Through-life Engineering Services (TES) Market and Data Review

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Executive Summary

Through-life Engineering Services (TES) encompass the design, creation and in-service sustainment of complex engineering products with a focus on their entire life cycle, using high-quality information to maximize their availability, predictability and reliability at the lowest possible through-life cost. As a collection of technologies and approaches, it is difficult to estimate the future potential impact that TES may have across different manufacturing sectors, and thus the scale of the market opportunity. Previous estimates (Mehta, 2015) have focussed on a single sector concerned with specialist repair and maintenance (Standard Industrial Classification (SIC) code 33 the whole of which, amounting to 0.5% of UK whole economy gross value added (GVA) in 2014, was considered in that previous work to be potentially TES related.

To attempt to expand beyond SIC code 33, the TES Project Team drew from the list of sectors used by the Technology Strategy Board in their review of the 2012 High Value Manufacturing landscape including Energy, Transport and the Built Environment. The team divided this group into sectors which produce products providing TES outputs (Maker sectors) and those which may potentially use those products in transforming their own output (User sectors). Using a modified Delphi methodology and an approach used by Innovate UK to estimate the impact on the economy of additive manufacturing, upper and lower percentage bounds of potential TES penetration were created for each sector. These percentages were then used in combination with the output size in terms of the gross value added (GVA) of each sector to produce estimates of the extent to which TES activities may diffuse by 2025 excluding SIC 33.

The estimates of total GVA in the affected sectors as a percentage of total economy GVA for 2025 were based on the 2014 shares of GVA. This essentially assumes that each sector maintains the same relative growth rate so that sector shares are assumed to remain the same.

Aggregate Maker sector effects for the whole economy suggest a lower bound of GVA which could be attributed to TES applicable products of £15.4 billion, or roughly 1% of the whole UK economy’s GVA. The corresponding upper bound estimates are £64 billion and thus approximately 4% of the GVA of the economy as a whole.

For the User sectors the lower bound estimate of activities associated with the use of TES is over £16 billion, or roughly 1% of the GVA of the UK economy. The corresponding upper bound estimates are £120 billion, or around 7.3% of whole economy GVA. The upper bound estimates are greater than the estimates for the Maker sectors primarily because the total share of UK GVA in the User sectors is much greater than for the Maker sectors (11.87% compared with 4.97%) while the upper bound percentage weights are very similar. The lower bound estimates of the aggregate effects for the User sectors are, however, similar to those for the Maker sectors because the estimated lower bound percentage weights are much lower for the User sectors than for the Maker sectors and this offsets the greater GVA of the user sectors.

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1 The UK Standard Industrial Classification of Economic Activities (SIC) is used to classify business establishments and other statistical units by the type of economic activity in which they are engaged. Groups of activities are given code numbers with up to 4 digits with 4 digits being the most disaggregated. The data in this report relates to the latest major revision in SIC 2007. See e.g UK Standard Industrial Classification of Economic Activities (SIC) 2007 Hierarchy http://www.neighbourhood.statistics.gov.uk/HTMLDocs/SIC/ONS_SIC_hierarchy_view.html
Introduction

This report is designed to provide estimates of the potential market opportunity associated with the diffusion by 2025 of Through-life Engineering Services (TES) across the UK economy. TES encompass the design, creation and in-service sustainment of complex engineering products with a focus on their entire life cycle, using high-quality information to maximize their availability, predictability and reliability at the lowest possible through-life cost.²

The report treats TES as an example of a general-purpose technology (GPT). GPTs such as TES, ICT and advanced materials are characterised by their capability to disrupt existing business models, products and processes across multiple sectors. They are also characterised by great uncertainty in the early stages of their development as to their ultimate effects both in terms of scale and nature, and in terms of the extent to which their diffusion involves complementary developments in downstream user sectors to ensure their adoption and design integration. These characteristics in turn pose major challenges in terms of estimating the future potential impact that they may have.

In keeping with these characteristics this report attempts to provide an estimate of the penetration of TES related activities in both the sectors which create products providing TES outputs (Maker sectors) and those which may potentially use those products in transforming their own output (User sectors). It also develops a method for providing a first pass estimate of upper and lower bound estimates of potential TES penetration using an iterative expert opinion process.

TES is defined in the first substantive section which also describes it in terms of the GPT concept and provides a set of current TES examples to ground the subsequent analysis. The report then moves on to discuss methods of obtaining estimates of potential TES penetration using expert opinion. A further section describes the sectors which are used in this report in making the expert opinion assessments of TES penetration. This includes a description of the sectors in terms of their coverage, their attribution to the maker and user sector groups and their characterisation in 2014 in terms of a number of variables including gross value added (GVA), employment, gross fixed capital formation, exports, imports and capital intensity. This is followed by a section which sets out the main empirical findings in relation to TES penetration. The final section draws brief summary conclusions and is followed by the references section and an annex which sets out the background to the project, lists the Steering Committee members, the project delivery team and internal and external experts involved in fixing the upper and lower bound estimates.

² Definition based on A National Strategy for Through-life Engineering Services consultation paper presentation by EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services (www.through-life-engineering-services.org/strategy). Launch event held at the Houses of Parliament, 10 September 2015. This definition emerged as a result of a process which, inter alia, included 1) the authors of this report reviewing a wide range of relevant publications identified from a Boolean search of keywords derived from the term Through-life Engineering Services along with a range of other terms including manufacturing services, and servitization 2) discussion and refinement at Steering group and Workshop practitioner sessions. The most relevant publications identified by the current authors are contained in the list of references to this report. They appear alongside the list of references made to support specific points made in the analysis and discussion of other issues in the text.
Through Life Engineering Services (TES): Definition and Characteristics

Through-life Engineering Services – TES – encompass the design, creation and in-service sustainment of complex engineering products with a focus on their entire life cycle, using high-quality information to maximize their availability, predictability and reliability at the lowest possible through-life cost.

TES includes a wide range of technologies and business models which may be applied and exploited across a wide variety of sectors. Any industry that produces complex engineering products and where the producers have the opportunity to consider returns available over their whole life cycle is one in which TES principles and associated business models may apply to a greater or lesser extent.

Equally buyers of inputs in any industry that uses complex engineering products and where those buyers are concerned with maximising the generation of value over the whole production life-cycle is also one in which TES principles and associated business models may apply to a greater or lesser extent.

The central role of information flows and monitoring in TES and the wide cross-sectoral range of applications means that TES has the characteristics of a general-purpose technology. This is in the specific sense that TES has the potential for what has been identified as a key characteristic of general-purpose technologies: an innovation which produces a discontinuous change in technology and modes of production, and which has “pervasive use in a wide range of sectors in ways that drastically change their modes of operation” (Helpman, 1998).

A particular feature of GPTs is that they are essentially enabling technologies which provide new opportunities for exploitation in a wide variety of sectors and circumstances, but where the opportunities are not completely understood or presented as final solutions by makers of GPT products or by potential users. This is typically because the diffusion of GPTs requires significant downstream innovation by potential users and interaction between producers of the technology-based products and their potential users. The variety of possible applications requires design and development in the context of input demand in specific sectoral contexts. The trajectory of diffusion may be complex to map and may take forms and uses not identifiable at the early stages of the introduction of such technologies. This is apparent from the management and economics literature on well-known general-purpose technologies, such as those connected with information and communication, and specialist materials, (e.g. for microelectronics, architecture, construction, biomedical and aerospace uses). This literature also shows that the productivity effects of GPTs such as TES may be widespread in User sectors even if they do not generate productivity gains in the sectors producing the GPT products themselves. Thus a major breakthrough in a new advanced material or computing technology may not be introduced with cost reducing methods in the sector producing them, but may transform performance and productivity in sectors using them (Bresnahan and Trajtenberg, 1995). Tracking the TES opportunity must therefore involve estimating the scale of outputs that could be affected in both Maker and User sectors.

To make matters more concrete, the range and diversity of current examples of TES is shown in Box 1. It provides some examples spanning aviation, defence systems, rail transport, automated manufacturing equipment and servicing.
Introduced in 1997, TotalCare, Rolls-Royce’s ‘power by the hour’ offering transformed the engine services landscape by tying maintenance costs to usage and reliability. Since then it has evolved in response to maturing civil aviation engine fleets and the changing expectations of engine owners and lessors.

Babcock provides through-life engineering support for both surface warships and submarines at all stages of the procurement, operation and disposal cycle as either an independent outsourced service working alongside a client or by forming an integrated team with them.

BAE Systems has recently been awarded a £112m contract by the Ministry of Defence to extend the Typhoon Availability Service (TAS) for the in-service support of the Royal Air Force’s Typhoon fleet. Initially trialled with Tornado, this is the latest in a series of availability contracts which guarantee the provision of aircraft to the RAF. Under the contract, BAE Systems is responsible for delivering Typhoon aircrew and ground crew training and maintenance of the aircraft, along with providing technical support and managing spares, repairs and logistics.

Maintenance is vital to the smooth running of the UK’s rail operations. Bombardier supports, among others, the Voyager fleet, operated by Cross Country and the West Coast franchises, with overnight maintenance performed at its dedicated Central Rivers site. Bombardier’s support of London’s train operators during the Olympics resulted in record levels of availability and contributed to Bombardier winning the National Transport Award 2013 for supplier of the year.

Lambert Engineering supplies and supports automated manufacturing equipment for the FMCG, OEM, medical, healthcare, food and automotive markets. They also provide equipment engineering services, manufacturing complex machines from print and optimisation of CNC machining processes for complex components. [http://www.lamberteng.com/](http://www.lamberteng.com/)
Aerospace: Integrating engineering knowledge in computational models to enhance design of jet engines

Birmingham City University’s Knowledge-Based Engineering (KBE) Lab worked with Rolls-Royce to provide a deeper understanding of the lifecycle of jet engine components and to use this knowledge to support design innovation in new products. The resulting software allows rapid creation of detailed designs and the ability to examine their properties through extensive low-cost simulations, as opposed to slow and expensive testing of real product prototypes. Using KBE techniques in the design and development of one aspect of a jet engine has resulted in a reported £0.5M saving through a 40% reduction in overall engineering lead time, and a 50% reduction in design staff requirement. Another example focusing on the design of a 3D Aero model from a new specification reduced the time required to accomplish this task from 10 days to one day.

Built Environment: Building Information Management (BIM) systems development

Building Information Modelling (BIM) research at the University of Salford has contributed to the concept and development of an integrated approach towards improved efficiency in the UK construction sector. Through development and demonstration of integrated, multi-user distributed databases and virtual workspaces, BIM’s technologies, process and collaborative behaviours allow new and more efficient ways of working at all stages of the project life-cycle. According to the UK Government, “The initial estimated saving to UK construction and its clients is £2bn pa through the widespread adoption of BIM.”

Rail: Modelling different maintenance strategies and their resulting whole-life cost

Researchers from the University of Durham applied Bayesian linear estimation to the maintainable items in all of the stations, bridges and other structures of London Underground. The aim was to provide estimates of asset degradation, costs, risks and probabilities for each maintainable item, with a whole-life cost strategic planning process for maintenance and renewal of civil engineering assets, under varying funding constraints, over a 100-year planning horizon. A 2009 audit report stated that the anticipated benefit of the project was a 20% saving, equalling about £600m. The project also improved passenger safety by combining safety, business and financial risk factors into a single modelling process.
**Nuclear: Extending the lifespan of power stations through accurate determination of residual stresses**

The OU and British Energy created a research training partnership involving neutron diffraction measurements of residual stress in long and short weld repairs. These were the first measurements of their kind and demonstrated that the predictions of stresses at weld repairs routinely used by British Energy were not conservative. The new understanding of weld repairs and refined life analysis methods allowed the lives of two AGR power stations to be extended to 300,000 hours from the previous restriction of 175,000 hours. In aggregate the economic impact of lifetime extensions for these twin-reactor power stations, from 2011 to 2019, amounts to electricity generation worth over £8 billion. The numerical modelling methods underpinned by these measurements are now widely used by the global nuclear industry in life assessment procedures.

**Defence: Controlling uncertainty with cost engineering tools**

Cranfield University developed a best practice process and software tool to predict the obsolescence resolution cost for electronic components and materials. The tool helps to reduce UK defence costs through reducing the contingency sums incorporated into availability contracts by defence contractors, and providing a greater incentive for contractors to design equipment to minimise obsolescence issues. A DTZ Global Consulting estimate shows a £213 million per annum financial benefit for BAE Systems and the MoD.

**Manufacturing Engineering: Design for reliability and in-service support**

Software developed by City University London in cooperation with Rolls-Royce helps to improve the design of aircraft engines. The software, `4Cast`, allows engineers to elicit design characteristics that in turn allow the design to be modelled relative to reliability targets. The targets are determined by failure rates. This enables better evaluation of design choices and of the risk of faults and failures in engines and supports rapid decisions as to whether a proposed design meets requirements. This supports Rolls-Royce’s programme to reduce the so-called ’Disruption Index’, a measure of the cost of supporting engines and other engineered products.

The examples shown in Boxes 1-7 indicate the range of sectors which may be affected and the varying combinations of technologies involved in TES applications.

The scale and diversity of TES applications combined with the technical and commercial uncertainty associated with its diffusion as a GPT means that there is scope for a very wide range of possible outcomes in terms of TES diffusion. A method of analysing opportunities across Maker and User sector which recognises this great uncertainty is therefore required.
Estimating the Potential Scale of TES Related Opportunities: Methods

In this section we move beyond the illustrative case studies currently available to provide a quantitative estimate of the potential scale of applications of TES. The analysis takes a broad perspective across a wide range of sectors which may be affected and addresses the highly uncertain nature of the future trajectory of TES related activities.

One way of approaching the analysis, if resources permitted, would be to adopt the well-known Delphi approach to assessing possible futures associated with scientific and technical change (see e.g. UNIDO http://www.unido.org/fileadmin/import/16959_DelphiMethod.pdf). The Delphi method is designed to deliver qualitative as well as quantitative results. The precise Delphi methodology may vary from application to application but in general it is based on the use of information obtained from experts in the topic being analysed. Typically, information about expected outcomes would be derived from a first round expert survey. The outputs of estimates from this are then fed back to the survey participants in one or more iterative rounds for further comment and refinement. This process is monitored by a group which provides the feedback to the participants after each survey round on an anonymous basis. The participants may if they wish refine their own judgements in the light of the responses of other expert participants. The essential characteristics of this process are that there is great uncertainty about the future around which people may hold divergent views. The sharing of information across the experts and the iterative feedback is designed to facilitate the emergence of a consensus estimate.

A full Delphi method approach is resource intensive and beyond the resources and time available for this report. This report, however, is based on an attempt to follow some of the processes inherent in the Delphi approach and is similar to an approach recently adopted as input to the UK National Strategy on Additive Manufacturing, looking at AM’s potential contribution to UK GVA.

As input to that study, Innovate UK Lead Technologist Robin Wilson took 4-digit SIC code level data from the Annual Business Survey and used it to take a view based on expert inputs on the extent to which additive manufacturing could contribute to GVA in each sector by 2021. This took the form of an estimate in each case (e.g. 2%; 0.1%; 0%) which was then multiplied by the total GVA to give a figure for the whole economy.

In this case, it was estimated that AM would contribute over £1.1bn of GVA to the economy by 2020, in a total market size of £1.1tn; an average of 0.1% penetration.

TES is not a single technology; nonetheless, an approach based on the Innovate UK and modified Delphi methods discussed above can be used to estimate the size and importance of the TES applicable sectors. More specifically, the estimates prepared for this report attempt to capture both the scale of output of TES related products in TES Maker sectors and the scale in terms of the output of sectors using TES inputs in their production processes.

The approach adopted begins by identifying a set of UK industrial sectors which are considered to have characteristics relevant to TES applications. This means in particular sectors characterised by the production and/or use of long lived complex engineering products and where the use of high-quality information can be incorporated in business models to maximize their availability, predictability and reliability of those assets at lowest possible through-life cost.
The scale of these sectors in the UK in 2014 is taken as the starting point for a process of using expert knowledge to fix upper and lower bound estimated percentages of TES penetration by sector by 2025. The method of fixing the upper and lower bounds involved three stages. The first was a small pilot survey of 22 practitioners. This was followed by a meeting of 4 internal project experts to discuss, in the light of their own knowledge and experience and of the survey, their separate independent estimates of upper and lower bound percentages for each of the sectors. This second stage led to an agreed consensus range for the upper and lower bound values in each case. This was followed by a third stage of the programme which consisted of interviews with 20 industry practitioners and other experts who were asked for their own independent views of potential market shares. This independent round of information was used to refine the internal range of estimates.

The outcome of this process of fixing upper and lower percentage bounds is then used in combination with the size in GVA of each sector to produce estimates of the extent to which TES activities may diffuse by 2025.
In previous work attempting to indicate the scale of TES actual and potential activities, attention has focused on the SIC sector 33, which covers the repair and installation of machinery and equipment not covered in the activities of other sectors (Mehta, 2015). This includes the specialised activities aimed at:

- restoring machinery, equipment and other products to working order.
- general or routine maintenance (i.e. servicing) on such products to ensure they work efficiently and to prevent breakdown and unnecessary repairs.

It could be argued that the whole of this sector’s output could be TES related and a previous report (Mehta 2015) provides an account of its TES potential. In 2014 the GVA of this sector was £7.4bn which amounted to roughly 0.5% of total UK economy GVA.

However, the description of the division implies that related activity is reported elsewhere; for example:

- The repair of computers and personal and household goods is classified in division 95 (Repair of computers and personal and household goods)
- The repair of motor vehicles is classified in division 45 (Wholesale and retail trade and repair of motor vehicles and motorcycles).

More generally, a substantial amount of repair and improvement is also done by the manufacturers of machinery, equipment and other goods themselves. The classification of these repair and manufacturing activities will often assign these combined activities to the SIC sector of original manufacture. If end of life commercial and industrial machinery and equipment is restored to the original specifications or better, then this activity would be classified within individual SIC sectors 25 – 30. For example, the remanufacture of electric motors is included within 27110, ‘Manufacture of electric motors, generators and transformers’ (see: UK Standard Industrial Classification of Economic Activities (SIC) 2007 Hierarchy http://www.neighbourhood.statistics.gov.uk/HTMLDocs/SIC/ONS_SIC_hierarchy_view.html)

Moreover, the definition of TES used in this report covers more than repair and improvement of existing capital equipment and systems and includes significant product and process innovation. In this report, therefore, a wider coverage is adopted to capture TES activities beyond sector 33. The full list of these other sectors is shown in Table 1.
The list is drawn from an analysis carried out by the Institute for Manufacturing at the University of Cambridge for the Technology Strategy Board’s 2012 Landscape for the Future of High Value Manufacturing in the UK. The broad sectors identified in the first column of the table consist, in some cases of aggregations or subsets of SIC codes based on the 2007 SIC. The SIC codes used are shown in column two with a brief description in words in column three. The list extends beyond the normal definition of manufacturing included in the standard industrial classification used in official UK statistics. In particular it includes some energy, transport and construction sectors. It includes both Maker and User sectors. It is important to note that it does not include the whole economy; for example, retailing, wholesaling and financial services are excluded from this analysis.

Indicators of the scale of the sectors, and also some measures of the extent to which they reflect the characteristics embodied in the definition of TES used in this report in terms of capital intensity and technological intensity are shown in Table 2. All but the final column of indicators are based on data generously provided by BIS.

<table>
<thead>
<tr>
<th>Sector</th>
<th>SIC07</th>
<th>Sectors covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>10</td>
<td>Food manufacture</td>
</tr>
<tr>
<td>Pharma/BioPharma</td>
<td>21; 72.11</td>
<td>Pharma products and preparations, BioTech research</td>
</tr>
<tr>
<td>Agritech and Agriscience</td>
<td>72.19</td>
<td>Other research and experimental development on natural sciences and engineering</td>
</tr>
<tr>
<td>Medtech</td>
<td>32.5</td>
<td>Manufacture of medical and dental instruments and supplies</td>
</tr>
<tr>
<td>Defence and Security</td>
<td>30.4; 25.40</td>
<td>Manufacture of military fighting vehicles, Manufacture of weapons and ammunition</td>
</tr>
<tr>
<td>Aerospace</td>
<td>30.3</td>
<td>Manufacture of air and spacecraft related machinery</td>
</tr>
<tr>
<td>Space</td>
<td>30.3</td>
<td>Manufacture of air and spacecraft related machinery</td>
</tr>
<tr>
<td>Automotive</td>
<td>29; 30.9; 45.2; 28.3</td>
<td>Manufacture of motor vehicles, motorcycles, and agricultural tractors; Maintenance and repair of motor vehicles</td>
</tr>
<tr>
<td>Rail</td>
<td>30.2</td>
<td>Manufacture of railway locomotives and rolling stock</td>
</tr>
<tr>
<td>Marine</td>
<td>30.1</td>
<td>Building of ships and floating structures</td>
</tr>
<tr>
<td>Energy*</td>
<td>27.1; 35.1</td>
<td>Manufacture of electric motors, generators and transformers, Manufacture of electricity distribution and control apparatus, Production, transmission, distribution and trade of electricity</td>
</tr>
<tr>
<td>Nuclear</td>
<td>24.46</td>
<td>Processing of nuclear fuel</td>
</tr>
<tr>
<td>Oil &amp; Gas</td>
<td>19.2; 35.2</td>
<td>Mineral oil refining, Manufacture, distribution, trade of gas</td>
</tr>
<tr>
<td>Built environment</td>
<td>41; 42; 43</td>
<td>Building and construction of commercial, domestic, roads railways, bridges, utilities, telecomms, water, other civil engineering and demolition</td>
</tr>
<tr>
<td>Machinery manufacture</td>
<td>28</td>
<td>Multiple mechanical and process machinery types</td>
</tr>
<tr>
<td>Chemicals</td>
<td>20</td>
<td>Chemicals (excl. e.g. plastics, rubbers and immediate downstream products)</td>
</tr>
<tr>
<td>Electronics and ICT*</td>
<td>26; 61; 63; 95</td>
<td>Manufacture of electronic components, computers, communications equipment, process control, optical, electrotherapeutic, etc. equipment</td>
</tr>
</tbody>
</table>

Table 1: TES Sectors

The list is drawn from an analysis carried out by the Institute for Manufacturing at the University of Cambridge for the Technology Strategy Board’s 2012 Landscape for the Future of High Value Manufacturing in the UK. The broad sectors identified in the first column of the table consist, in some cases of aggregations or subsets of SIC codes based on the 2007 SIC. The SIC codes used are shown in column two with a brief description in words in column three. The list extends beyond the normal definition of manufacturing included in the standard industrial classification used in official UK statistics. In particular it includes some energy, transport and construction sectors. It includes both Maker and User sectors. It is important to note that it does not include the whole economy; for example, retailing, wholesaling and financial services are excluded from this analysis.

Indicators of the scale of the sectors, and also some measures of the extent to which they reflect the characteristics embodied in the definition of TES used in this report in terms of capital intensity and technological intensity are shown in Table 2. All but the final column of indicators are based on data generously provided by BIS.
<table>
<thead>
<tr>
<th>Sector</th>
<th>SIC07</th>
<th>Estimate of GVA (£m)</th>
<th>GVA as % of whole economy</th>
<th>Estimate of employment (‘000s)</th>
<th>Share in employment in firms &gt;250 people (%)</th>
<th>Exports (£m)</th>
<th>Imports (£m)</th>
<th>GFCF 2014 (£m)</th>
<th>£ GFCF per employee</th>
<th>%GFCF of GVA</th>
<th>Intensity/Complexity of innovation (Peneder)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>10</td>
<td>20,414</td>
<td>1.25%</td>
<td>376</td>
<td>65.4</td>
<td>102,624</td>
<td>28,088</td>
<td>2,534</td>
<td>£6,792.55</td>
<td>12.5%</td>
<td>Med-low</td>
</tr>
<tr>
<td>Pharma/BioPharma</td>
<td>21; 72.11</td>
<td>13,332</td>
<td>0.82%</td>
<td>46</td>
<td>79.2</td>
<td>21,839</td>
<td>25,253</td>
<td>2,164</td>
<td>£44,139.14</td>
<td>16.2%</td>
<td>High</td>
</tr>
<tr>
<td>AgriTech and Agriscience</td>
<td>72.19</td>
<td>8,952</td>
<td>0.55%</td>
<td>123</td>
<td>58.3</td>
<td>-</td>
<td>-</td>
<td>6,174</td>
<td>£50,216.98</td>
<td>69.0%</td>
<td>Med-high</td>
</tr>
<tr>
<td>Medtech</td>
<td>52.5</td>
<td>2,519</td>
<td>0.15%</td>
<td>42</td>
<td>-</td>
<td>3,049</td>
<td>4,488</td>
<td>292</td>
<td>£6,922.80</td>
<td>11.6%</td>
<td>High</td>
</tr>
<tr>
<td>Defence and Security</td>
<td>30.4; 25.40</td>
<td>1,106</td>
<td>0.07%</td>
<td>18</td>
<td>-</td>
<td>454</td>
<td>446</td>
<td>140</td>
<td>£7,913.19</td>
<td>11.7%</td>
<td>High</td>
</tr>
<tr>
<td>Aerospace</td>
<td>30.3</td>
<td>7,013</td>
<td>0.43%</td>
<td>94</td>
<td>92.1</td>
<td>22,580</td>
<td>19,664</td>
<td>1,854</td>
<td>£19,652.71</td>
<td>26.4%</td>
<td>Med</td>
</tr>
<tr>
<td>Space</td>
<td>30.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Med-high</td>
</tr>
<tr>
<td>Automotive</td>
<td>29; 30.9; 45.2; 28.3</td>
<td>20,314</td>
<td>1.24%</td>
<td>376</td>
<td>38</td>
<td>35,123</td>
<td>49,531</td>
<td>4,512</td>
<td>£12,011.00</td>
<td>22.2%</td>
<td>Med-high</td>
</tr>
<tr>
<td>Rail</td>
<td>30.2</td>
<td>527</td>
<td>0.03%</td>
<td>5</td>
<td>-</td>
<td>158</td>
<td>483</td>
<td>47</td>
<td>£9,266.67</td>
<td>8.9%</td>
<td>Low</td>
</tr>
<tr>
<td>Marine</td>
<td>30.1</td>
<td>1,330</td>
<td>0.08%</td>
<td>33</td>
<td>80</td>
<td>1,494</td>
<td>1,537</td>
<td>399</td>
<td>£11,919.41</td>
<td>30.0%</td>
<td>Low</td>
</tr>
<tr>
<td>Energy*</td>
<td>27.1; 35.1</td>
<td>19,559</td>
<td>1.20%</td>
<td>75</td>
<td>-</td>
<td>4,137</td>
<td>5,231</td>
<td>8,653</td>
<td>£116,039.04</td>
<td>45.2%</td>
<td>Med-high</td>
</tr>
<tr>
<td>Nuclear</td>
<td>24.46</td>
<td>N/A</td>
<td>N/A</td>
<td>?</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
<td>N/A</td>
<td>Med-high</td>
</tr>
<tr>
<td>Oil &amp; Gas</td>
<td>19.2; 35.2</td>
<td>8,818</td>
<td>0.54%</td>
<td>47</td>
<td>-</td>
<td>19,373</td>
<td>22,038</td>
<td>3,708</td>
<td>£78,746.86</td>
<td>42.1%</td>
<td>Med-low</td>
</tr>
<tr>
<td>Built environment</td>
<td>41; 42; 43</td>
<td>99,751</td>
<td>6.10%</td>
<td>2,117</td>
<td>14.4</td>
<td>1,965</td>
<td>2,185</td>
<td>19,053</td>
<td>£5,000.00</td>
<td>19.1%</td>
<td>Med</td>
</tr>
<tr>
<td>Machinery manufacture</td>
<td>28</td>
<td>14,662</td>
<td>0.90%</td>
<td>174</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1,956</td>
<td>£11,241.58</td>
<td>13.3%</td>
<td>Med</td>
</tr>
<tr>
<td>Chemicals</td>
<td>20</td>
<td>9,116</td>
<td>0.55%</td>
<td>95</td>
<td>50.2</td>
<td>24,916</td>
<td>25,270</td>
<td>11,475</td>
<td>£115,404.04</td>
<td>125.0%</td>
<td>Med-high</td>
</tr>
<tr>
<td>Electronics and ICT*</td>
<td>26; 61; 63; 95</td>
<td>47,768</td>
<td>2.92%</td>
<td>502</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>24,332</td>
<td>£48,470.12</td>
<td>50.9%</td>
<td>High</td>
</tr>
<tr>
<td>Total HVM sectors</td>
<td>275,272</td>
<td>16.84%</td>
<td>4,130</td>
<td>145,212</td>
<td>182,191</td>
<td>48,873</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole economy</td>
<td>1,634,260</td>
<td>100%</td>
<td>33,045</td>
<td>39.8</td>
<td>515,191</td>
<td>549,723</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: TES Sectors and economic measures (All data refers to 2014)
The table provides for each sector for 2014; an estimate of the GVA for that sector as a measure of output; its share of GVA in the economy as a whole; total employment; the value of exports and imports; and gross fixed capital formation (GFCF).

GFCF is an estimate of net capital expenditure (acquisitions less the proceeds from disposals) on assets used in production processes for more than one year (fixed assets). This includes expenditure on tangible assets such as machinery and equipment, military weapons systems, transport equipment, factories, dwellings and roads, as well as intangible assets such as design, artistic originals and software and research and development. This broad measure thus captures a wide range of tangible and intangible investments in fixed assets relevant to TES. In addition the table shows two measures of capital intensity of production. These are based respectively on GFCF per employee and GFCF as a percent of GVA.

The final column is qualitative. It provides an analysis of the intensity or complexity of innovation in each sector. It is adapted from the taxonomic work of Peneder (2010). The taxonomy is based on the clustering of quantitative measures, innovation and technological characteristics of firms classified to each of the sectors. High innovation intensity sectors are characterised as having a high share of firms focused on product innovations, with high levels of own account R&D and patenting. Medium-high intensity sectors have a relatively greater focus on process innovations and lower levels of own account R&D, with some patenting activity. Medium intensity groups are characterised as having a relatively large share of firms pursuing innovation through the acquisition of external knowledge for innovative products. The medium to low groups are also characterised by adaptive behaviour and the acquisition of new technologies with a focus on process innovation. Finally, the low intensity group has the lowest focus on the application of new technologies and products, and relatively low levels of innovation and knowledge appropriation.

The table shows that all high value manufacturing sectors together (excluding nuclear, for which data could not be provided) account for £275 billion of GVA in 2014. This represents 16.8% of total UK economy GVA. These same sectors also employed over 4 million workers. The sectors were responsible for over £145 billion worth of exports whilst imports totalled £182 billion. The sectors spent nearly £49 billion on GFCF.

The most capital intensive sectors measured in terms of GFCF per employee were Energy, Chemicals and Oil and Gas, Agri-tech, Electronics & ICT and Pharma. When capital intensity is measured in terms of percent of GVA, Chemicals, Energy, Agri-tech, Oil and Gas, and Electronics & ICT also emerge as the most capital intensive. Of these sectors, Pharma and Electronics & ICT are classified as high intensity/complex sectors whilst Chemicals, Energy and Agri-tech are classified as medium-high.

Taken together, the data and information which is presented in the table provides an overview of the landscape on which TES activities may be located. The extent to which TES activities may diffuse across the landscape depends upon the extent to which each sector is potentially amenable to TES transformations and also the scale of each sector. Thus, a small sector in terms of GVA which may be estimated to be a likely candidate for extensive penetration of TES may carry less weight than a very large sector which has a lower potential rate of penetration. In other words, the potential penetration of TES in a sector must be weighted by that sector’s size in activity measured, for example, in terms of GVA. In terms of GVA, the largest sectors identified in the aggregations used in the table are the Built Environment, Electronics & ICT, Food, Automotive and Energy sectors. A given potential TES penetration in these sectors would therefore carry more overall weight in the economy than the same potential penetration in smaller sectors.
Estimating the Potential Scope of TES: Developing Weights

To make an estimate of the potential for TES penetration by sector, the different sectors were first split into two groups: Maker groups whose GVA stems primarily from the manufacture of complex, long-lived engineered products; and User groups whose GVA relies on the inputs of long-lived complex engineered products. For example, the Aerospace and Automotive sectors manufacture complex, engineered products, while the Food and Chemicals sectors rely on complex, long-lived plants, machines and equipment to create their products.

A preliminary pilot postal survey of 120 steering group members and their sector networks was conducted to obtain opinion on the potential and current role of TES adoption, and the constraints affecting it. Data from the 22 respondents revealed awareness of the major disruptive potential impact on TES Maker and User sectors but considerable uncertainty as to quantitative estimates of future rates of adoption.

In the light of their own knowledge and expertise and the qualitative responses from the survey each of Maker and User sectors was examined in turn by the internal TES team. An estimate was made as to the maximum proportion of GVA in Maker sectors which could in principle be generated by the sale of TES-based products, assuming all feasible opportunities to adopt the approach were taken. In the case of User sectors, the estimate was based on the extent to which value added in those sectors could be based on the maximum use of TES-applicable engineering inputs. These proportions, when multiplied by the actual GVA in each sector, create a maximum estimated amount of GVA which could be affected were each sector to fully adopt TES methodologies and practices in output production in the Maker sectors and in input use in User sectors.

The first stage maximum estimated proportions were then discussed in interviews with sector representatives and experts. They were asked to consider whether these maximum proportions were reasonable. They were also asked for their views on the extent to which these TES-related maximum potential outputs and input opportunities would be captured by 2025. This process was intended to help to refine the estimated upper-boundary generated by the internal group reflection while also providing a figure for the future rate of adoption which would indicate how close to the maximum potential the sectors might move.

It is important to note that these estimates must be treated with some caution. They were of necessity derived from a small sample of albeit very well-informed individuals. Moreover, as the Strategy Sector Report summarising the interpretation of the interviews comments, “Few interviewees were prepared to hazard a guess at potential market size in the UK . . . . The ranges of possible TES uptake indicated for individual sectors in this survey are therefore very large, and as a result, comments highlighting particular sectors as ‘targets for TES’ should be treated with some caution.” A national strategy for engineering services Sector Report June 2016 (www.through-life-engineering-services.org/strategy)
In the absence of forecast GVA for the Maker and User sectors the estimates of total GVA affected sectors for 2025 were based on the 2014 level of GVA. This essentially assumes that each sector maintains the same relative growth rate so that sector shares are assumed to remain the same.

It is important to note that from the point of view of measuring the output of TES related products the estimates for the Maker and User sectors are to some degree measuring opposite sides of the same coin. Thus, some of the inputs of UK firms in User sectors will be outputs from UK Maker sectors (the rest will be imported TES inputs), whilst some of the TES-based outputs of the Maker sectors will be sold to UK users and the rest to foreign firms through exports. If we were concerned with measuring the UK output of TES related products the Maker estimates would be sufficient. However, our purpose here is to make an estimate of the potential scale of output across the UK sectors that captures User sectors too. This is because their competitiveness and productivity may be strongly impacted by the use of TES inputs. For our particular purpose we may therefore aggregate the User and Maker GVA measures.
Estimates of Scale of TES Opportunity: Maker and User Sectors

Estimates of the scale of the TES opportunity in terms of Maker and User sectors is presented in Tables 3 and 4. These estimates as discussed above exclude sector 33 which accounted for 0.5% of whole economy GVA in 2014.

In relation to the Maker sectors, Table 3 shows the GVA in 2014 in terms of £million and as a percentage of whole economy’s GVA. The sixth column shows the upper and lower bound estimates of the percentage of each sector which TES may have penetrated by 2025. These upper and lower bounds are based on the expert estimation process discussed earlier in this report.

The estimated attrition percentages vary considerably within sectors, reflecting the uncertainty surrounding these estimates. They also vary across sectors, reflecting the expert views of the extent to which TES penetration may take place by 2025. The next two columns report lower bound estimates in terms of percentage of the whole economy and millions of pounds of GVA, which are derived by applying the lower bound percentages to the estimates of the size of the sector shown in columns 3 and 4. The final two columns show similarly derived results for upper bound estimates. The summation of the individual sector effects is shown at the bottom row of the table.

It is important to note that since Energy and Electronics & ICT are considered to be both makers and users of TES activities they have been arbitrarily allocated on a 50/50 basis between this Table and Table 4, which analyses the User sectors.

Aggregate Maker sector effects for the whole economy are shown in the bottom row of columns 4 to 6. These estimates suggest a lower bound of GVA which could be attributable to TES applicable products of £15.4 billion, or roughly 1% of the whole UK economy’s GVA. The corresponding upper bound estimates are £64 billion and thus approximately 4% of the GVA of the economy as a whole.

The greatest contribution to the upper bound estimates for whole economy scale of TES activity in the Maker sectors are to be found in the Automotive and Electronics & ICT sectors, which contribute 1.12% and 1.32% of the total of 3.92%. Both of these sectors are also subject however to the widest range between upper and lower bound penetration estimates. They are still amongst the top three contributors to the total economy lower bound estimate. This reflects the fact that they are the largest sectors in the table in terms of GVA. The largest contributor to the lower bound estimate is to be found in the Aerospace and Space sectors which together contribute 0.3% of the overall lower bound estimate of 0.94%. A similarly narrow range of penetration estimates is to be found in the Rail sector; in this case, the high estimate effects combined with a relatively low scale of the sector in terms of GVA therefore make only a small contribution to the overall economy-wide GVA effect.
<table>
<thead>
<tr>
<th>Sector</th>
<th>GVA (£m)</th>
<th>GVA as % of whole economy</th>
<th>Upper bound GVA (£m)</th>
<th>GVA as % of whole economy</th>
<th>Lower bound GVA (£m)</th>
<th>GVA as % of whole economy</th>
<th>Lower and upper bound %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medtech</td>
<td>2,519</td>
<td>0.15%</td>
<td>504</td>
<td>0.03%</td>
<td>504</td>
<td>0.03%</td>
<td>Makes 20% - 50%</td>
</tr>
<tr>
<td>Defence and Security</td>
<td>1,196</td>
<td>0.07%</td>
<td>359</td>
<td>0.02%</td>
<td>359</td>
<td>0.02%</td>
<td>Makes 30% - 80%</td>
</tr>
<tr>
<td>Aerospace</td>
<td>7,013</td>
<td>0.43%</td>
<td>4,909</td>
<td>0.30%</td>
<td>4,909</td>
<td>0.30%</td>
<td>Makes 70% - 90%</td>
</tr>
<tr>
<td>Space</td>
<td>30.3</td>
<td>0.39%</td>
<td>957</td>
<td>0.06%</td>
<td>957</td>
<td>0.06%</td>
<td>Makes 10% - 20%</td>
</tr>
<tr>
<td>Automotive</td>
<td>20,314</td>
<td>1.24%</td>
<td>4,063</td>
<td>0.25%</td>
<td>4,063</td>
<td>0.25%</td>
<td>Makes 70% - 100%</td>
</tr>
<tr>
<td>Rail</td>
<td>1,330</td>
<td>0.08%</td>
<td>369</td>
<td>0.02%</td>
<td>369</td>
<td>0.02%</td>
<td>Makes 0% - 50%</td>
</tr>
<tr>
<td>Marine</td>
<td>1,466</td>
<td>0.08%</td>
<td>133</td>
<td>0.01%</td>
<td>133</td>
<td>0.01%</td>
<td>Makes 0% - 100%</td>
</tr>
<tr>
<td>Energy*</td>
<td>8,802</td>
<td>0.54%</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
<td>Makes 0% - 100%</td>
</tr>
<tr>
<td>Machinery and ICT*</td>
<td>21,496</td>
<td>1.32%</td>
<td>5,865</td>
<td>0.36%</td>
<td>5,865</td>
<td>0.36%</td>
<td>Makes 50% - 100%</td>
</tr>
<tr>
<td>All Maker sectors</td>
<td>64,032</td>
<td>3.92%</td>
<td>15,385</td>
<td>0.94%</td>
<td>15,385</td>
<td>0.94%</td>
<td>Makes 50% - 100%</td>
</tr>
</tbody>
</table>

Table 3: TES Maker Sectors (GVA for 2014)
The corresponding results for the User sectors are shown in Table 4, which has the same format as Table 3. Once again it is important to note that Energy and Electronics & ICT are shown in this table on the basis of a 50/50 split of their activity in terms of GVA between the User and Maker categories. As with the Maker results, the table reveals substantial variations between upper and lower bound estimates of TES penetration both within and across sectors. The lower bound estimates are, however, typically lower than those for the Maker sectors while the upper bound percentages are similar.

For the User sectors the lower bound estimate of activities associated with the use of TES is over £16 billion, or roughly 1% of the GVA of the UK economy. The corresponding upper bound estimates are £120 billion, or around 7.3% of whole economy GVA. The upper bound estimates are greater than the estimates for the Maker sectors primarily because the total share of UK GVA in the User sectors is much greater than for the Maker sectors (11.87% compared with 4.97%) while the upper bound percentage weights are very similar. The lower bound estimates of the aggregate effects for the User sectors are, however, similar to those for the Maker sectors because the estimated lower bound percentage weights are much lower for the User sectors than for the Maker sectors and this offsets the greater GVA of the user sectors.

The greatest contribution to the upper bound estimates for the whole economy is to be found in the Built Environment sector (3.05%). This is the result of a combination of relatively low estimated penetration ratios combined with a relatively large sector size (6.1% of UK economy GVA). The next most important contributor to the upper bound estimates is Electronics & ICT, which accounts for 1.32%. This is followed by Food with 0.94%. The Built Environment and Electronics & ICT sectors are also the most important contributors to the lower bound estimate of 0.99% of UK economy GVA. Both are subject to a very wide range of upper and lower bound estimates.

Since Energy and Electronics & ICT are split between the User and Maker tables it is important to show the results of combining their results across the two tables. When this is done the former accounts for 1.08% of the combined upper bound total Maker and User impact of 11.3% and the latter for 2.64%. Thus, the two most important sectors in terms of percentage contributions, taking Tables 3 and 4 together, are Built Environment (largely because of the scale of the sector) and Electronics & ICT. The next most important contributors are the Automotive and Food sectors.
<table>
<thead>
<tr>
<th>Sector</th>
<th>SIC07</th>
<th>GVA (£m)</th>
<th>GVA as % of whole economy</th>
<th>Primarily makes or uses complex engineers</th>
<th>Upper and lower bound %</th>
<th>Lower bound GVA (£m)</th>
<th>GVA as % of whole economy</th>
<th>Upper bound GVA (£m)</th>
<th>GVA as % of whole economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>10</td>
<td>20,414</td>
<td>1.25%</td>
<td>Uses</td>
<td>0% - 75%</td>
<td>0</td>
<td>0.00%</td>
<td>15,311</td>
<td>0.94%</td>
</tr>
<tr>
<td>Pharma/BioPharma</td>
<td>21; 72.11</td>
<td>13,332</td>
<td>0.82%</td>
<td>Uses</td>
<td>10% - 50%</td>
<td>1,333</td>
<td>0.08%</td>
<td>6,666</td>
<td>0.41%</td>
</tr>
<tr>
<td>Agritech and Agri-</td>
<td>72.19</td>
<td>8,952</td>
<td>0.55%</td>
<td>Uses</td>
<td>10% - 50%</td>
<td>895</td>
<td>0.05%</td>
<td>4,476</td>
<td>0.27%</td>
</tr>
<tr>
<td>Energy*</td>
<td>27.1; 35.1</td>
<td>9,780</td>
<td>0.60%</td>
<td>Uses</td>
<td>0% - 90%</td>
<td>0</td>
<td>0.00%</td>
<td>8,802</td>
<td>0.54%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>24.46</td>
<td>n/a</td>
<td>n/a</td>
<td>Uses</td>
<td>30% - 60%</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Oil &amp; Gas</td>
<td>19.2; 35.2</td>
<td>8,818</td>
<td>0.54%</td>
<td>Uses</td>
<td>30% - 100%</td>
<td>2,645</td>
<td>0.16%</td>
<td>8,818</td>
<td>0.54%</td>
</tr>
<tr>
<td>Built Environment</td>
<td>41; 42; 43</td>
<td>99,751</td>
<td>6.10%</td>
<td>Uses</td>
<td>5% - 50%</td>
<td>4,988</td>
<td>0.31%</td>
<td>49,876</td>
<td>3.05%</td>
</tr>
<tr>
<td>Chemicals</td>
<td>20</td>
<td>9,116</td>
<td>0.56%</td>
<td>Uses</td>
<td>30% - 50%</td>
<td>2,735</td>
<td>0.17%</td>
<td>4,558</td>
<td>0.28%</td>
</tr>
<tr>
<td>Electronics and ICT*</td>
<td>26; 61; 63; 95</td>
<td>23,884</td>
<td>1.46%</td>
<td>Uses</td>
<td>15% - 90%</td>
<td>3,583</td>
<td>0.22%</td>
<td>21,496</td>
<td>1.32%</td>
</tr>
<tr>
<td>All User sectors</td>
<td></td>
<td>194,047</td>
<td>11.87%</td>
<td></td>
<td></td>
<td>16,179</td>
<td>0.99%</td>
<td>120,001</td>
<td>7.34%</td>
</tr>
</tbody>
</table>

Table 4: TES User Sectors (GVA for 2014)
Summary Conclusions

The estimate of potential market penetration of TES across the sample of UK high value added sectors considered in this report is significant even if the lowest bounded estimates are taken. Both the Maker and User sectors have lower bound estimates which equate to approximately 1% of the GVA of the whole economy, while the upper bound estimates are 4% and 7.3% respectively\(^4\). The range of estimates, however, speaks to the uncertainty as to future rates of adoption. There is an innate uncertainty around the scale and impact of wide-ranging, general-purpose technologies such as TES. The estimates in this report would undoubtedly benefit from a longer period of engagement with a larger number of interviewees and survey respondents to refine the predictions with which this report concludes. Equally there are other sectors of potential use in the public and private sector which are not considered in this report.

The case study examples cited in this report, when taken alongside the findings of the interview programme and workshops carried out as part of the wider programme of research of which this report is a part, demonstrate that some sectors are already adopting TES methodologies. Maximising and capturing the value which could be created by their wider adoption as a general purpose technology in the UK will require co-ordinated effort across Maker and User sectors. This will be required in order to respond to the skills, resource and business model changes needed to fully capture their value for the UK.

The estimated potential penetration of TES in the sample of UK Maker and User sectors analysed in this report is very substantial. A successful national strategy to maximise the creation and capture of value associated with TES would have pervasive implications for the performance of the overall UK economy.

\(^4\) These estimates exclude sector 33 covering specialised repair and maintenance which accounted for around 0.5% of economy wide GVA in 2014 on which a separate report on potential TES activity has already been published (Mehta 2015)
References


Fox, J. and Glass, B. (2000), “Impact of integrated vehicle health management (IVHM) technologies on ground operations for reusable launch vehicles (RLVs) and spacecraft”, *Proceedings of the Aerospace Conference*, Big Sky, MT.


Technology Strategy Board (2012), *A landscape for the future of high value manufacturing in the UK*, London


Annex:
Project Background, Steering Committee Membership, Internal and External Expert Assessors

Background

Some 50 firms and organisations with an interest in TES were convened by Cranfield University at a workshop in May 2015 to explore the opportunity for cooperative development of capability in TES and the specific action areas that might provide greatest impact. This was written up in a white paper that prompted the formation of a steering committee to drive the development of a national industrial strategy for TES. Steering committee members include senior leaders from the aerospace, defence, rail and machinery sectors, government and government agencies, academia and industry associations.

The TES strategy has been developed through a process of consultation and research, drawing on:

- Three regional strategy development workshops attended by over 80 representatives from a range of industrial sectors – including automotive, aerospace, defence, marine, energy, nuclear, electronics, and logistics – and from manufacturing trade associations, government agencies and academia
- Sector perspective discussions, with sector leads in the Department for Business, Innovation and Skills (BIS), selected industrialists and in some cases literature review
- This market and data review

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6 A national strategy for engineering services – Delivering UK economic growth by making things work better for longer
The TES Strategy was prepared on behalf of the Industry Steering Committee by:

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Andy Shaw, Internal Expert Assessor, Cranfield University
Alan Hughes, University of Cambridge
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Alan Murdoch, BAE Systems Member
Clare Maret, BIS Member
Rajkumar Roy, Cranfield University Member
James Selka, Manufacturing Technologies Association Member
Rob Cowling, Bombardier Transportation Member
Steve Foxley, Siemens Member
Richard Drake, Babcock International Member
Andrew Cannon-Brookes, MOD Member
Neil Barnett, ADS Member
Nick Frank, Frank Partners Member
Andy Neely, IFM Cambridge University Member
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Tim Baines, Aston University Member
Laura Smith, CBI Member
Andy Sellars, Innovate UK Member
Michael Folkerson, APMG Member
Andy Shaw, Cranfield University Secretary
Andrew Gill, Cranfield University Support
Paul Tasker, Cranfield University Support
Chris White, Member of Parliament Advisor

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Willie Thomson, Harbro
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Martin Walder, Schneider Electric
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