to other kinds of cost, such as the time of bargaining. The main areas through which NPL helps to reduce transaction costs is by reducing uncertainty around the measurement, assuring that the labelled dimensions of a product are accurate (as an example). This often occurs where NPL works with a large calibration firm to disseminate more accurate measurements down a calibration chain. This is known as fan-out[9] and often impacts those outside of the initial transaction.

## 3.3 FUTURE IMPACT

➔ Where NPL produced knowledge, helping future research and innovation, providing impact on Science rather than for the Economy/Citizens. If applications were found for these innovations, impact would be generated in the future. The indicators used were:

g. Longer-term impact – This statement was put together by combining two categories within the time profile question: Long Term impact and No impact yet. These both suggest that the impact (or potential impact) is likely to be felt for over 5 years. These would involve work with ground-breaking innovation (e.g. work with 5G) or helping to solve a worldwide problem (e.g. climate change)
h. R&D – Research & Development is done for the purpose of generating new knowledge, be it fundamental metrology research conducted in-house and paid for by the NMS for be paid for by outside companies tasking NPL with solving a problem on their behalf.
i. High breadth of impact – the R&D conducted at NPL must also affect a large section of society at this point in time, not just the future. The work with the Oil & Gas industry still helps to produce energy needed to power society, which clearly impacts society greatly.

For this analysis, an assumption is made that all three of the impact themes are equal in weight to one another, allowing for an equal comparison. However, it must be acknowledged that Future impact is fundamentally different to the other two impact themes. Direct and

9 Fan-out is detailed by the following: The key users of the NMS laboratories are commercial calibration companies. By taking traceability from the NMS laboratories, these calibration companies disseminate reliable calibrations to their customers. In short, these companies are the next link in a chain that links measurements done by the public and private sectors to the primary standards maintained by the NMS laboratories. Along with a system of protocols, accreditation, and international agreements, this chain of interlinked calibrations ensures that a measurement can be performed once but accepted everywhere. Domestic and foreign confidence in this system avoids duplicating tests and circumvents disputes, which reduces the cost of verifying that goods conform to specification, as well as, aiding consistent regulation and taxation.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/712629/uk-measurement-strategy-delivery-plan-2017-2020.pdf

Indirect Impact can be merged to generate an impact theme assessing impact now, while independently they can be used to look at impact at the present. Future impact assesses impact dynamically, seeing what work is being done now that has the potential of produce impact in the future. Unlike its counterparts, future impact is not guaranteed, it is merely a probability. Tied to the fact the present values are larger than future values, as part of formulation, it cannot be expected that each theme is weighted equally in the real world

These three impact themes are vital for informing a transformational change. By implementing impact themes, an assessment can be made concerning structure of NPL's output as it has existed over the last 20 years. By seeing how each sector/activity relates to each impact theme, a judgement can be made on which sectors/activities to emphasise to promote the impact theme wanted by upper management. The models that follow show how the data can be structured to inform that discussion.

## 4 THEORETICAL FRAMEWORK

To provide structure to the analysis, models were developed to aid understanding and to structure potential discussions concerning impact. The nature of these models won't cause the transformational change, but by assessing the sectors through these, the change wanted by upper management can be better informed. The two frameworks used which encompass all three themes of output are:

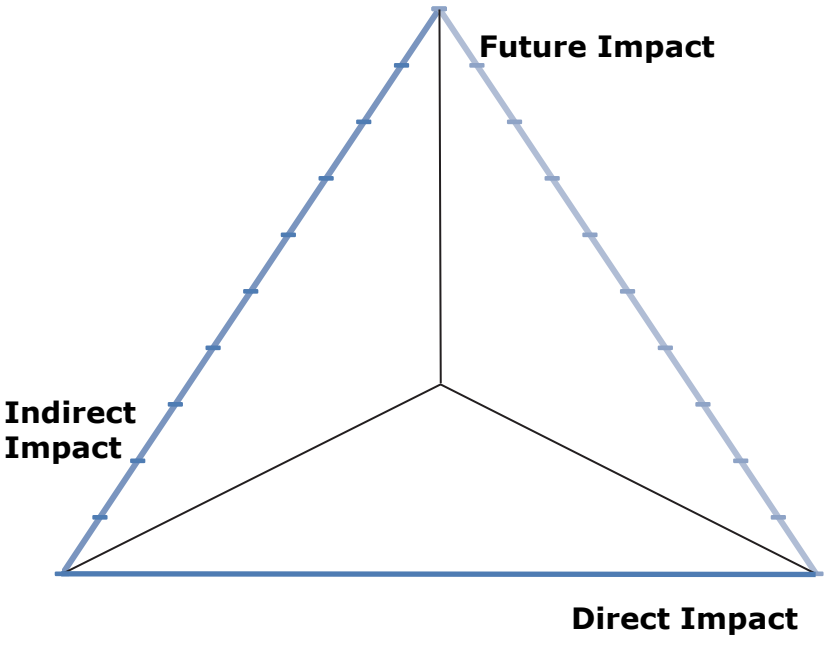
- Triangle Model
- Technological Lifecycle Model

In an ideal world, all three axes would be plotted on a 3D graph in order to express the proportional and absolute impact profiles of the sectors/activities. However, this is unrealistic due to limitations of drawing a 3D graph on a 2D plane. Therefore, two models were used for the following reasons:

- Triangle Model – Static model, assessing proportional differences between sectors/activities
- Technological Lifecycle Model – Dynamic model, assessing absolute differences between the sectors/activities.

### 4.1 THE TRIANGLE MODEL

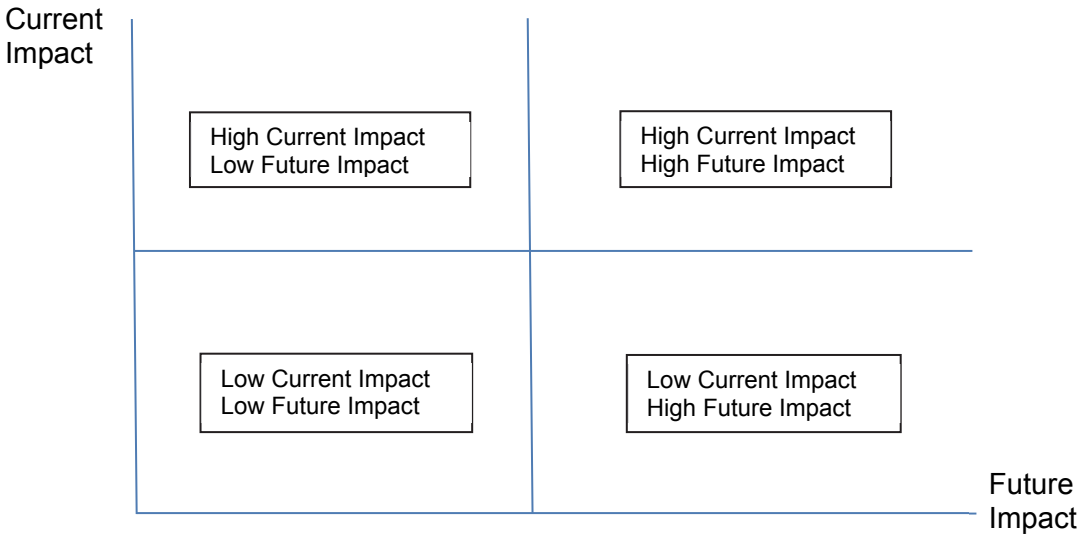
The Triangle Model was developed as a way to compare all three themes to each other, given equal weighting of importance. Using 3D axes, in the shape of a triangle, the sectors



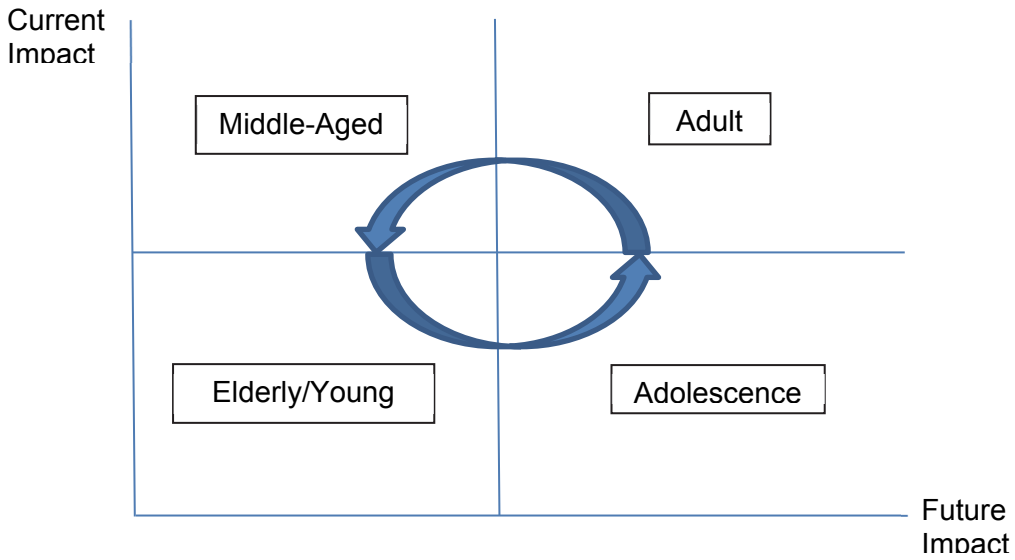
can be compared to see which theme they seem to prioritise over the others. If a sector is closer to the corners, it would appear to be focusing on one of the factors over the other. Conversely, if a sector happened to reside in the middle, the case studies indicate that the sector in question is likely to have an even split between the 3 themes of output. The sectors/Activities would be plotted in a graph as seen below.

4.2 TECHNOLOGICAL LIFECYCLE MODEL

Richard Barker is the Sector Head of Energy & Environment, who has spoken and informed government on Environmental policy. He developed a conceptual model which assesses NPL's output, judging that NPLs outputs should be targeted towards addressing future impacts with innovation and through the provision of current impacts, with indirect and direct impacts used to calculate this. This concept of output should also inform NMS investment, as it would allow for strategic prioritisation between investing for impact at this point in time and investing for the future. Constructed graphically, to assess the inner workings of NPL, the model could look like this. The two types of output would be on the x and y axis, with NPL's average level of output used as a benchmark to compare the sectors/groups to.




This model could be used to assess the lifecycle of a sector/group. Our initial theory is that sectors/activities will undertake an anti-clockwise movement around the quadrants. At the start, a group will be in the bottom left corner, where there is likely to be little current impact and the research conducted is likely to provide low impact in the future. Often, the youngest sectors/activities lie here. Then, as the sector/group matures and becomes "adolescent", there would be a movement from the bottom-left quadrant rightwards, with the research becoming more important. This aging from "adolescence" towards "adult" is where both outputs are high. This would be indicated by an upwards movement. Eventually, the sector/group would move from "adult" to "middle aged", where the research being conducted would likely become of lower priority, as the research reaches its fulfilment. This would move the sector/groups to the left, with only high current impact. After this, the sector/groups would move from "middle aged" to "elderly", where the direct impact would begin to reduce as the products being offered aren't being demanded or are being offered by industry. This would shift the sectors/groups from the top left to bottom left.




This lifecycle, as seen above, may not be wholly true. Some groups may not reach points at which they are able to provide any form of benefit, along with some groups that may just be operating as a commercial entity, not producing any strategic research but providing essential services to industry. Interpreting this model for NPL as a whole, the placement of the groups on this model is neither good nor bad. It merely provides information on the output. Future impacts are used as seen in the table, but current impacts are generated by calculating a projection between the direct and indirect impacts. For these scores, the NPL average is equal to one, with the remaining points plotted around the average.

## 5 COMPUTATIONAL APPROACH

In order to operationalise the models, several assumptions had to be made in order for the analysis to work. Firstly, the three themes as detailed above (Future, Indirect and Direct impact) are believed weighted equally during analysis. This allows for an apples-to-apples comparison to be made between the themes. Secondly, the 3 themes are viewed as 3 dimensions in an x-y-z space, orthogonal to one another in the form of a 3-D plot. The natural reference point when referring to the sectors is the NPL average. As quotients are being used, the reference point is equal to 1, with the sectors/activities referred to as being higher-than-(NPL)average, lower-than-average or not significantly different to the NPL average. The time period is also approximate as mentioned above, with the case studies spanning the last 20 years. Because of this, the findings of this analysis can be interpreted as the trends of the sectors over the last 20 years, with future iterations looking at better defined time periods. The final assumption is that all of the indicators are picked up in a non-disproportionate way, meaning each indicator is no hard than its counterparts to assess for within the database.

Once the assumptions are made, the calculations of each theme can be conducted. For each theme, there were three questions concerning specific areas of interest, with each question answered by their respective quotient score to determine the placement of the sectors. To aggregate these into a score for impact theme, means were used to calculate the impact score for each sector/activity for each Impact theme. This holds true for the Triangle model and the Technological Lifecycle model. Following this step, the methods diverge for the two frameworks.

Further details of the analysis reside within the CS report annex, a separate document which goes through the entire process in detail.

### 5.1 TRIANGLE MODEL

Unlike the Technological Lifecycle Model, all three impact themes are used to scale impact.

In order to do this, the magnitude of each sector (i.e. the distance of each sector from the origin) has to be found. This indicates the scale of the output, assuming each impact mechanism is equal to one another. This was done using the following formula (this formula is a generalised version of the one used previously):

$$y_s = \sqrt{\frac{\sum(x_{is})^2}{n}}, i \in \{Direct\ Impact, Indirect\ Impact, Future\ Impact\}, s \in \{Sectors, Activities\}$$

Where:
$x_{is}$= The Quotient Score for the Impact theme and sector in question
n = Number of Impact Themes
$y_s$= Magnitude of Sector in question

The magnitude generated can then be used to ratio the three forms of impact using the following formula, generating p, the proportion of impact for each sector (s) accounted for by each theme (i):

$$p_{is} = \left(\frac{\left(\frac{x_{is}}{\sqrt{n}}\right)}{y_s}\right)^2, i \in \{Direct\ Impact, Indirect\ Impact, Future\ Impact\}, s \in \{Sectors/Activities\}$$

This scales the score for the three impact themes, assuming equal weighting across the three.

5.2 TECHNOLOGICAL LIFECYCLE MODEL

For the Technological Lifecycle model, we use Future Impact and Current Impact themes. Future Impact is the same as detailed previously, Current Impact assess impact in the here-and-now. This is done by assuming current impact as an X-Y projection, with the x axis being direct impact and the y axis being indirect impact. This allows for the projection to be calculated using the following formula

$$\frac{\sqrt{X^2 + Y^2}}{\sqrt{2}} = C$$

Where C = Current impact and $\sqrt{2}$ divides through to scale for the averages of both X & Y (Both are equal to 1, therefore: $\sqrt{1^2 + 1^2} = \sqrt{2}$)

The Current Impact is then plotted on the Y axis with Future Impact plotted on the X axis.

## 6 SECTORAL ANALYSIS

Using the case study database and 3 impact themes mentioned above, the following table was constructed:

| 5% positive | 10% positive | ***30% positive (1 Standard Deviation)*** | No Significance | ***30% negative (1 S.D.)*** | 10% negative | 5% negative |
|---|---|---|---|---|---|---|

| Theme | Category | Does the sector in question display significantly higher or lower than average levels of: | Advanced Manufacturing | Life Sciences & Health | Energy & Environment | Digital & Quantum Technologies |
|---|---|---|---|---|---|---|
| Direct Impact | Swann Mechanisms | Process Innovation case studies | 1.45 (±0.47) | 0.59 (±0.23) | 0.97 (±0.39) | 0.58 (±0.32) |
| | Customer/Collaboration | Customer-Based case studies | 1.31 (±0.35) | 0.68 (±0.22) | 0.96 (±0.31) | ***0.82 (±0.36)*** |
| | Products | Measurement services & Consultancy case studies | 1.11 (±0.31) | 0.92 (±0.3) | 1.05 (±0.35) | 0.78 (±0.35) |
| Indirect Impact | Externalities #1 | Externalities case studies | 0.43 (±0.13) | ***1.22 (±0.44)*** | 1.77 (±0.64) | ***0.77 (±0.38)*** |
| | Swann Mechanisms | Consumer Benefit case studies | 0.11 (±0.05) | 2.76 (±1.59) | 0.85 (±0.5) | ***0.46 (±0.37)*** |
| | Swann Mechanisms | Transaction costs case studies | 1.1 (±0.34) | 0.61 (±0.23) | ***1.25 (±0.48)*** | 1 (±0.51) |
| Future Impact | Time Profile | Longer Term impact case studies | 0.77 (±0.09) | ***1.04 (±0.16)*** | 1.22 (±0.18) | 1.17 (±0.24) |
| | Products | R&D case studies | 0.76 (±0.21) | 1.12 (±0.35) | ***1.1 (±0.34)*** | 1.25 (±0.53) |
| | Breadth of impact | non-niche market case studies | 0.88 (±0.19) | 0.98 (±0.26) | 1.08 (±0.29) | 1.22 (±0.44) |

**Table 1**

In this part of the analysis, the sectors were assessed with respect to their relationship to the 3 themes. The colour scheme indicates significance at certain levels. It should be noted that

for the 30% significance indicators, a hypothesis is constructed that suggests the sector in question could have significantly different levels of the indicator in question, with a need for more data to prove this. This is why the three least populated sectors have the highest number of these indicators. Using these values, the following table could be constructed using the method detailed in Chapter 3:

| | Advanced Manufacturing | Life Sciences & Health | Energy & Environment | Digital & Quantum Technologies |
|---|---|---|---|---|
| Direct Impact | 1.29 (±0.22) | 0.73 (±0.15) | 0.99 (±0.2) | 0.73 (±0.2) |
| Indirect Impact | 0.55 (±0.16) | 1.53 (±0.19) | 1.29 (±0.26) | 0.74 (±0.21) |
| Future Impact | 0.81 (±0.11) | 1.05 (±0.56) | 1.13 (±0.29) | 1.22 (±0.21) |
| Current Impact | 0.99 (±0.11) | 1.2 (±0.36) | 1.15 (±0.3) | 0.74 (±0.13) |

**Table 2**

## 6.1 TRIANGLE MODEL

Using these scores, we were able to plot the sectors on the two frameworks. By using these results, we see the following:

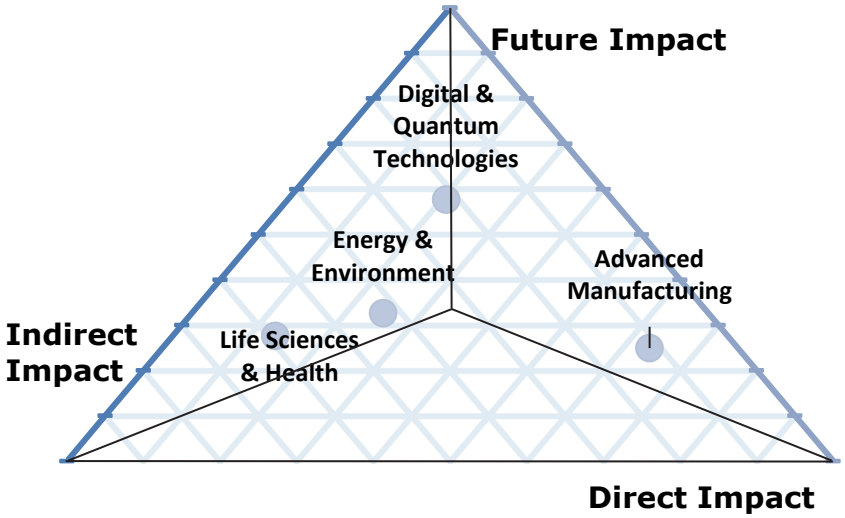



**Figure 1**

Digital & Quantum and Advanced Manufacturing are clearly different to one another, with one focusing on future impact and the other on direct impact. Meanwhile, Energy & Environment and Life Sciences & Health are similar to one another, though Energy & Environment is closer to the centre point. This indicates that Energy & Environment is the most balanced of the 4 sectors when it comes to the breakdown of its impact.

6.2 TECHNOLOGICAL LIFECYCLE MODEL

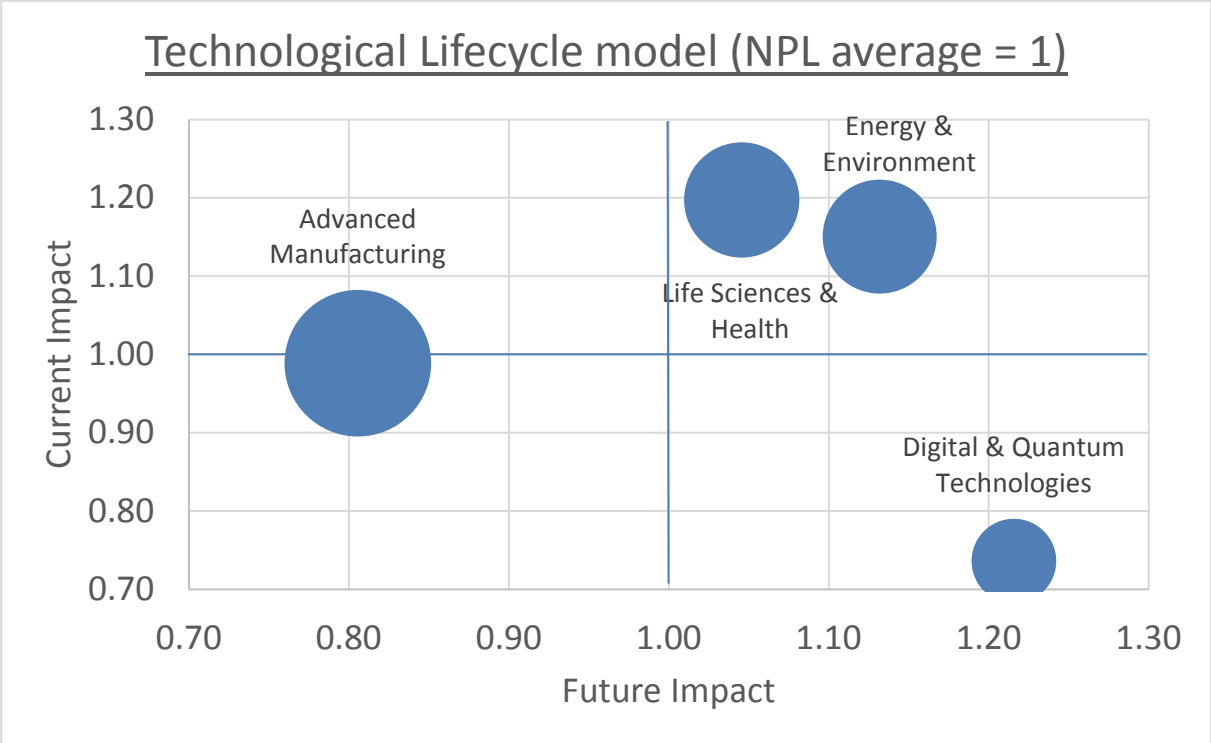



**Figure 2**

Advanced Manufacturing and Digital & Quantum Technologies are in opposite areas, with one focused purely on Future Impact and the other focused on Current Impact (mainly Direct impact, with the lack of indirect impact leading to low current impact). Meanwhile, Life Sciences & Health and Energy & Environment seem to have a greater focus on both current and future impacts. The health-based focus of Life Sciences & Health provides impact both now and, in the future, while Energy & Environment's work on carbon-neutral projects, new innovative energy sources and carbon monitoring provide a great deal of impact in both dimensions.

## 7 ACTIVITIES ANALYSIS

Another way of conducting the analysis is by assessing activities of which NPL has five. We classify them as following:

1. In-House R&D
   It is comprised of Redefining SI units, advancing fundamental measurement science and developing prototypes for new instrumentation.
   It includes collaboration with researchers from foreign NMIs and academics at world leading universities, Publication of journal papers and Academic awards and esteem.

2. Developing Infrastructure
   It comprises of getting redefinitions adopted by BIPM, developing the technical basis for pre-standards, shaping the development of policies, regulations, and standards for emerging technologies.
   It includes engaging with the National Quality Infrastructure (BSI and UKAS), Academic involvement through specialist research institutes, collaboration with international primes (anchor companies), as well as, professional associations.

3. Delivering & Maintaining Infrastructure

It comprises of maintaining UK's ability to realise SI units and derived units, updating measurement standards and processes to keep them fit-for-purpose, supporting MRAs and Legal Metrology, making incremental improvements to the National Quality Infrastructure, maintaining UKAS accreditation, performing Key Comparisons and running PT schemes or undertaking audits.
It includes engaging with Trading Standards offices and BSI committees and supplying calibration services or reference materials to the calibration labs or end-users.

4. Collaborative R&D & Instruments
   It is comprised of actively promoting the diffusion and exploitation of NPL's knowledge through undertaking collaborative R&D, jointly developing new and improved instrumentation, supporting complementary proprietary technologies of other firms and transferring know-how to firms with more commercial acumen.
   It usually involves government funding to incentivise firms to exploit NPL's knowledge for IP sharing arrangements, running schemes like A4I and M4R, Innovate-UK projects, contracting R&D for large primes and encouraging PhD students in the PGI to work with industry.

5. Consultancy & Training
   It involves helping firms to solve their measurement problems through the provision of consultancy or training services., upskilling workforce and supporting the adoption of new processes, conducting small pieces of analysis to help firms solve known problems.
   It includes developing training materials for other firms to deliver running events and workshops.

Using the case study database, 3 impact themes mentioned in Chapter 3 and the activities, the table below was constructed:

| 5% positive | 10% positive | *30% positive (1 Standard Deviation)* | No Significance | *30% negative (1 S.D.)* | 10% negative | 5% negative |
|---|---|---|---|---|---|---|

| Theme | Category | Does the sector in question display significantly higher or lower than average levels of: | R&D (In-House) | Developing Infrastructure | Delivering Infrastructure | Collaborative R&D and Instruments | Consultancy & Training |
|---|---|---|---|---|---|---|---|
| Direct Impact | Swann Mechanisms | Process Innovation case studies | 0.88 (±0.38) | 0.72 (±0.61) | 1.17 (±0.6) | 1.25 (±0.49) | 0.82 (±0.31) |
| | Customer/Collaboration | Customer-Based case studies | 0.34 (±0.11) | 0.74 (±0.48) | 1.46 (±0.58) | 0.81 (±0.25) | 1.5 (±0.45) |
| | Products | Measurement services & Consultancy case studies | 0 (±0) | 0.38 (±0.24) | 2.1 (±0.84) | 0.25 (±0.08) | 2.14 (±0.72) |
| Indirect Impact | Externalities #1 | Externalities case studies | 1.16 (±0.43) | 1.39 (±0.99) | 0.71 (±0.31) | 1.2 (±0.4) | 0.76 (±0.25) |
| | Swann Mechanisms | Consumer Benefit case studies | 1.42 (±0.84) | 2.07 (±2.44) | 0.75 (±0.53) | 1.09 (±0.59) | 0.5 (±0.27) |
| | Swann Mechanisms | Transaction costs case studies | 0.96 (±0.38) | 1.05 (±0.82) | 0.93 (±0.43) | 0.73 (±0.26) | 1.33 (±0.47) |
| Future Impact | Time Profile | Long term impact or No Impact yet case studies? | 1.41 (±0.47) | 1.45 (±0.93) | 0.57 (±0.23) | 1 (±0.3) | 0.82 (±0.25) |
| | Products | R&D case studies | 1.86 (±0.58) | 1.53 (±0.91) | 0.06 (±0.02) | 1.64 (±0.5) | 0.02 (±0.01) |
| | Breadth of impact | non-niche market case studies | 1.05 (±0.29) | 1.42 (±0.76) | 0.74 (±0.24) | 0.98 (±0.23) | 1.05 (±0.28) |

**Table 3**

Using the values in the above table, we then draw the following table using the method detailed in Chapter 3. This collates the categories of the themes and gives us Current (Direct and Indirect impact) and Future impact for each of the five Activities.

| | R&D (In-House) | Developing Infrastructure | Delivering Infrastructure | Collaborative R&D and Instruments | Consultancy & Training |
|---|---|---|---|---|---|
| Direct Impact | 0.41 ±(0.13) | 0.58 ±(0.28) | 1.4 ±(0.36) | 0.75 ±(0.19) | 1.3 ±(0.27) |
| Indirect Impact | 1.18 ±(0.18) | 1.51 ±(0.44) | 0.79 ±(0.33) | 1 ±(0.19) | 0.86 ±(0.27) |
| Future Impact | 1.62 ±(0.33) | 1.61 ±(0.9) | 0.47 ±(0.3) | 1.36 ±(0.25) | 0.63 ±(0.23) |
| Current Impact | 0.88 (±0.09) | 1.14 (±0.39) | 1.14 (±0.32) | 0.89 (±0.1) | 1.11 (±0.23) |

**Table 4**

## 7.1 TRIANGLE MODEL

Using the scores from the table above and the formula from 5.1, we can plot the impact mechanisms in the triangle below which is a mathematical illustration of their positions in respect to the three dimensions of the impact. The corners show that the Impact mechanism is tilted completely towards that mode of impact (Direct, Indirect or Future). The centre point shows that the respective Impact Mechanism is equally focused on delivering Direct, Indirect and Future impact.

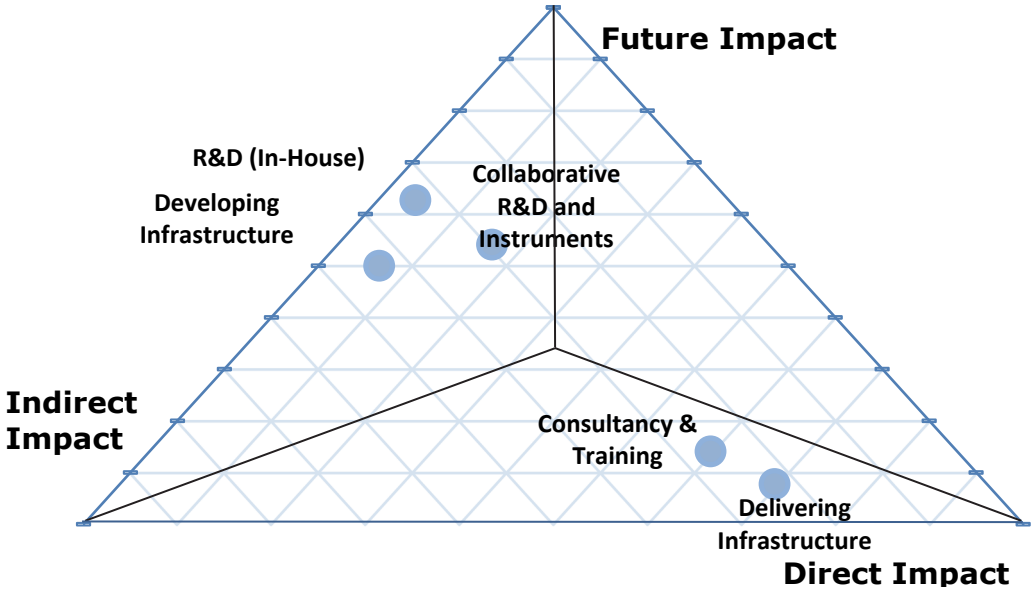



**Figure 3**

It is seen that Delivering Infrastructure and Consultancy & Training work differently as compared to the other three. The two focus on delivering direct impact, while the others tilt towards generating future impact. Out of the five impact mechanisms we see Developing Infrastructure is slightly inclined towards delivering indirect impact. Collaborative R&D can be seen closest to the central point which is if we looked at the first table constructed for the impact themes; we see its involvement in each of the three themes. Our accessibility to more data could mean that the results be statistically significant at a higher confidence level.

## 7.2 TECHNOLOGICAL LIFECYCLE MODEL

Using the above scores, we were able to plot the impact mechanisms on the two frameworks as shown below

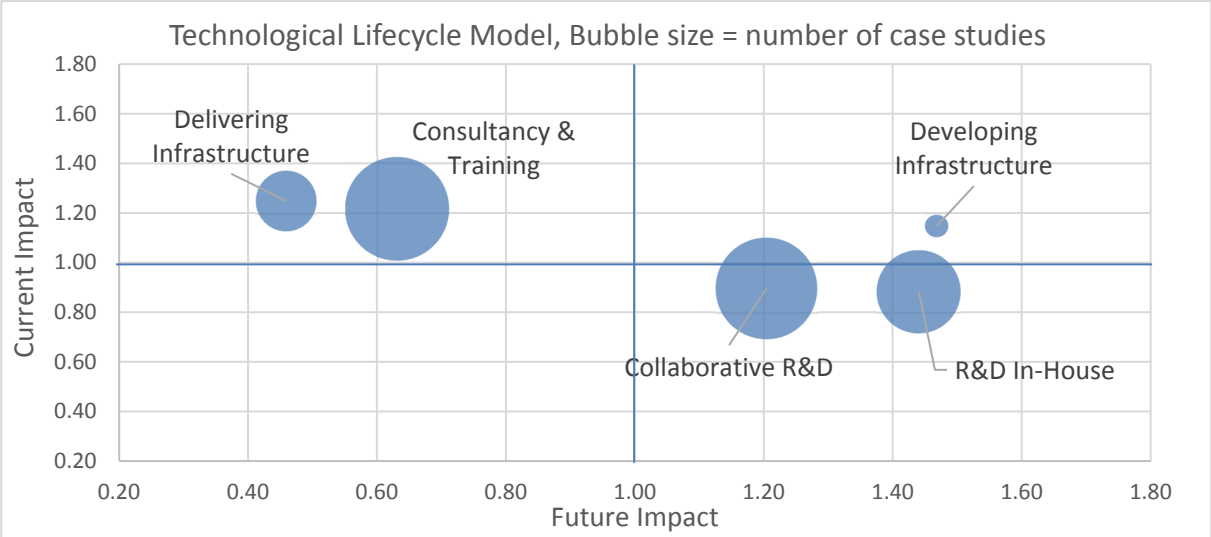



**Figure 4**

The above Bubble graph shows that Delivering Infrastructure and Consultancy & Training are working in an opposite direction to In-House R&D, Developing Infrastructure and Collaborative R&D. The former is focused on delivering current impact with little to no focus on generating future impact and the latter is focused on both generating future and current impact. For instance, we see developing infrastructure to be delivering high impact in both dimensions. For Developing Infrastructure, it has high confidence intervals due to the comparatively low number of case studies within this activity types when compared to the other four types. This could mean its position could vary but would only be testable with extra data.

## 8 QUOTIENT SCORES BETWEEN ACTIVITIES AND SECTORS

Analysis has also been conducted in a similar fashion to the previous examples with respect to the sectors and activities. This allows for an assessment into the types of activities each sector tends to focus on. Using Quotients as before and the same colour scheme, we see the following:

| Activities\Sectors | Advanced Manufacturing | Digital & Quantum Technology | Energy & Environment | Life Sciences & Health |
|---|---|---|---|---|
| In-House R&D | 0.86 (±0.32) | 1.03 (±0.6) | 1.13 (±0.51) | 1.05 (±0.47) |
| Developing Infrastructure | ***0.53 (±0.38)*** | 1.31 (±1.5) | 0.98 (±0.86) | ***1.53 (±1.34)*** |
| Maintaining and Delivering Infrastructure | 1.1 (±0.48) | 0.36 (±0.24) | ***1.41 (±0.75)*** | 0.83 (±0.44) |
| Collaborative R&D | ***0.74 (±0.25)*** | 1.49 (±0.79) | 0.93 (±0.38) | 1.16 (±0.47) |
| Consultancy and Training | 1.4 (±0.46) | 0.82 (±0.43) | ***0.73 (±0.29)*** | ***0.79 (±0.32)*** |

**Table 5**

Here we see Advanced Manufacturing performing strongly on Consultancy & Training, meanwhile we see Digital & Quantum indicating higher-than-average levels of Collaborative R&D and lower-than-average levels of Delivering Infrastructure. Several other points can be hypothesized as well. Advanced Manufacturing could have lower-than-average levels of Developing Infrastructure and Collaborative R&D, while Energy & Environment and Life Sciences & Health both could have lower-than-average levels of Consultancy & Training. It can also be hypothesized that Energy & Environment and Life Sciences & Health have higher-than-average levels of Delivering Infrastructure and Developing Infrastructure respectively.

# 9 THE PEN PICTURES

Using the analysis conducted on the case studies, we are able to see trends by sector and activity. The following are details of the analysis.

## 9.1 SECTORS

### 9.1.1 Advanced Manufacturing

According to the case studies, Advanced Manufacturing provides the most direct impact out of the four sectors, evidenced in a number of ways. Firstly, Advanced Manufacturing are the only sector to have a majority of case studies involving customers rather than collaborators and/or “no outside influence”. This suggests that external organisations are looking to work with Advanced Manufacturing directly, likely due to the impact the products/services provide for their firms. This is further seen by the products that Advanced Manufacturing mainly tends to be associated within the case studies. Over 50% of their case studies are made up of either Measurement Services or Consultancy, further proving that users see great benefit to working directly with Advanced Manufacturing. Finally, the main impact mechanism that Advanced Manufacturing works through is process innovation, which is likely due to the nature of the Manufacturing sector as a whole. Manufacturing worldwide tends to be focused more on cutting costs, improving accuracy and increasing speed of production. This isn’t disregarding the R&D that goes into creating new manufactured goods, rather showing the emphasis of manufacturing is on the maximising the efficiency of production.

Despite Advanced Manufacturing’s high levels of direct impact, there seems to be little indirect impact coming from the work conducted. This is likely due to the commercial nature of the work. As private firms often pay for the services, all impact go directly to the payee and their direct customers. Externalities are typified by third parties receiving impact without being involved in a transaction. If many third parties were to benefit from the work conducted, there would be little incentive to pay for the knowledge producing the impact in the first place. This is noticeable when looking at the consumer benefit impact mechanism. Consumer Benefit is seen when measurement looks to improve the lives and welfare of consumers as whole, through improved safety and health, which is something Advanced manufacturing appears to seldom do. However, despite these points, there is one avenue through which Advanced Manufacturing does seem to produce some indirect impact. Transactions costs are an impact mechanism where NPL has helped to reduce the cost associated with trading a good or service. Often this is done by providing measurement services to firms, reducing their uncertainties, which would often lead to fan-out.

Similar to the indirect impact, Advanced Manufacturing also has much lower levels of Future Impact, an example of which is fact it has the lowest levels of R&D-based case studies out of the four. The lack of Future Impact is further proven by the low breadth of impact. This is due to many of Advanced Manufacturing’s partners tending to be SMEs such as calibration labs, reducing the scope of benefit to only a few, small firms. Working with smaller firms also impacts the time profile of Advanced Manufacturing’s impact, with over half of the case studies indicate shorter-term impact (either one-off impact or short-term impact), due to the nature of doing small-scale, paid-for work.

One thing that is unique about this sector is the prevalence of training schemes. Only Advanced Manufacturing providing a significant number of training case studies, mainly around courses that had be provided by NPL at the behest of particular firms/industries. This level of knowledge transfer is likely indicative of Advanced manufacturing’s working relationship with the Manufacturing sector.

### 9.1.2 Energy & Environment

Energy & Environment has a far more mixed relationship with the three main methods of output. When assessing the sector for direct impact, there is some evidence of this form of impact. Despite lower levels of consultancy work, the high levels of measurement services indicate that the commercial relationship is built around calibration work rather than working alongside customers. This is backed up by the incidence of “Trade & Regulation” case studies, likely identifying calibration services. However, the commercial nature of the relationship is contradicted by the fact there is little process innovation occurring within this sector, with the focus on Transaction Costs instead. This is related to the work concerning emissions measurement, either through reducing uncertainties or by running Emission measurement systems, such as the Heavy Metals Network.

One outlier that exists within Energy & Environment is a significantly higher proportion of case studies conducting contract R&D, where NPL has been tasked with producing new knowledge to solve a customer’s problem. This suggests that the Energy & Environment’s working relationship is almost a “half-way house” between current and future impact; firms work with Energy & Environment to produce knowledge which may be important for their current research but is something they see the potential to monetize in the future. This emphasis on contract R&D for Energy & Environment also allows for more independence when working on a solution for a customer in comparison to collaborative work. This could suggest a level of trust that Energy & Environment’s working partners have in the sector to solve their metrological issues.

The future impact of Energy & Environment is also seen by the breadth and time profile of impact, both of which are higher than average. Many of Energy & Environment’s challenges, such as tackling climate change are large-scale, worldwide issues. The scope of these issues often leads the work conducted to have a large breadth of impact. Furthermore, these issues also prove impact for a long period of time due to the nature of Climate Change. This high breadth of impact is also backed up by high levels of indirect impact. Unlike Advanced Manufacturing, much of the work conducted with this sector is targeted at protecting the Environment.

Due to the Environment being a public good, its protection is likely to be underfunded by the private sector as the impact are often felt by third parties. Therefore, by working in this area, Energy & Environment is helping to internalise this positive externality. Not only by protecting a public good is Energy & Environment providing indirect impact, the measurement services also providing impact through fan-out. This is evidenced by transaction costs being the main impact mechanism through which Energy & Environment delivers impact to the economy. Often this is done through calibration of instruments used to monitor the Environment, be it working with the Facility for Airborne Atmospheric Measurements to improve climate observation or the aforementioned Heavy Metals network.

### 9.1.3 Life Sciences & Health

Life sciences & Health has very little direct impact according to the case studies. There are very few customers, the services it provides aren’t focused around measurement services or consultancy and the main mechanism of impact is Consumer Benefit rather than a form of innovation. This all leads to limited direct impact. Furthermore, the healthcare sector in the UK is based around the NHS, which is unlikely to pay for services due to funding restraints.

In contrast to the lack of direct impact, many of Life Sciences & Health’s case studies indicate high levels of future impact. Life Sciences has a far higher levels of R&D than the

two sectors mentioned already. Collaborative and In-House R&D account for more than 50% of all the case studies, with collaboration seems to be a focus for this sector as seen by the high number of case studies involving collaborators rather than customers. Further proof that research conducted by Life Sciences & Health has high levels of future impact is the level of breadth of impact. Life Sciences & Health faces large-scale challenges that the UK would have to face due to the importance of healthcare to a functioning economy. Furthermore, with the issues of an aging population around the world, the time profile of Life Sciences & Health's impact is evidently long term.

Not only is Life sciences & Health focus on future impact, this sector also boasts high levels of indirect impact. Similar to Energy & Environment, much of the work conducted with this sector is targeting a positive externality, in this instance the underprovision of healthcare. The underprovision of healthcare harms the wider public, further seen by consumer benefit being the impact mechanism that is strongest for life sciences and health. One thing that is noticeable is that Life Sciences & Health is very weak at reducing transaction costs, potentially identifying an area of improvement for this Sector.

### 9.1.4 Digital & Quantum technologies

Digital & Quantum technologies is arguably the most research-focused sector out of the four. Akin to Life Sciences & Health and Energy & Environment, a large proportion of their case studies are predominantly R&D-focused. However, unlike the sectors mentioned previous, the emphasis for Digital & Quantum is on in-house R&D, research with no outside commercial influences. This is where Digital & Quantum would either be either working alone or with academic collaborators. Due to the lack of "no outside influence" case studies, it can be assumed that work often involves non-private institutions (e.g. PSREs, Universities). This is likely driven by the research conducted within this sector. Further reinforcing the point on Digital & Quantum technologies' focus on strategic R&D, this sector also has the highest breadth of impact out of the four sectors. With the importance of much of the research conducted within this sector for Industry 4.0, there is a clear widespread reach for the work conducted within this sector. This focus on future solutions is seen in the time profile of impact, in which the majority of case studies are focused on longer-term impact, with 32% of case studies indicating that the impact from the work hasn't been felt yet. This emphasis on research is also seen within the logic model, with a strong emphasis on "research"-based case studies for this sector.

The youth of Digital & Quantum is also seen by its main impact mechanism, product innovation. Due to this area being more juvenile in comparison to the work conducted within the three sectors at NPL, the scope for new knowledge is far greater for Digital & Quantum. As the field ages, as seen with Advanced Manufacturing, the emphasis will shift away from creating new products/services. This will likely be done by the Private sector due to the profit motive becoming greater. NPL would then be tasked with aiding productivity gains in this area.

Despite a focus on innovation for the future, there seems to be limited impact at this point in time. This is likely due to the youth of the sector as a whole. Many of the fields that Digital & Quantum technologies work in (quantum detection, 2D materials) are still lacking the level of real-world applications that the other sectors have. This limits the number of commercial services that the sector could provide, limiting its commercial potential at this time. The lack of customers is further indicative of this. As the technology is being developed in several areas, the indirect impact isn't fully apparent, though the level of reducing transaction costs as an impact mechanism appears to be following the NPL average. This suggests the metrology research is having impact and could lead to fan-out of measurement.

## 9.2 ACTIVITIES

### 9.2.1 In-House R&D

This Activity's impact is primarily driven by Future impact, with all three of the indicators for this impact theme are either greater than or equal to the NPL average. The main two indicators driving impact for this are "R&D case studies" and Longer-term impact case studies. Much of the work conducted as a part of this activity is the fundamental metrological research that underpins the great work conducted here, often conducted with Academia. This research is the bedrock on which future commercialisation projects can be conducted. Because of this, the impact generated can only happen in the future rather than now. R&D case studies link strongly with this activity due to the clear links between R&D as a product and R&D as an activity.

We also see some indication of indirect impacts for this activity as well. This is mainly driven by evidence of potential significance of Consumer Benefit. This requires further investigation but would suggest that the work done in this activity could have impacts on the livelihood of the public. This is mostly likely driven by healthcare and environmental benefits of certain areas of research done at NPL. Externalities also lean towards the positive, likely due to the fact research doesn't always impact those who partake in the work, there are significant impacts for third parties, particularly if the research aims to solve healthcare or environmental issues.

The weakest area of impact is direct impact. This is driven by the lack of customers and Measurement services & Consultancy case studies. This is due to the fact that R&D isn't a service for a customer (apart from contract R&D, but that has little relevance for this activity), rather it is done in collaboration with other organisations. Furthermore, there is little chance for direct impact due to the fact future and direct impact have a negative correlation, work being conducted for the future has no real chance of having impact on the here-and-now. Measurement services and Consultancy are both services which rely on prior knowledge, which isn't a function that this activity relies upon as it generally is used to develop new knowledge

### 9.2.2 Collaborative R&D and Instruments

There is limited evidence of Direct Impact for this activity but with one important caveat, driven by the low levels of measurement services and consultancy. As mentioned as a part of In-house R&D, measurement services and consultancy rely on prior knowledge, while the work conducted here is often generating new knowledge. Because of this there is likely little overlap between this activity and measurement services and consultancy. The aforementioned caveat is that in spite of the overall indicator being negative, there is an indication that this activity leads to process innovation. This is likely by providing innovative solutions to problems firms may have, linked to the work conducted as a part of contract R&D.

This activity seems to follow the NPL level of indirect impact, due to two indicators which seem to be higher and lower than the NPL average. R&D, as mentioned previously, tends to have higher levels of externalities, with research itself likely to benefit those outside of the transaction itself. However, transaction costs seem to be low. This suggests that the link between traceability and collaborative research projects seem to be low, likely due to the fact traceability is a metrological focus rather than a generally scientific one. This leads to the belief that firms that look to collaborate on research aren't doing so to focus on pure metrology.

Finally, this sector appears to have high levels of future impact. This is mainly driven by R&D case studies. This is for the same reasons as In-House R&D but is mainly driven by

collaborative and contract R&D products. However, the research here differs to the type conducted in In-House R&D as the research target often fulfil the goals of the users NPL works alongside, rather than NPL's own goals. This often involves private firms but can include public bodies such as the NHS. The other two indicators seem to follow the NPL average, perhaps due to the fact that contract R&D tends to be focused on solving problems for customers, so is unlikely to have a high level of impact into the future.

### 9.2.3 Developing Infrastructure

It should be noted that this activity had a very low proportion of the case studies (<10% of total case studies). Significance could be found for most of the indicators, but more case studies may affect the finding here more than the other sectors.

Similar to In-House R&D, this activity had high levels of Future impact, indicating significantly higher than the NPL average case studies on all three of the indicators. This was mainly driven by R&D case studies. This would involve the work done around the redefinitions of the SI units over the last few years. The redefinition work, along with general regulatory input, is likely to have a great deal of impact in the future due to nature of regulations being implemented over the long-term, rather than immediately. Also, the non-niche work such as the collaborative work being conducted also has the potential to generate impact on a broad scale, with committees such as those at BIPM looking to drive metrology forward rather than assessing where metrology is now

Unlike In-house R&D, we see clear evidence of indirect impact. As much of this work is on regulatory impact, along with redefinitions, much of the impact will likely be 3rd party benefits. The aforementioned types of work that sit within this activity are likely to help the country as a whole with its metrological functions. Furthermore, NPL gains "soft power" from this activity more so than any other by working alongside NMIs and prestigious organisation on panels such as those at BIPM. There are also clear examples that the benefits to regulation are seen by protecting health and safety of the public, such as the work decommissioning Sellafield.

This activity also has low levels of Direct impact, likely driven by low levels of measurement services & consultancy. Much of the work conducted as part of this activity won't be directly with customers. Rather it would be focus on collaborative works with other NMIs, institutions and sectors of industry as a whole. This means that the direct impact will be sacrificed for the other two impact themes.

### 9.2.4 Delivering and Maintaining Infrastructure

This is one of the two activities that display high levels of direct impact. This has been primarily driven by NPL's measurement services. This clearly links with measurement services and consultancy case studies for obvious reasons. As part of NPL's remit as an NMI, realising the SI and being able to disseminate accurate measurements down the traceability chain, this activity's link with measurement services provide clear examples of direct impact. This links with customer case studies as measurement services are conducted primarily with customers, due to the direct impacts it may have for the firm paying for the service in question and their customers/partners.

Linked to the high levels of direct impact, we also see low levels of indirect impact, due to the fact that is customer-based. This is due to the fact that a firm wouldn't pay for a good if it were able to gain the same benefits indirectly from a transaction conducted by another company. As this logic holds for direct impact, the fact the good/service is excludable (i.e. free consumption of the good/service is limited) there is low chance for indirect impact. It must be noted that it is hypothesized that this activity would also aid with reducing

Transaction costs, believed to be done by improving traceability to NPL. However, this activity wasn't significantly different to the NPL average, something that could be investigated further.

There are also very low levels of future impact for this activity, with each indicator suggesting significantly lower levels of case studies. As the bulk of the case studies in this activity are measurement services, much of this work is focused on the present. Because of this, it is unlikely that much of the work will have longer-term impact. Furthermore, R&D looks to generate knowledge, while delivering and Maintaining infrastructure looks to utilise current knowledge, limiting the role for R&D here.

#### 9.2.5 Consultancy and Training

For similar reasons as Delivering and maintaining infrastructure, this activity's has high levels of direct impact, driven by two main categories. Due to the nature of consultancy and training programmes, often the end-user would be paying for both of these, rather than collaborating on them. This is down to consultancies and training programmes relying on prior knowledge, which is disseminated using these methods. These are all behind a paywall to recoup the costs of generating the knowledge used in them, meaning they can only be accessed directly. Also, the second part of measurement services and consultancy is obviously consultancy, so the clear link is fairly obvious.

Again, as mentioned in Delivering and Maintaining Infrastructure, there are low levels of Indirect impact as many of the services are excludable, leading to low externality effects for this activity; the impact is solely given to those who pay. The work also seems to have limited impact on health and safety, likely due to the emphasis on the private sector in a customer-supplier relationship. There is a tendency for the public sector to focus on collaborating with NPL rather than being a customer. It should be noted is that this activity appears to reduce transaction costs. Often consultancy work is providing answers to customers metrological questions, such as accuracy of measurement to meet a standard partly developed by NPL, reducing the costs of trade. Also, training courses achieve a similar purpose with a different method, helping a firm upskill its workforce's metrological skills to reduce uncertainties in measurement.

The low levels of future impact are driven primarily by a lack of R&D case studies. This is due to the fact that prior knowledge is used for these activities. This means that there is little need for R&D. The other indicators each follow the NPL average or aren't significantly different. This suggests that the work conducted has some impact over the longer term and are non-niche. This is likely due to the fact consultancy work has the potential to solve issues that firms/organisations may have with their larger scale projects.

## 10 CONCLUSION

### 10.1 MONITORING & EVALUATION

The major finding of this study is that each sector and each activity has a dominant impact theme (e.g. direct impact). This is something that isn't identified elsewhere in NPL's evidence portfolio, as this is the first study (qualitative or quantitative) to investigate NPL's constituent sectors and activities, compared to previous studies that assessed aggregate impact. These differences don't prevent comparison between sectors/activities, but underline that multiple lenses have to be used to fairly judge the impact of these respectively, because a given sector/activity tends to be stronger along a particular impact theme but weaker on others. The assessment of the sectors and activities using impact themes has allowed for pen pictures to be developed, a picture in words describing the impact profile of each sector/activity.

The use of metrics can lead to distortions in funding allocation in the case of indirect impact. This is because it's difficult to measure, unlike direct impact which can be measured through

invoiced income. This challenge was mentioned in Swann's report for the NMS[10], where he noted that the "choice of an empirical methodology to value measurement activities" was important when assessing various types of impact. If techniques focus on the "bottom-line value of a project", in particular willingness-to-pay, then the indirect impact, by contrast, will be almost impossible to ascertain – the result of which could be "an incomplete measure of the economic impact" of the work conducted by the NMS labs. The use of incomplete measures creates the potential to judge equally worthy projects unfairly, with those that have higher levels of direct impact judged more favourably than those that have higher levels of indirect impact – creating a misleading picture[11] with regards to economic impact.

Using the frameworks detailed above, we can see clear differences in orientation with regards to the sectors. Using an astronomical analogy, *Health & Life Sciences* and *Energy & Environment* are "young stars", producing high levels of impact now and into the future. Meanwhile, we see *Digital & Quantum* as a "nebula", that is not as impactful now but has potential to provide impact into the future. Finally, we see *Advanced Manufacturing* as a "red giant", still providing impact but with less potential to provide impact in the future. As there is an understanding concerning the sectors' orientations and position in the lifecycle, each sector can be set different goals and targets moving forward.

For example, in Advanced Manufacturing's case, there is the expectation that the sector would renew itself, similar to how old stars give off gases which turn into new Nebulae. This would likely be done by adopting the premises of Industry 4.0, looking to help facilitate Digitally-Enabled-Supply-Chains, along with work concerning Robotics and Additive Manufacturing. This would see a relationship between Advanced Manufacturing and Digital & Quantum, with considerable crossover and assimilation between the sectors. When an old star dies, a white dwarf often remains, the core of the former star. The core that would remain for Advanced Manufacturing would be the SI units, many of which exist within this sector. This would remain so moving forward.

Lastly, there are intrinsic benefits to improving the evidence available for use during NPL's formulation process, so that it can even more closely follow the ROAMEF cycle. By better evidencing NMS investment plans, the business cases submitted to BEIS would be strengthened, providing better evidence for officials tasked with assessing business cases.

## 10.2 IMPACT ON FORMULATION

The framework detailed within this report is a simple, dynamic model which allows for NPL to articulates questions concerning its direction and priorities of different modes of impact, such as what weightings should each impact theme having for NPL as a whole and a given sector?

It should be noted that there are limitations when using this model in the real world. The main two issues that arise with this model are:

- Appropriateness of framework as a whole, could be missing some of the granularity of the impacts generated ("oversimplification").
- Assuming that the framework is appropriate, the degree to which the questions correlate with the forms of impact is a point which can be debated. However, this can be improved in future

10 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/297870/prof-swann-report-econ-measurement-revisited-oct-09.pdf

11 Misleading as the use of techniques that focus on bottom-line attempt to represent the whole picture, when in reality they can only focus on direct impact, omitting indirect impact of areas.

iterations by adding more questions and asking a diverse group of scientists, administrators, and other employees about the reports.

Despite the limitations as detailed above and in section 2.1, assuming buy-in with regards to the model as a whole and the initial attempt to operationalise it, these are the implications:

- This can be used to help NPL achieve objectives set by the NPL board, by providing information to NPL's upper management to aid formulation activities.
- Furthermore, this provides a model to articulate NPL's direction moving forward. This is done by determining weightings of impact theme, given the direction NPL wants to head in.

Although Analysis & Evaluation aren't prescriptive with regards to the impact profile that the sectors should have, there is a natural point where NPL's sectors should be aiming for as it would clearly be a "sweet-spot" in terms of impact. This would correspond to the top right quadrant of our chart representing the technological lifecycle, where both current impacts and future impacts are higher-than-average.[12] It cannot be expected that all the sectors can make it to this point, but plans can be implemented so that those that aren't already there can head towards that point. The use of plans is important for NPL if it wishes to increase its impact, no matter the form. The following plans could be implemented for sectors that aren't already in the sweet spot:

- For sectors that appear young (high future impacts, low current impacts), there should a movement towards current benefits. This can be done by speeding up commercialisation or by generating public goods to provide indirect impacts (either method is fine as direct and indirect benefits are equally weighted in current impacts).
- For older sectors, there is a need to prevent obsolescence within their work. This can be done by innovation, a form of creative destruction where future impacts are derived from the work being conducted.[13]

This feeds into an ongoing conversation concerning divestment for mature areas. If a mature capability is able to generate direct impacts, a recommendation could be to spin-off or transfer these assets to a commercial company[14], as it can be a source of income. However, if a mature capability generates indirect impact, the service won't generate enough income to be sustainable, even though it creates impacts. In short, there may be an argument for ongoing public funding of mature capabilities if they predominantly generate indirect impacts. This can be seen already within NPL, such as the work conducted alongside DEFRA concerning the Heavy Metals Network. Other areas of NPL have the potential to benefit from public funding of mature areas, such as in Healthcare, with the Breast Cancer scanner as an example. The use of divestment of direct-impact-producing capabilities would free up resources for use in more fertile, younger research areas.

It should be noted that the study is somewhat limited as it has confirmed the beliefs of Programme Management in the necessity to shift sectors towards the "sweet spot" detailed above. The analysis' mechanical nature meant the similarities in results and commonly held beliefs were purely coincidental, as it would incredibly difficult to "massage" the results in order to match the views of Programme Management. The concept of funding activities not sectors, with sectors bidding to each activity-focused pot has also been utilised independent of this reports research. As a consequence of these coincidences, there is little argument for

12 this in theory, not possible in this model as it currently exists, as the sectors make up NPL so they can't all be above average

13 This can be seen in older athletes, who have to work harder to maintain their performance. This allows for a better approach to the aging process rather than wasting away. This "creative destruction" can work for certain areas but may not be applicable for others.

14 NPL could retain a small, non-controlling stake in the spin out, but the firm would be run by a management team within the private sector

change with regards to the general structure of formulation and programme management. However, there is still the potential for benefits to be derived from this work. Further refinement of the categorisation developed in this report could allow for standardised definitions of expected benefits for each project/group/sector, providing greater structure and objectivity to the formulation process.

Lastly, this report provides new insights for the Analysis & Evaluation team about NPL's diversity of impact and mechanism through which it's achieved. This stands in contrast with the current evidence portfolio, which is made up of empirical analysis based on data at an NPL-wide level. This aggregation hides the diversity of NPL's constituent parts, and such evidence fails to provide actionable insights for each respective sector and activity. The evidence developed in this report is a first step towards the Analysis & Evaluation team being able to provide granular, disaggregated evidence to management concerning the sectors and activities. This could subsequently be used to inform bespoke plans for each sector, allowing for sectors to better understand the make-up of their activities and adapt their weightings of activities to better achieve the goals of NPL. The longer-term aim would be to provide a "map and compass" with which NPL could better understand and monitor its location and direction, improving its ability to chart a course in-line with the heading set by NPL.

# 11 APPENDIX

## 11.1 SUMMARY STATS TABLE

| | | Activities | | | | | Sectors | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Question Groups | | Collaborative R&D and Instruments | Consultancy & Training | Delivering Infrastructure | Developing Infrastructure | R&D (In-House) | Advanced Manufacturing | Digital & Quantum Technology | Energy & Environment | Life Sciences & Health |
| | Total | 100 | 102 | 59 | 22 | 82 | 133 | 48 | 87 | 89 |
| Products | Measurement Services | 6 | 0 | 57 | 2 | 0 | 24 | 5 | 20 | 15 |
| | Training | 0 | 17 | 0 | 0 | 0 | 15 | 0 | 0 | 1 |
| | Collaborative R&D | 67 | 0 | 0 | 7 | 0 | 20 | 12 | 15 | 24 |
| | Contract R&D | 4 | 1 | 2 | 3 | 3 | 1 | 2 | 8 | 2 |
| | Consultancy | 4 | 83 | 0 | 2 | 0 | 39 | 11 | 19 | 20 |
| | L.Transfer | 15 | 1 | 0 | 0 | 0 | 6 | 3 | 2 | 5 |
| | In-House R&D | 5 | 0 | 0 | 9 | 79 | 28 | 17 | 23 | 22 |
| Impact Mechanisms | Transaction Costs | 23 | 43 | 17 | 7 | 25 | 45 | 16 | 34 | 17 |
| | Process Innovation | 29 | 30 | 17 | 4 | 22 | 55 | 8 | 23 | 15 |
| | Product Innovation | 33 | 22 | 18 | 4 | 19 | 31 | 21 | 19 | 24 |
| | Consumer Benefit | 15 | 7 | 6 | 6 | 16 | 2 | 3 | 9 | 33 |
| | Non-Niche market (0/1) | 71 | 59 | 28 | 20 | 55 | 74 | 37 | 59 | 55 |
| | Externalities | 43 | 28 | 15 | 11 | 34 | 20 | 13 | 54 | 38 |
| Time Profile of Impact | One-off impact | 17 | 29 | 22 | 3 | 1 | 43 | 7 | 9 | 13 |
| | Short term impact | 33 | 31 | 20 | 3 | 23 | 39 | 13 | 25 | 30 |
| | Long-term impact | 43 | 40 | 15 | 13 | 49 | 47 | 19 | 48 | 42 |
| | No Impact yet | 7 | 2 | 2 | 3 | 9 | 4 | 9 | 5 | 4 |
| Working Relationship | Collaborators | 59 | 33 | 14 | 14 | 40 | 42 | 26 | 37 | 50 |
| | Customers | 35 | 66 | 37 | 7 | 12 | 75 | 17 | 36 | 26 |
| | No Outside influence | 6 | 3 | 8 | 1 | 30 | 16 | 5 | 14 | 13 |

## 11.2 EXEMPLAR CASE STUDIES BY SECTOR/ACTIVITY

### 11.2.1 Advanced Manufacturing

**Shaken, not stirred: Micro-vibration device tests ESA satellites**

Satellites are vulnerable to vibrations, which reduce the resolution of images and accuracy of measurements made over great distances. Vibrations can be caused by a multitude of equipment within satellites, such as solar array drives and rotating cryocoolers. ESA needs to test and correct for these jitters to improve the accuracy of its Earth observations

To make such testing possible, NPL developed a micro-vibration platform for ESA that can measure vibration made by subsystems to an unprecedented degree of accuracy. The platform also generates small, controlled forces and torques to shake satellite instruments and components in six degrees of freedom. The lower section of the platform isolates it from the vibrations from the surrounding environment, like footsteps, allowing the upper section to measure micronewton-scale vibration free from interference. The platform is housed in a tent to limit perturbations caused by airflow and can also be used in a vacuum. The instrument will be used to measure and correct for internal vibrations, and to test satellite components under a range of controlled vibration conditions.

**Reducing energy and maintenance costs in food packaging manufacture**

The UK produces over 8.2 billion beverage cans each year, with a single production line making up to 500 million cans every year. The main procedure to form the can is done in one continuous punch stroke by a 'Bodymaker' in about a fifth of a second. The 'bodymaker' punch is made from a very hardwearing material that can resist the high forces at play, but the punch can cause issues with vibration and alignment due to its speed. In order to keep the can dimensions consistent, the Bodymaker needs constant maintenance.

If the density of the punch can be reduced while maintaining/improving wear resistance and stiffness, large savings in energy, raw materials and maintenance time could be made. Working with the manufacturer of the punches, Sandvik and the beverage can manufacturer, we investigated how the bodymaker punches wear and whether lower density materials with lower densities might behave when made into lighter-weight punches. Using electron microscopy techniques, we assessed the ways different metal alloys wear away, developing a system to test materials in the same environment they are used in. These results will help to reduce maintenance, energy costs and improve efficiency.

### 11.2.2 Energy & Environment

**The UK's first decommissioned nuclear power plant**

In the final stage of the decommissioning process of the Windscale Advanced Gas-cooled reactor (WAGR) in May 2011, the outer membrane from the reactor's bioshield (a concrete structure designed to protect workers from high levels of radiation) was removed. The United Kingdom Atomic Energy Authority (UKAEA) decommissioned the reactor in 1981 to develop and demonstrate the knowledge, methodology and skills required to undertake such a task.

NPL scientists analysed concrete samples from differing depths within the shield wall to assess whether they would be assigned as either free release material, very low-level waste, low level waste or intermediate level waste. This work involved novel measurements of nuclides that aren't normally determined and led to the creation of a standardised concrete reference material, allowing others to analyse their own samples and process radioactive waste accordingly in the future.

**Increasing the lifetime of hydrogen technologies**

Hydrogen fuel cells produce electricity from the reaction of hydrogen with water, while electrolysers use electricity from the grid to split water and generate the hydrogen fuel. These devices both have a key role to play in the implementation of a sustainable energy infrastructure. However, their performance can suffer if the reaction isn't uniformly distributed throughout the cell, making inefficient use of expensive catalysts and can lower performance. They also arise naturally during start up and shutdown of the cell, leading to reactions that corrode the cell, reducing its working life.

To better characterise the distribution of reactions, we developed an innovative reference electrode for polymer electrolyte membrane (PEM) fuel cells and electrolysers. By connecting a reference electrode directly to the PEM with an acidified Nafion tube, accurate mapping of electrolyte potential across the active area of each electrode was possible for the first time. The technique was shared and widely adopted by several manufacturers and led to carbon savings of 0.4 megatonnes, according to an independent study by Technologia.

### 11.2.3 Life Sciences & Health

**GeT-ing genes delivered**

NPL scientists have replicated the process through which viruses infect human cells, with the aim to apply the approach to gene therapy, which looks to correct defective genes such as those that cause cancer. Gene Therapy is in its infancy, with difficulties around targeting damaged cells and crating corrective genes. An equally important issue is the transport of corrective genes to cells, as cell membranes have poor permeability.

This research addresses this challenge by describing a model peptide sequence, dubbed GeT (gene transporter), which mimics the process Viruses use to infect human cells. To prove their concept, the researchers used GeT to transfer a synthetic gene encoding for a green fluorescent protein that can be seen and monitored using fluorescence microscopy. The design could provide a template for non-viral gene delivery systems and future treatments of genetic disorders.

**New ultrasound sensors for improved breast cancer screening**

NHS breast cancer screening is currently carried out using X-ray mammography, which can be uncomfortable for women, with also the inability of 2D X-ray mammography to separate overlying tissue can lead to false positives and false negatives. Further issues arise with hazards associated with ionising radiation limit the frequency with which X-rays can be performed. Normal ultrasound is dependent on its operator and suffers from imaging problems, making cancerous tissues hard to distinguish from healthy tissue.

NPL, with its partners, are developing a prototype clinical system for a new breast screening technique - using ultrasound computed tomography (UCT). NPL has developed and patented a novel detection method employing pyroelectric sensors, which convert ultrasonic energy into heat, generating electrical signals which are eventually used to form the ultrasound image. These sensors should produce fewer image artefacts than regular piezoelectric detectors.

### 11.2.4 Digital & Quantum Technologies

**Delivering trusted time for UBS infrastructure**

The Markets in Financial Instruments Directive (MiFID II) requires all trades to be timestamped, in some cases to within 100 microseconds. The law applies to anyone trading any product listed in the EU. However, conventional timing systems used for trading, such as GPS, are prone to jamming and interference, causing trading irregularities

UBS and TMX Atrium signed an agreement with us to secure NPLTime, our service providing a precise time signal directly traceable to Coordinated Universal Time (UTC) and independent of GPS. Our Atomic clock, NPL-CsF2, is accurate to one second every 158 million years, with NPLTime an extension of our decades in time dissemination expertise, providing industry direct access to reliable timing straight from the sources. NPLTime provides end users with timing capability that underpins traceable timestamping, latency, monitoring & synchronisation. The signal is the one means of ensuring that trades comply with MiFID II without further monitoring and calibration costs.

**Precision time for satellites**

Galileo Time Service Provider (TSP) is driven by the constellation of 30 global navigation satellites. The signal from a navigation satellite travels at light speed (300-million m/s) so a tiny error in a time signal can throw navigation a long way off course. This means the satellites need precise and synchronised time.

NPL is part of a core consortium developing the Galileo Time Service Provider (TSP). It is developing algorithms that will draw upon time data from atomic clocks across the world for transmission to the clocks at Galileo ground stations controlling and managing the orbiting satellites (within 28 billionth of a second).

### 11.2.5 In-House R&D

**NPL unveils improved means of measuring ultrasonic cleaning systems**

Ultrasonic Cleaning Systems widely used across the medical industry, using high frequency waves to form small detergent bubbles which are later imploded to clean contaminant particles. The current NHS system requires Aluminum foil, which erodes and is punctured by the imploding bubbles, leading it to be unreliable and can contaminate the vessel cleaning fluid. This increases costs even more.

The new NPL CaviMeter is a measurement system for cleaning system, providing a new and improved method of quality assurance. The CaviMeter monitors the acoustic signals generated when the bubbles implode, identifying how much cavitation is taking place at a given location, allowing for equipment to produce the optimal quantity and distribution of cleaning action The CaviMeter supports ultrasonic baths and allows health agencies to select the optimum cleaning system. It was developed in response to longstanding consumer need, with the cavitation sensor conceived and developed under Strategic Research, with the other electronics supported by the Measurement for Innovators program.

**Smart textiles - the answer for wearable electronics?**

Most current plans for wearable electronics require weaving conductive materials into fabrics, which have limited flexibility and can only be achieved when integrated into the design of the clothing from the start. NPL's plan provides a way to print silver directly onto fibres, allowing for easily integrated circuits within clothing.

The technique involves chemically bonding a nano-silver layer onto individual fibres to a thickness of 20 nm. The conductive silver layer fully encapsulates fibres and has good adhesion and excellent conductivity. The technique has applications in a range of fields, from fashion to sports. Furthermore, silver has antibacterial properties, further allowing for medical applications.

11.2.6 Developing & Maintaining Infrastructure

**DIAL**

DIAL (differential absorption lidar), a highly flexible air quality measurement technique, pioneered at NPL, has been recognised by stakeholders in the oil and gas industry, air quality regulators and the European Commission as a 'Best Available Technique' (BAT), leading to significant uptake of the method by industry.

NPL carried out a series of research projects with the strategic goal of providing UK industry and regulatory authorities with a unique capability to monitor and control fugitive emissions using DIAL technology. DIAL is a unique mobile optical remote sensing system able to spatially map and quantify pollutants in the atmosphere. NPL developed and refined the capabilities for DIAL, improving detection sensitivities and analysis and validating the technique Government and industry funded projects.

**NPL scientists set to create 'Google Earth' of cancer tumours**

Pioneering research, led by NPL, to develop a 'Google Earth' of tumour mapping, creating a reproducible, standardised way to fully understand different tumour in unprecedented ways. The Project was made possible thanks to £16 million from Cancer Research UK's Grand Challenge awards.

The research will use mass spectrometry imaging techniques and instruments developed to study individual breast, bowel and pancreatic tumours. The team will map and visualize every bit of these tumours to create 3D representations for the first time. The team will also create a database containing their data, making it available to researchers around the world, providing a standardised way for other scientists and doctors to use these techniques in their work and clinic.

11.2.7 Delivering Infrastructure

**The unbelievable impact of calibration**

NPL maintains the UK standard for density measurement. NPL makes this standard available to UKAS-accredited laboratories. Those laboratories calibrate their own equipment to the NPL standard. Companies then test their products in the UKAS-accredited laboratories

Radius Systems manufactures and supplies polyethylene (PE) pipeline and services to over 300 customers across various industries. To confirm that the pipe material is fit for purpose Radius Systems test its density using a calibrated float supplied by H&D. H&D calibrate their equipment to NPL's standards

**Measuring satellite antennas**

The satellite, HYLAS 2, was built for Avanti Communications plc, a UK-based provider of data communications by satellite by Orbital Sciences Corporation (OSC). However, OSC needed help in ensuring that its designs met the demanding specifications for the needed gain and cross pole performance of the antennas.

NPL calibrated the probe required for the all-important antennas carried on board the spacecraft with measurement techniques that employed are absolute methods, in that they do not require reference to the known properties of another antenna.

11.2.8 Collaborative R&D and Instruments

**Ensuring safe natural gas transportation**

Natural gas is a complex mixture of hydrocarbons and other species (nitrogen, carbon dioxide etc.). The Hydrocarbon Dewpoint occurs when hydrocarbon liquids separate out in the pipeline due to pressure, temperature and so on. This could cause several problems such as monitoring meters filling with liquid or damage to components, and in the worst case,

pipeline shutdown which has huge financial implications. The National Grid uses a manual technique to monitor the dewpoints at strategic locations across the UK pipeline network.

Two UK SMEs, Michell Instruments Ltd and EffecTech Ltd, have developed innovative automatic methods based on different techniques that allow dewpoints to be monitored remotely. The SMEs teamed up with NPL under a Joint Industry Project to undertake a rigorous comparison of their methods with the traditional method the National Grid uses.

**Researching effects of nanoparticles**

We have helped HPA set up the National Nanotoxicology Research Centre (NNRC) at their Centre for Radiation, Chemical and Environmental Hazards with the aim of advancing research into the possible toxic effects of nanoparticles. Nanoparticles have a variety of applications, from electronics to medicine. However, their toxicology is poorly understood and believed to be different to larger particles.

An NPL expert in nanoparticles was seconded to the HPA to advise them how to realise their need for a world-class aerosol nanotoxicology laboratory, with sections for measurement instrumentation, physical design of the experiment and advice for setting up quality and calibration systems to ensure the most reliable results possible. We are one of the few worldwide institutions with the expertise in nanoparticles to assist the HPA in such a way.

11.2.9 Consultancy & Training

**NPL launches Portable Co-ordinate Measurement Systems Training (LVM) to meet industry demands**

NPL established a LVM training programme following several calls from big business across the UK, Europe and the US, such as Airbus and Boeing. Before this, there were no independently recognised courses available. NPL's modules provide a framework that will be rolled out internationally to meet the LVM needs of industry. The courses apply the training objectives of the existing framework to the equipment and methods used in LVM, which presents challenges due to the scale of the equipment and being outside of the laboratory.

This will help employees build in systems to the manufacturing process, reducing waste, maximising accuracy and efficiency, increasing productivity. Airbus UK part-funded the project as they believed strongly in the training scheme. Firms like Rolls-Royce and Boeing have helped to shape the course along with leading academics.

**NPL helps ESA gain ISO quality stamp**

The ESA has its own cobalt-60 source at its ESTEC technical and engineering centre in Noordwijk, the Netherlands in order to test space materials against gamma radiation, one of the biggest threats to the electronics with spacecraft. NPL's Radiation Dosimetry group worked closely with the ESA team to help them achieve an independent accreditation to the ISO 17025 standard - General requirements for the competence of testing and calibration laboratories.

NPL played the crucial role of external adviser, helping to improve methods of testing and the accompanying technical documentation. After achieving the accreditation, the facility can assure all users that the results have well-defined uncertainty margins, following testing anf quality procedures that adhere to international standards.