UNIVERSITY OF BIRMINGHAM

Digital Manufacturing for Cleantech

Innovation Acceleration

eit Climate-KIC

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mtc Manufacturing Technology Centre

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ENERGY RESEARCH ACCELERATOR

At the forefront of energy transformation

Innovate UK

Contents

Executive Summary

With a need to urgently de-carbonize the global energy supply, Climate-KIC identified innovation clusters as a catalyst for the introduction of new green energy solutions. The UK's Clean Growth Strategy projects that the low-carbon economy could grow four times faster than GDP, at 11% a year until 2030. The focus of this work is the supply chains that will be needed to support the success of the innovation ecosystems.

As many diverse products are rapidly brought to market, demand will be dynamic. Agile supply chains which are both scalable and adaptable will be at a premium in seeking to fulfil requirements. Traditional supply chain models will offer some growth but face significant limitations in terms of speed of implementation and responsiveness. Digital manufacturing however, which is the extraction of value from data in a manufacturing environment, offers a transformative opportunity. This potential was recognised by the Energy Research Accelerator and in 2016 the consortium allocated £10 million of the £60 million awarded by Innovate UK to research solutions to provide a step change in performance. Led by the University of Birmingham and with additional academic support from Loughborough University, the principal project delivery partner was the Manufacturing Technology Centre (MTC) in Coventry. Over £20 million of industrial funding was attracted before the project's conclusion in 2019.

The FIAB presents as an autonomous production facility. However it is the *underlying smart system*, capable of being deployed to support scale-up of a multitude of *diverse innovations* that is the central asset.

Rejecting the spectre of incremental improvement, the team sought to create a set of user requirements that would amaze and delight manufacturers and then to realize it. The aspiration set was to devise a lights out fully automated cell that could be comprehensively monitored and controlled via a web based Control Centre, making it rapidly deployable in a remote location.

With economic impact essential, quick and clear communication of the developed capability was fundamental. Hence, it was agreed to deliver a physical demonstrator, referred to as a Factory in a Box (FIAB).

Central to the FIAB are its smart features which, embedding intelligence within the system, facilitate efficient operation of the unit with minimal intervention. Capabilities include various optimization tools and the ability to identify and integrate maintenance tasks within the production schedule. A Digital Twin function allows the operator to understand the true state of all FIAB parameters in real time and a Virtual Factory feature makes possible the exploration of alternative courses of action to fulfil various operating requirements.

Targeting the development of agile supply chain solutions for clean energy companies, the aim was to choose one product which would support clean energy innovation and produce it in the FIAB demonstrator. Over 50 companies were evaluated against wide ranging business performance metrics and a pipe to enable scale-up of the application of Dearman's innovative cryogenic engine within refrigerated transport trucks was selected.

To support projected business needs, a challenging specification was defined which included brazing of pipe lengths to multiple T-pieces and also bending of the pipes. The complex automated operations within the FIAB include cutting, brazing, bending, de-burring, transport by robot, visual inspection, attachment and removal of pneumatic connectors and pressure testing.

> **"Digital manufacturing however, which is the extraction of value from data in a manufacturing environment, offers a transformative opportunity."**

The FIAB presents as an autonomous production facility. However it is the underlying smart system, capable of being deployed to support scale-up of a multitude of diverse innovations that is the central asset. Whilst a single software vendor solution would have been simpler, a multi vendor 'best of breed' approach was adopted to ensure the solution was accessible to as wide an audience as possible. These software providers, termed Industrial Suppliers, having been selected by objective means, collaborated robustly with MTC to become central to the FIAB solution.

Engagement with industrialists generated widespread interest, with particular attention being drawn from the transport, energy, power and defence sectors and early phase projects had been kicked off before the sell-out public launch event in March 2019.

With the first FIAB a spectacular showcase for the developed solution, validation of the smart system architecture was planned by a second cell designed to produce phase change material. Offering striking contrast to the first, notable interest was piqued from the fast moving consumer goods and pharmaceutical sectors. To extend the appeal of the second demonstrator, an emulator replaced the physical workings of the FIAB, hence clearly communicating the possibility of virtual validation of an entire FIAB system.

> **“The FIAB demonstrator stands unique, in a space on its own – the only full scale working factory in a box. It offers agility, scalability and remote and rapid deployment.”**

To date, it has been larger companies embracing FIAB development, with limitations of bandwidth and complexity impeding the progress of smaller companies. Advancement can be transformed by providing clean energy innovation clusters access to the knowhow and implementing mechanisms to facilitate usage. It is proposed that MTC, supported by its academic partners, provides knowledge and support and also negotiates facilitating mechanisms. Recommended mechanisms include an aggregated Industrial Supplier offering to simplify access for innovators, grouping of requirements of innovators with similar needs to increase benefits for Industrial Suppliers and preferred offerings for technical support during FIAB service.

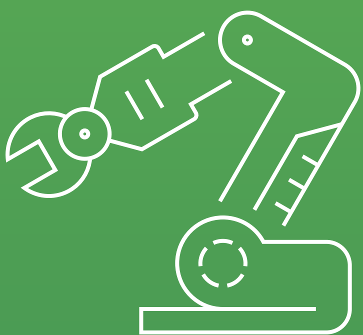
Access to the FIAB methodology provides proven agile supply chain solutions and, together with enabling mechanisms, will ensure companies extract full value from their innovations. This commanding proposition will draw in investors, enhancing further the prospects for clean energy businesses.

Through deployment within clusters and indeed the further research that is warranted, best practice will evolve. It is recommended that, in keeping with its mission, MTC promotes progress and communicates developments across all innovation clusters.

The FIAB demonstrator stands unique, in a space on its own – the only full scale working factory in a box. It offers agility, scalability and remote and rapid deployment. If recommendations within this report are pursued, it will provide a unique opportunity to fulfil the supply chain needs of clean energy innovation clusters.

Advancement can be *transformed by providing clean energy innovation* **clusters access to the knowhow and implementing mechanisms to facilitate usage.**

Rejecting the spectre of incremental improvement, the team sought to create a set of user requirements that would *amaze and delight manufacturers* **and then to realize it.**



1.0 Introduction

The Paris Agreement (COP21) marked a significant step change in global acceptance of the need to take immediate and accelerated action on carbon reduction in order to avoid catastrophic climate change. Challenging carbon reduction goals were established to limit global temperature rise to well below two degrees.

Delivery on the Paris commitment will require an unprecedented depth and breadth of change – not just within sectors but across city systems and nation states. This was recognised at Katowice (COP24), with an emphasis emerging for the private sector to deliver innovative solutions on an unparalleled scale and with a pace of change stretching the boundaries of previous achievements. There are many companies today striving to overcome technical and business challenges in the development of clean energy products. These include wide ranging technologies from companies such as Dearman, Intelligent Energy, Bennamman, Noblegen and Sure Chill. However, in order to deliver the necessary impact on the energy landscape, rapid scale-up of deployable capacity is one of the most important, yet demanding, business challenges. In an environment already strained by growth, responsiveness and agility are also critical facets of a successful supply chain.

Whilst it is the small companies now developing products to address the energy needs of the future, large companies are starting to reap benefits from Industry 4.0, or digital manufacturing. Digital manufacturing is the extraction of value from data in a production environment and can transform businesses. Such systems enable the integration of business and manufacturing systems and by embedding smart functionality, facilitate efficient operation of production resources.

Understanding the needs of energy innovators and the potential of digital manufacturing, in 2016 the Energy Research Accelerator consortium launched, with funds awarded by Innovate UK, the Smart Manufacturing Accelerator (SMA) project. Led by the University of Birmingham and with clean energy innovators the target, the SMA project aim was to harness digital manufacturing to create and embed within energy ecosystems ground breaking supply chain solutions.

> **‘Digital manufacturing is the extraction of value from data in a production environment and can transform businesses.’**

This study, conducted by the University of Birmingham as part of the Climate-KIC initiative, explores the opportunity presented by the SMA project and recommends next steps to maximize the benefits for clean energy innovators.

2.0

Supply Chain in Focus

2.1 Supply Chain Challenge

The UK's Clean Growth Strategy predicts that the low-carbon economy could grow 11% a year between 2015 and 2030, four times faster than the projected growth in GDP. To fulfil this demand side growth over such a sustained period will present a significant challenge; the default of organic growth of existing supply chains cannot be relied upon to achieve the climate change imperative.

With numerous innovations being brought to market during the coming years, there will be great diversity, although the types of product are as yet unknown. Predictions of demand for each innovation will be made but there will be no certainty; some products may achieve unprecedented levels of success, a number may be rapidly superseded by subsequent innovation and others may not achieve targeted volumes. Within this dynamic business environment, companies need to be singularly agile, coordinating responses throughout each vertical strand of the supply chains. There are many software packages used in industry to manage manufacturing and logistics including: Enterprise Resource Planning (ERP), Material Requirement Planning (MRP), Manufacturing Execution System (MES) and Product Lifecycle Manager (PLM) but typically they are not fully integrated with each other, resulting in significant demand for human intervention to manage interfaces. There will routinely be a large number of variables that operations teams have to control in the pursuit of successful outcomes and the best course of action is rarely immediately evident. It is far from usual for businesses to have the analytical tools to explore the effects of adjusting such variables throughout a supply chain strand, or even within their own organisations. Despite these fluctuating demand signals, it is essential that products are supplied on time and in full compliance with requirements, as the innovations will form essential parts of carefully devised integrated energy systems.

"Within this dynamic business environment, companies need to be singularly agile, coordinating responses throughout each vertical strand of the supply chains."

The growing supply chain need could be tackled using an evolutionary approach, expanding existing facilities and adapting current processes within factories to accommodate the new product ranges. It is however not always attractive for successful companies to develop new products for emergent innovations, particularly if they already have thriving business models and growth opportunities that present lower risks. Such reservations will compound the already substantial challenge of fulfilment of the need for exceptional growth. Further, in instances where companies embrace the opportunities, the operational methods intrinsic to their business processes will impose significant limitations in terms of speed of introduction and agility once in service.

In summary, it is clear that plotting a course based on the evolution of existing supply chain models represents a significant threat to the crucial mission of tackling climate change.

2.0 Supply Chain in Focus (continued)

2.2 Digital Manufacturing Opportunity

Whilst conventional supply chains based on legacy systems face significant limitations, new technologies exist which have the ability to overcome such impediments and indeed to go beyond.

The opportunity is presented by the surge in capability of digital manufacturing with its ability to exploit ever further the value of data in the manufacturing environment. Processes can be transformed by development of smart systems with high degrees of integration between manufacturing cells and other business functions and indeed across supply chains. Mechanical automation is commonplace in many sectors, thus eliminating errors associated with repetitive tasks. However, digital manufacturing goes far beyond and in facilitating integration of the wider business landscape offers the potential to eliminate much of the human input, which often results in errors but is necessitated routinely to address scheduling conflicts and revisions to demand. In essence, digital manufacturing enables the difficult, time-consuming and inexact human pursuit of a goal within a conventional non-integrated system to be replaced by rapid automated determination of an optimized course of action.

Implementation of digital manufacturing changes the role of the operations manager. Once enabled, the function requires the setting of overall objectives against which the smart system evaluates options and recommends a solution. The operations manager can then confirm the choice, or explore alternatives. In addition to delivering orders on time, objectives can include such functions as when to conduct maintenance tasks and how to minimize the use of raw materials, consistent with delivering the required output.

The adoption of digital manufacturing processes enables manufacturing cells to be remotely deployed and controlled, thus giving companies the ability to rapidly scale-up on a global scale.

2.3 The Energy Research Accelerator Vision

Working with business and industry the Energy Research Accelerator is creating an energy systems acceleration ecosystem.

Since being formed in 2016 by the universities of Aston, Birmingham, Leicester, Loughborough, Nottingham and Warwick together with the British Geological Survey, capability has been enhanced further still by the joining of Cranfield and Keele universities. The Energy Research Accelerator harnesses the research of 400 academics and 1,000 PhD students, aiming to transition low carbon energy solutions to market and grow the much needed energy sector skills.

The Energy Research Accelerator was awarded £60 million funding from Innovate UK and partnering with industry a further £120 million of business funding has been attracted in the drive to fast track to market clean energy innovations. Recognising that supply chain capability is an essential part of this process, the Energy Research Accelerator allocated £10 million of the funding to the Smart Manufacturing Accelerator (SMA) project and during the programme in excess of £20 million of industrial funding has been attracted. With the University of Birmingham as the lead party, the SMA project targeted the development of smart manufacturing solutions which would be highly integrated, remotely locatable and rapidly deployable.

“The Energy Research Accelerator harnesses the research of 400 academics and 1,000 PhD students”

2.4 SMA Approach

The target was to develop the most advanced and capable supply chain solution possible. The thought process, discarding the concept of incremental improvement, was to consider what would amaze and delight manufacturers and then to make it possible.

A multi-disciplined research team was engaged with the capability of exploring possibilities in terms of supply chain configuration and performance by using the latest in digital technologies. The team was challenged to shed the constraints imposed by incremental improvement of existing methods. The thrust was to seek a disruptive step change based on combining enhancements to cutting edge technologies with a systems and integration philosophy. With the goal of achieving a ground breaking result, the team developed a set of user requirements based on aspirations that would exceed the expectations of any operations team. The target was then to develop methodologies to deliver these user requirements within a system which had practical industrial application.

Observing that manufacturers and suppliers use a wide variety of software tools and wishing to ensure relevance, the target was therefore to embrace solutions from a range of software providers and to integrate them into a single comprehensive system.

The communication of the research results was thought to be best done by development of a working demonstrator, together with supporting documentation. The headline specification adopted for the demonstrator was a lights-out highly automated remotely operable manufacturing cell which became known as a Factory in a Box (FIAB). The aim was for demonstration of the FIAB to enable the true potential of the developed solution to be understood within a matter of minutes and to leave observers in no doubt as to the potential of the opportunity on offer. Further, the target was for the demonstrator to be transportable, so as to reach significant audiences within UK, Europe and beyond.

Build of the FIAB

3.0 The Journey so Far

3.1 Vision and Planning

3.1.1 The Role of the Manufacturing Technology Centre

The University of Birmingham chose the Manufacturing Technology Centre (MTC) as its partner to lead the collaborative research.

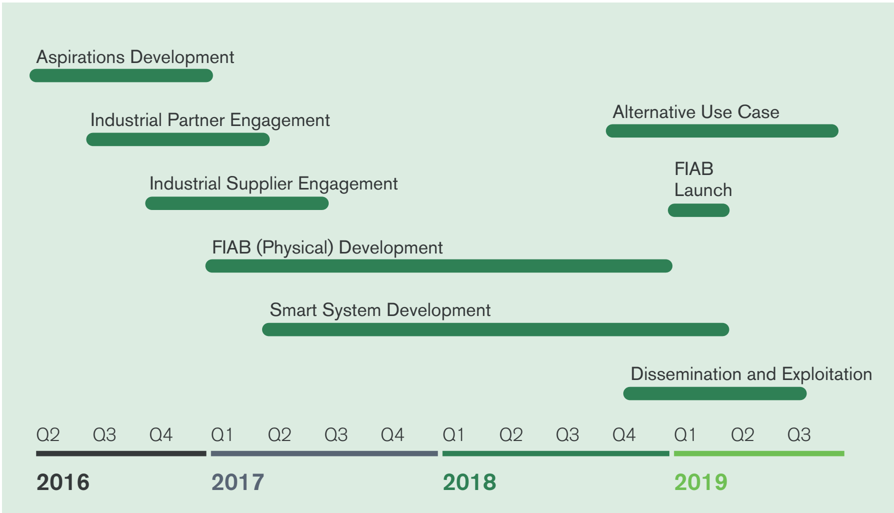
MTC is part of the government's High Value Manufacturing Catapult and, supported by its membership and Innovate UK, its vision is to inspire Great British manufacturing on the global stage. The capabilities and aims of MTC are well aligned with the mission of the SMA project.

The MTC's core business is the development and proving of innovative manufacturing processes and technologies in an agile, low risk environment, in partnership with industry and academia. There is a major focus on delivering bespoke manufacturing solutions for its major customers. MTC works with its founding shareholders, a number of Midlands based universities, including the University of Birmingham to extract the value from academic research and partner with industry to deliver benefits to the market place. This approach, known at the MTC as 'bridging the Valley of Death', is well established and has led the MTC to grow successfully and in 2019 the organisation claims 115 member businesses, a turnover of £74 million and 800 staff. It is the wealth of technologies amongst the member businesses, coupled with the capabilities of the research staff that ideally position the MTC to form the hub and to lead the delivery of the SMA project.

By inclusion of capability from software suppliers, termed Industrial Suppliers, within the FIAB demonstrator, exploitation traction was significantly elevated as this group of companies join the stakeholders aiming to derive commercial benefits. Further, the wider MTC membership provides an additional catalyst, with dissemination of results to the community offering the prospect of exploitation of the SMA solutions to better serve their customers.

3.1.2 Project Timeline

The project team constructed an ambitious process and timeline. Kicking off in April 2016, the early phase was dedicated to identifying the most promising emerging low carbon energy technology companies. In parallel, aspirations for the FIAB demonstrator were developed and the team engaged with Industrial Supplier companies capable and willing to contribute to the holistic solution.



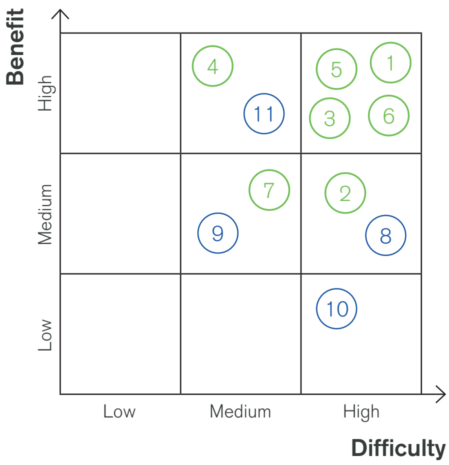
The physical design and development of the FIAB was pursued in parallel with the smart system to operate it. In March 2019, with the FIAB development complete, the dissemination and exploitation activities received a major boost with a public launch event being held. To validate the smart system that is central to the FIAB's capabilities, an additional use case model was developed.

Delivery of the project to the timeline was achieved through a governance process based on extensive project and technical reviews which included parties external to MTC, most notably the academic bodies of the University of Birmingham and Loughborough University and various industrial parties.

3.2 Early Choices

3.2.1 Aspirations

The concept of a FIAB can be interpreted in many different ways and offers boundless possibilities in its realisation. However, the project brief was clear – to develop a physical working demonstrator that would communicate what can be achieved. Whilst it was necessary to grapple with and indeed to overcome difficult challenges, it was essential to deliver a working demonstrator. In order to anchor that vision with clear goals that could be recognised by team members of all disciplines, a set of top level FIAB user requirements was developed. Since these were beyond the bounds of what was easily reachable, they were termed 'Aspirations'. Having generated a long list of potential aspirations, understanding was anchored by development of concise definitions for each. Before evaluating and selecting which aspirations should be pursued, they were positioned by consensus, on a bi-axial chart of benefit to the project versus difficulty to deliver. The method was based not on objective data but perception, discussion and agreement. Whilst no attempt was made to draw a boundary between accepted and rejected aspirations, the chart, an extract of which is shown (right), assisted with subsequent discussions and convergence on the choices.



Adopted

1. No manual intervention during manufacturing process
2. Design derived from CAD to directly control manufacturing operations and robot path
3. Real-time 'live' link between FIAB and simulation models
4. Intelligent system for automated scheduling and sequencing of orders
5. Condition monitoring and intelligent maintenance scheduling
6. Production of certified parts
7. Feedback from QC processes to refine production settings

Rejected

8. Automated packaging of parts produced by FIAB
9. Use of voice recognition software to interact with the FIAB
10. If FIAB 'fails' simulation model can replicate failure and advise best course of action
11. Use MTC high performance computer to run big data analysis

In considering the Aspirations the relationship between various candidates had to be considered, as adoption of one could facilitate the delivery route for another.

Although full mechanical process autonomy within a factory does not give it Industry 4.0 credentials, it is an appropriate core for a FIAB demonstrator. The aspiration to have no manual intervention during the manufacturing process (1) was adopted, with the implication that full automation of each individual process was required, including brazing of various joint types and transfer between all automated workstations. The aspiration to monitor and control the factory from a remote web based app on a tablet was also adopted providing essential flexibility of access to the FIAB. Consideration was given to possible loss of communication and deemed important and a requirement to buffer 24 hours of data thereby allowing continuity of autonomous operation in such circumstances was therefore written into the requirements.

The ability to respond automatically to design data without extensive human intervention was considered a challenging but attractive feature and hence an aspiration for design derived from CAD to directly control the manufacturing operations and robot path (2) was adopted.

3.2 Early Choices (continued)

Features of the FIAB later to become central to the tool known as the Digital Twin were considered fundamental to the concept and were included in the specification within the Aspirations. These included a real time 'live' link between the FIAB and the simulation models representing the FIAB (3) and the use of the same simulation model to optimize the FIAB design, specification and control system during its design.

Also considered imperative was the ability to demonstrate optimization capability within the FIAB. The most pertinent aspects were chosen as the optimization of stock use and an intelligent system for automated scheduling and sequencing of orders (4) and these were added to the Aspirations.

In order to run efficiently over long periods of time, FIAB maintenance is a critical issue. Effective prediction, scheduling and execution of maintenance tasks are fundamental to the successful operation of a smart factory. Accordingly, condition monitoring and intelligent maintenance scheduling (5) and the use of virtual reality and augmented reality to support maintenance tasks were both adopted as aspirations.

To successfully complete a fully automated process, parts have to be validated as conforming to specifications. Hence production of certified parts (6) was written in to the Aspirations. The possibility of rectifying non-conforming product was debated but in order to design a process to achieve this, the scope of defects has to be anticipated and accommodated within automated procedures. Such aspirations were considered and rejected but the team did include an aspiration for feedback from the quality control process to be used to refine production settings (7).

The adopted Aspirations were considered ambitious within project time frames and budgets and there were a number of possibilities considered and rejected. Notable amongst these was the automated packaging of parts produced by the FIAB (8). It was considered that this would be particularly challenging to develop and not being central to the end-to-end manufacturing process, would add limited value to the demonstrator. Although perceived as being less difficult to implement, use of voice recognition software to interact with the FIAB was rejected (9) on the basis that it would add little in terms of capability demonstrated. Also discussed and discarded was the idea that should the FIAB fail, a simulation model would replicate the failure and advise the best course of action (10). Whilst this is undoubtedly a possible route for developers of a FIAB to take, solution development even for a relatively limited set of failures would be time consuming and add little value to a demonstration scenario.

A final potential aspiration worthy of particular mention is the use of the MTC high performance computer to run big data analysis (11). It was recognised that this concept is central to the extraction of the true value from smart machines and FIABs. However, the benefit is derived when either one machine, or ideally a fleet of similar devices, operates over an extended time span. This was rejected principally as there would be limited operational data available during the development phase of the project and hence demonstration potential would be minimal.

The Aspirations became the guiding rule book for delivery of the FIAB and indeed they are potentially relevant to almost all future FIABs, irrespective of their purpose.

3.2.2 Industrial Partner Engagement

With a key focus of the project being to accelerate the route to market of clean energy companies, the team identified and researched as many candidates, known as Industrial Partners, as possible. The plan was to build the demonstration capability around the technology of the most promising and appropriate businesses. This approach would offer the benefit to the winning Industrial Partner innovator of a platform from which to accelerate the scale-up of its manufacturing. The identified companies were evaluated both in terms of their prospects for success and also with respect to the benefits they would derive from a FIAB application. To prepare for the screening process, detailed assessment methodologies were devised which examined technology readiness levels and included investigation of manufacturing capability, supply chain maturity, design development, market potential and the performance of a wide range of business functions. A financial health assessment was also part of the selection process.

Further, it was a requirement of the successful Industrial Partner candidate that their product would be suitable for production in a FIAB. This had implications for the size of the finished product, number and type of input materials and the range of manufacturing processes used.

The project team identified and evaluated over 50 innovative clean energy companies. As a result of these evaluations 15 were chosen for further investigation and in-depth engagements were pursued. Detailed assessments of all aspects of the businesses were performed on those which had both the capacity and appetite to engage with the project.

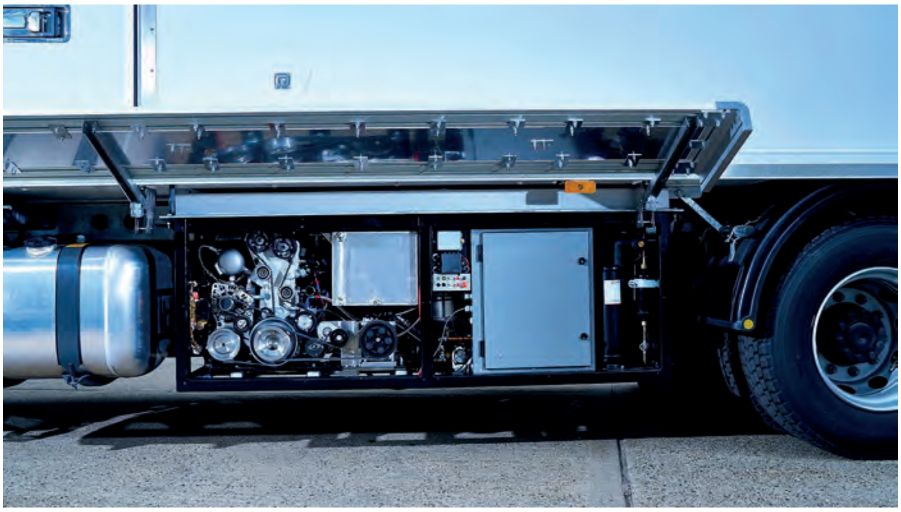
Feedback from MTC enabled the companies to enhance their prospects of success, through understanding of strengths, confirmation of validity of plans, pinpointing of weaknesses and identification of opportunities to exploit untapped potential.

3.2.3 Dearman

Dearman, the developer of the liquid nitrogen powered Dearman Engine, engaged early with the project. The company has a vision which is well aligned with that of the Climate-KIC project, aiming to use its cutting edge clean cold power technology to address the global challenges of food, energy and water. The company has been validating its solutions through the process of field trials to provide zero emissions refrigeration of transport for food across Europe. Food transportation trucks are fitted with Truck Refrigeration Units resulting in reductions, relative to diesel applications, in emissions of carbon, NOx and particulates.

The company projects that scale-up of the refrigerated transport products will be limited by the ability to supply components to meet local demands in appropriate configurations. The cryogenic systems identified as presenting particular challenges included pumps, tanks and pipes. Each of these was evaluated as an option for a FIAB application and the pipe was chosen for three reasons. First, the demand for pipes will be for a range of different configurations to provide for a range of chassis types, body styles and Dearman engine sizes resulting in a need for complexity that would offer an appropriate level of challenge. Second, brazing of cryogenic pipes is a skill in short supply and third there is no requirement for a supplier to offer access to background intellectual property that would constrain the FIAB's relevance to other companies.

Dearman Truck Refrigeration Units



Dearman engine installation on board

3.3 Demonstrator Development

3.3.1 Product Specification

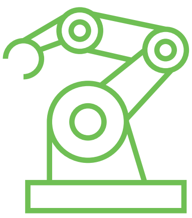
The requirement set by Dearman was to produce within the FIAB brazed pipes from 5/8" K65 copper tube having a safe working pressure of 120bar. This is a high performance material designed specifically for cryogenic applications made in accordance with DIN EN 12449 from material EN CuFe2P CW1076. The target set was to be able to deliver any design of pipe that fits within a 1.0m x 0.5m x 0.5m cuboid, has up to three T-pieces and a maximum of two bends per pipe length each of angle no greater than 180°.

Pipes Produced in FIAB

Container preparation for FIAB build

3.3.2 Box for a Factory

The purpose of the demonstrator is to communicate to an audience what is achievable through the use of a transportable and rapidly deployable FIAB. The most appropriate form of FIAB was thought to be a shipping container. With international standards governing design and use, not only is a container easily transportable but the message is clearly communicated. The need was for the demonstrator to be a representation but not to conform to all of the standards' requirements. Most importantly, windows were included for viewing the physical processes within. Given the need for care in handling the 'container' with windows, it was built so as to be transportable by road but not by rail, or indeed transited through container ports. Base corner fixings were included to facilitate fixing by a container truck and it was accepted that to conform to the allowed space the external air conditioning system and aerial could be demounted before transport. In order to provide for the option of reconfiguration, a steel panelled floor with a matrix of holes was used. This raised machine mounting surface also provides for electrical, communication and other services to be routed underneath.



Although a lights out factory does not need space for human presence during production, operators need, when the FIAB is inactive, to add raw material and remove finished goods without the risk of either damaging equipment or injuring themselves. Other physical requirements to support development of the FIAB integrated safety solution include the fitting of interlocks on the end access doors and E-stops near the windows.

The length and width of the demonstrator are those of a 40' shipping container with the height being slightly increased to allow ease of human access below the track mounted overhead robot. The FIAB is supplied with three phase power through a universal connector mounted within a recessed access panel.

FIAB interior ready for fitout

3.3.3 Physical Process

For the FIAB to deliver product to the required specification a number of physical processes are required as illustrated in the diagram opposite. With the exception of loading raw materials to the stock storage system (1) and removing of finished goods, these are all done automatically.

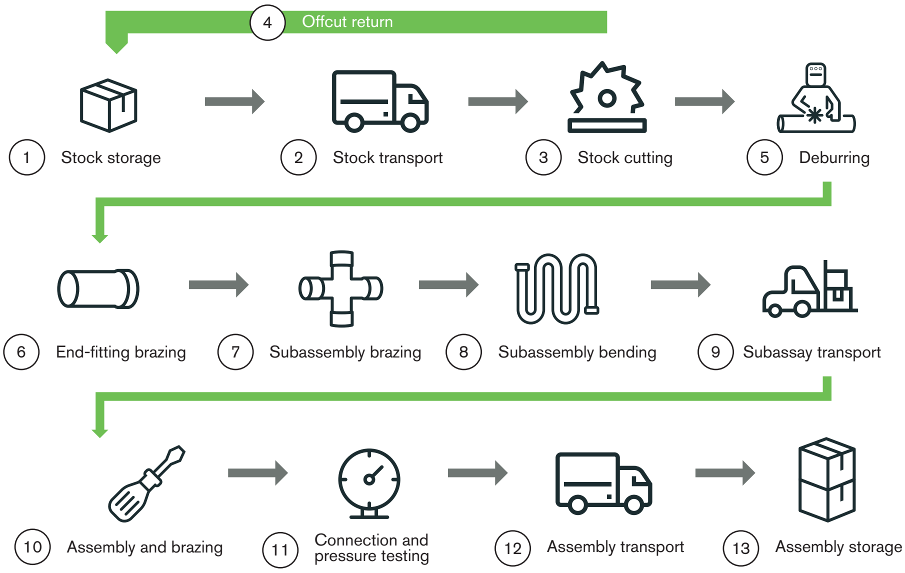
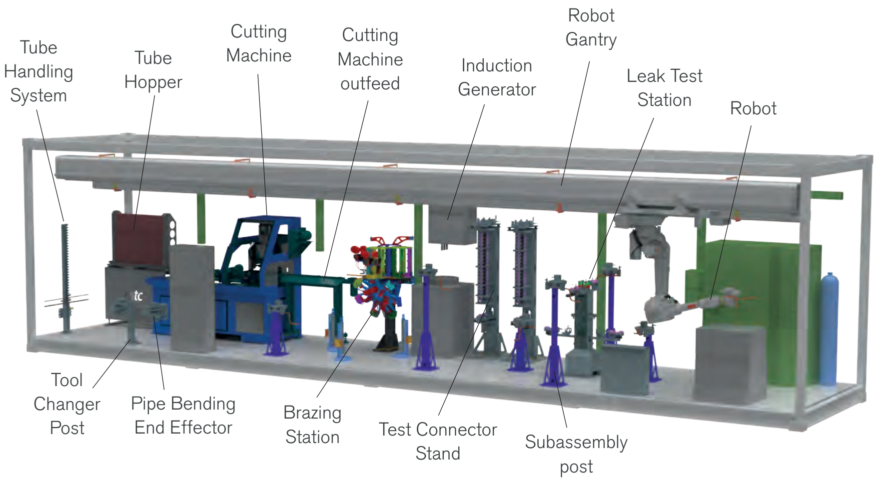
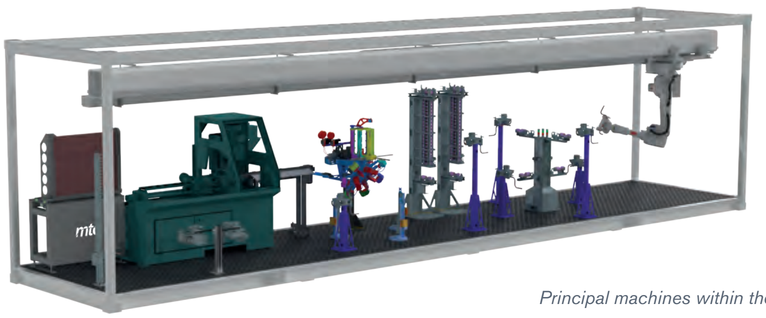


Diagram showing work flow within the FIAB

At the start of the manufacturing process the pipes are dispensed (2) to a machine which cuts them to the required length (3). A robot, suspended by an overhead gantry the length of the FIAB provides general transport services, including transfer of the offcut (4) to a rack system and the pipe to be used to a station for de-burring (5). The pipe is then transferred to the automated brazing station where it is brazed to an end-fitting (6). The same machine produces other such pipes as required and then brazes them to a T-piece (7). The robot collects a bending tool (end-effector) and bends each length of the pipe to the required angles and orientations (8). The robot transports the partially complete subassemblies to static locations (9) whilst other pipes are brazed and bent. The process is repeated as required and the subassemblies then joined to the final T-piece (10). The last pipe length is then bent, and the final assembly undergoes pressure testing, followed by a non-contact geometric assessment and verification (11). Due to the relatively long cycle time of the pressure testing the system is configured to test multiple assemblies simultaneously. The final assembly (12) is then moved by the robot to the assembly storage area (13).





Principal machines within the FIAB

3.3 Demonstrator Development (continued)

3.3.4 Smart System

The smart system is the very essence of the FIAB. Mechanical automation is not new; the automation system itself could be chosen from a multitude of possibilities as the foundation for a smart factory. Ideally a smart system should be able to undergo basic adaptation to be able to drive any automated mechanical system, this being the intention in devising the SMA solution.

There were two principal avenues available at the outset – either a multi-vendor system approach, or a single vendor software solution. Many companies use a system integrator to allow them to embrace a multi-vendor business environment. Whilst it undoubtedly brings complexity, it does facilitate adoption of 'best of breed' solutions for all business, technical and operational functions. They consider that such a landscape enables them to constantly adapt and improve. Perhaps companies reduce a perceived risk of being beholden to a powerful integrated solution provider but in so doing undoubtedly embrace the certain risks associated with system complexity.

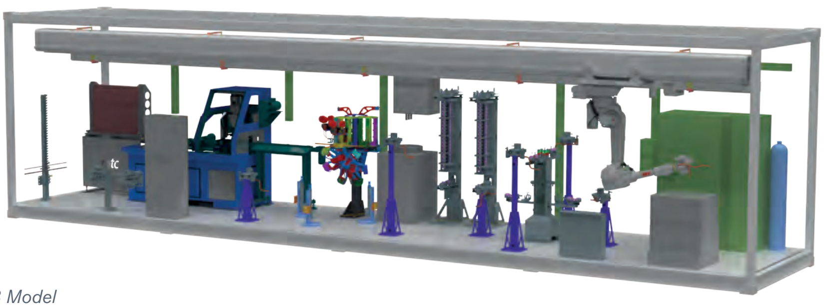
Whilst not the choice of all companies the alternative approach of purchasing integrated solutions from a single vendor is also used by many. However, it is quite possible that at some point they will be involved in a merger or acquisition with a company which uses either a different single vendor solution, or a multi-vendor approach. In such a case there will be challenges as the migration to different software is costly, requires a lot of skilled resource and is disruptive. Even if not involved in a merger or acquisition, with Industry 4.0 offering ever greater opportunities to the industrial landscape, deployment of integrated business solutions with suppliers and customers will be necessary to remain competitive. In essence, for reasons specific to their particular circumstances, some companies choose single vendor solutions and others adopt a multi-vendor system approach.

Given the above understanding and also the project team's aim to provide a demonstrator with the widest possible relevance, not withstanding complexities, the choice was made to devise a multi-vendor solution. Essentially, for each element of the architecture, 'best of breed' was adopted but of course in making choices many points had to be considered.

The challenge that was embraced was to devise an outline architecture which had the capability to deliver the Aspirations. Of critical importance were the communication protocols. Possible schemes were reviewed and a number of options developed to account for the inclusion of solutions from diverse providers. These outline architectures were used to develop specifications for the individual functional elements of the outline architecture. In parallel with this process, lists of potential vendors for each functional element were generated, as was a selection method. The approach comprised various considerations, including functionality, ease of use, interface options, stability of the company and commercial proposition. Also considered was the company's ability to engage on the project. Finally and in view of the project's aims, significant weight was given to the vendor's perception of the potential of the project and their consequential appetite to invest in it.

The Industrial Suppliers engaged on a contractual basis that protected their background IP, but gave them access to the resulting IP and hence positioned them so as to be able to exploit the results for their commercial benefit.

The process of selection of Industrial Suppliers was critical to the success of the project and MTC was ideally placed with the combination of its extensive knowledge of manufacturing business processes and software and also its considerable network across the manufacturing technology supply base. Having devised an outline architecture, developed specifications for the elements, chosen Industrial Suppliers and then gone on to perform the detailed technical research to create a working solution, the resulting landscape now forms the core of the FIAB solution.

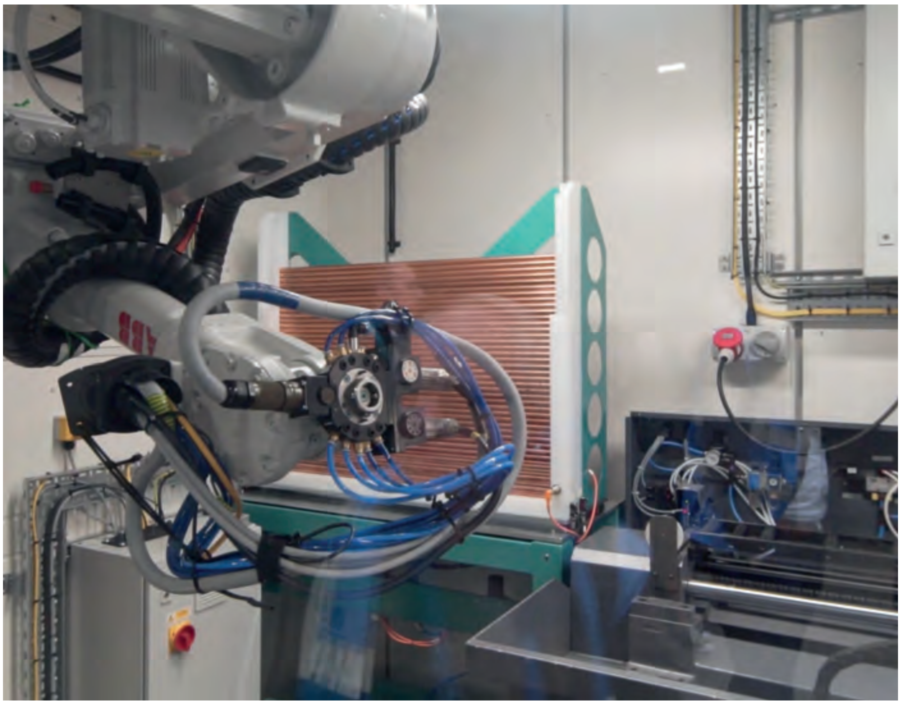


FIAB Model

3.3.5 Control Centre

Whilst the performance of the smart system was important for efficiency, ease of use was essential. The delivery of the navigable Control Centre with its unified single screen app-based interface fulfilled the project team's aim for an operator to be able to monitor and control the FIAB from a remote location.

By navigating the menus within the Control Centre, all information can be retrieved and is presented intuitively and all control instructions can be easily issued. The system has a home screen which gives headline information for multiple FIABs at disparate sites and also presents warnings should any parameter stray beyond prescribed boundaries. It is this functionality that transforms the smart system for a fleet of FIABs from one that can be operated by a highly trained expert, to one that is accessible by a competent general manager. The images show the FIAB in operation and the Control Centre.



Robotic Manipulation within FIAB

FIAB Control System

3.3 Demonstrator Development (continued)

3.3.6 Demonstrator Capability

The core function of the FIAB is to be able to efficiently produce any pipe which conforms to the given specification, whilst being controlled from a remote location. The mission of the demonstrator is to make clear how this is achieved, whilst also communicating the power of the smart features.

In setting up a demonstration there are two choices – either the FIAB can be located remotely, or it can be collocated with the Control Centre. The options offer different practical advantages, with the messaging being powerful for both scenarios. If collocation is chosen the observer is able to view the working FIAB, a large touch screen Control Centre portal, a number of CCTV views of the working FIAB and the Hardware in the Loop model in operation. The Hardware in the Loop model is a 3D rendered computer model of the working elements of the FIAB responding to the control instructions within the physical FIAB and animating accordingly. This powerful tool is a critical element of the Digital Twin, which is defined as 'A set of data and information to represent the true state of a physical component/system in real time'. The Hardware in the Loop display provides the operator with a visual check of the control instructions being issued within the FIAB and can be readily compared with expectations based on issued instructions from the Control Centre and also the CCTV stream.

'The core function of the FIAB is to be able to efficiently produce any pipe which conforms to the given specification, whilst being controlled from a remote location.'

The benefits of the Virtual Factory, which is defined as 'An integrated simulation toolset enabling redesign and re-engineering of a product and/or a production process throughout its lifecycle', are clearly communicated to the observer during a demonstration.

A demonstration typically starts with an introduction to the home screen which shows locations of all FIABs controlled by the operator, headline status of each FIAB, weather conditions in those locations and any active alarms. Whilst the demonstration environment provides access only to the FIAB already commissioned, the Control Centre is capable of managing additional units in the future. Navigating through the screens relating to the physical FIAB the operator is able to select sales orders, accept them, select items from the catalogue of validated parts and submit orders to the Manufacturing Execution System. The operator can access tools to optimise both use of available stock and also the job execution schedule to ensure customer orders are fulfilled at the earliest possible time. When complete, the Control Centre is used to start the production process, setting the FIAB in motion. At this point the Hardware in the Loop model responding to the control signal closely replicates the image on the CCTV screen and indeed the behaviour of FIAB itself.

Whilst the FIAB is producing the parts, the operator can use the Control Centre to interrogate the system. Status of each machine process (active, waiting, idle) may be displayed, as can the expected time of finishing and the forecast time that the pipe assemblies will be completed. The Control Centre also allows interrogation of raw material and consumable stock levels.

During pipe validation, the system can display the applied pressure throughout the cycle and following non-contact geometric check, a graphic and digital readout of the deviations to norm. This data, together with trace records of material used and production process information is retained for all parts produced and is accessible at any time. The Control Centre allows the operator to clearly demonstrate the smart functions for FIAB maintenance. The data from a number of sensors within the FIAB are compared to historical records and health indicators are reported alongside a forecast of remaining life for the corresponding asset. Whilst the operator can access this at any time, the system will register an alarm if predefined thresholds are breached, or a signal from one of the machines deviates from expected norms, indicating a potential fault. Once the operator has used this system to determine a list of required maintenance tasks, it is then possible to integrate this with the production demand and optimise the overall activity schedule. Maintenance work can be carried out with the aid of augmented reality such that an untrained operator is able to follow directions using a headset which overlays 3D instructions on the true image of the parts to be maintained.

Automated Pipe Cutting

For a customer to place an order for a new part it needs to be added to the catalogue. Before inclusion, it requires validating and this is done using the Automated Robot Path Planning (ARPP) tool. The function of the ARPP, through a process of exploration and iteration, is to determine a valid operation sequence and set of robot paths to produce the requested part. If it is not achievable it will be rejected. If it is feasible, it will be accepted and added to the parts catalogue and can then be ordered by a customer. This process demands use of a powerful computer for a significant duration and it is not generally practical to incorporate it within a typical demonstration.

Another aspect of the FIAB which is best communicated in a dedicated forum is one of the processes by which it was validated prior to build. The technology used is known as virtual commissioning. The model central to the Hardware in the Loop capability was animated during the development phase using a form of the control code. The technique allowed the engineering team to identify logic failures and physical clashes and to rectify these before parts for the final design were produced and assembled within the FIAB. As an additional demonstration and to assist with explanation of this method a full 3D CAD model has been produced and can be animated by the control code. Using this technology known as Software in the Loop, an observer is able to experience the complete FIAB operation from within its space using a 3D virtual reality headset.

The FIAB's ability to be transported and then re-commissioned is also better communicated in a dedicated forum. Re-commissioning requires the introduction of the displaced coordinates of the machines and fixtures, as a result of any slight distortion during relocation, within the FIAB control architecture. However, this functionality is easily communicated by reference to the installed mobile 3D camera based vision system within the FIAB, which serves the purpose of recording revised machine positions.

3.3.7 Handbook

A handbook was created documenting all of the tools and techniques devised during the project to deliver the FIAB. The handbook ensures that the project knowledge gained is preserved, its contents being well structured and easily navigable and interpreted whether accessed for the delivery of a complete FIAB, or adoption of a specific technique devised during the SMA project.

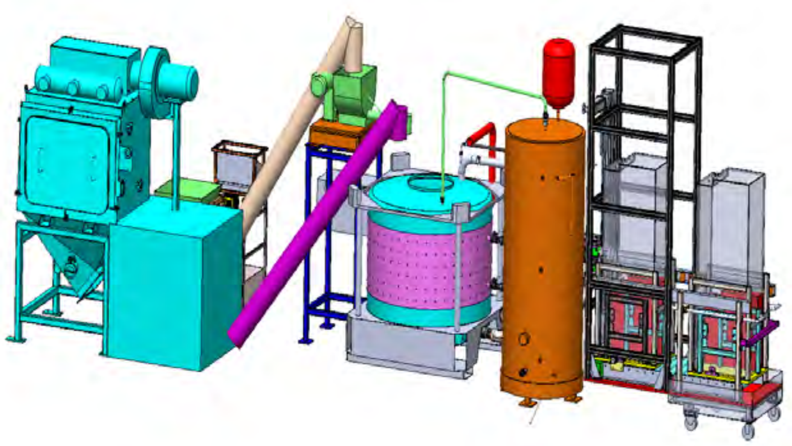
MTC's principal focus is to assist companies in taking new manufacturing technologies to market. Having successfully delivered the SMA project, including development of the FIAB demonstrator, MTC is ideally placed to enable companies to adopt Industry 4.0 techniques, establish highly automated smart factories and introduce FIABs. The handbook is fundamental to this process.

3.4 Extracting the Benefits

3.4.1 Alternative Use Case

The purpose of the FIAB demonstrator was not simply to provide a solution for companies wishing to flexibly manufacture pipes, or indeed to prove the potential of the FIAB business model. It was to provide a smart solution architecture which would form the basis of commercially deployed FIABs of the future. A second FIAB demonstrator was planned to validate the smart solution architecture, with two additional benefits being cited.

First, the pipe-manufacturing FIAB demonstrator's success is reliant on the realisation of a series of mechanical operations producing a product to a given form. Whilst these are the characteristics of many manufacturing operations, sectors such as pharmaceuticals and fast moving consumer goods are more typically process based, with most of the machinery and equipment dedicated to handling substances. It was considered important to demonstrate capability relevant to as many sectors as possible, these included and batch production of a generic phase change material was chosen as the use case for the second FIAB demonstrator. The diagram shows a schematic of the second demonstrator.



Phase Change Material FIAB

Second, in order to build on the virtual commissioning process of the first FIAB demonstrator, the physical FIAB hardware was replaced by an emulator. The function of the emulator is to imitate, in the virtual environment, all of the physical and control processes that occur in the physical FIAB, if and when it is built. The imitation must be achieved by replication of the full response set to all of the control signals both internal to the emulator and in terms of input and output. This project element clearly communicates to an audience that it is possible to design and evaluate a complete process in the digital environment, including all physical elements, control systems and with the Control Centre providing a unified user interface and smart functionality. Problems can be identified and eliminated and the system validated in the virtual domain before commitment of funds to procure parts and building the FIAB.

This phase change material FIAB has already sparked significant interest in fast moving consumer goods and pharmaceutical circles. It is also expected to pique interest in companies seeking to maximize the benefits of using digital technologies for validation during the design phase of a project.

3.4 Extracting the Benefits (continued)

3.4.2 Launch Event

The SMA and FIAB demonstrator launch event was planned well in advance and held on 13 March 2019. The venue of the Advanced Manufacturing Training Centre was ideally located within the industrially important area of the West Midlands and is well connected by excellent transportation infrastructure. Registrations were cut off five weeks ahead of the event when 35% above capacity. With 200 present on the day, attendees were drawn from diverse industrial sectors, arriving from a wide range of countries as well as the locality.

The purpose of the event was to explain to as wide an audience as possible what had been achieved and to communicate the opportunities that the project opened up through deployment of digital manufacturing in general, and the developed solution in particular. Central to the event was the series of pipe-manufacturing FIAB demonstrations running throughout the day. Demonstrations were as outlined in section 3.3.6, with the FIAB being collocated with the Control Centre.

"Feedback confirmed the event was a thorough success!"

The programme to promote the event included direct engagement by MTC with its membership of 115 companies, creation of a dedicated website coupled with a social media stream and engagement by the Industrial Suppliers with their customers. In addition to the technical and project presentations by MTC, the Industrial Suppliers hosted stands within an exhibition space and all took up the opportunity to showcase their company contributions to the process. In parallel, workshops were held to enable interested parties to explore in depth the capabilities and technical details underpinning specific developed features and capabilities.

A large number of MTC staff attended to explore opportunities with delegates and expand the growing database of interested parties. Formal feedback confirmed the event was a thorough success, partly due to careful planning and preparation but in no small part due to the unprecedented levels of achievement of the project – a working FIAB demonstrator had never been produced before.

FIAB in Operation

3.4.3 Engagement and Exploitation

As the FIAB demonstrator progressed from concept to detailed specification and then build, the team accelerated the external engagement in a number of directions. A holistic understanding of the FIAB was unveiled to the Industrial Suppliers and they were able to work with their partners and customers to plan exploitation of the project results. Further, the project was presented to partners of the academic institutions, the energy innovators with whom the project engaged during the early phases and also with the member companies of the MTC.

The overall effect of the engagement was powerful; in addition to over 200 attendees participating in the launch event, a significant number of industrialists of all levels of seniority watched private demonstrations of the FIAB both before the launch event and indeed afterwards. The opportunity that the FIAB solution presents is recognised by both large and small companies. For small companies, whilst they are often unable to respond immediately due to limited bandwidth and pressing priorities, the potential that it presents in their journey of growth is clearly understood. The question for many is one of timing and available capacity to tackle the various complexities in order to catalyze controlled expansion at the opportune moment.

"The opportunity that the FIAB solution presents is recognised by both large and small companies."

For larger companies, usually with an extensive portfolio of activities and a leading position in at least one field, the argument for early adoption has already proven to be compelling. Interest from such companies started early, with a number of discovery projects kicked off before the March 2019 launch event. Leading the field of companies with plans for early implementation are businesses in sectors including energy, transport, power and defence. However, the alternative use case FIAB targeted at companies in process based sectors has quickly drawn interest and a number of companies are pursuing opportunities.

Robot ready for installation

4.0

The Opportunity for Innovation Clusters

To have impact on the timescales required by the Paris agreement there is an urgent need for widespread scale-up of clean energy innovations.

The opportunity for clusters is to create an environment in which clean energy businesses can take advantage of the technology presented by the SMA project and in particular the FIAB. To date much of the engagement with the project is with blue chip companies, typical drivers being remote deployment, integration of business and operational systems and with the potential for rapid deployment attracting particular interest from the defence sector. Whilst there has been significant engagement from innovative growth companies, they have been slower to commit to development than larger companies. The reasons for this vary but the inability to free up capacity to dedicate to such a development project is often cited, as are the demands of embarking on a complex project with a disparate supply base. To make the opportunity attractive for innovators, an environment in which it is easily accessible needs to be created. To succeed, a framework must be developed within innovation clusters to overcome three potential stumbling blocks: 1) innovators need to have access to knowledge and support for the development of FIABs, 2) the Industrial Suppliers need to be accessible and in a position to engage and support projects and 3) commercial mechanisms must be in place to provide technical support during production operation of FIABs and smart factories. The most obviously accessible solution appears to lie with the team which delivered the SMA project – MTC as the delivery partner, supported where necessary by the project academic partners. MTC is ideally placed to offer knowledge and support within innovation clusters, thus addressing the first of these three challenges and indeed this is entirely consistent with the project exploitation plans.

The second challenge of developing a supportive and accessible Industrial Supplier base, is equally important. Whilst it is possible to engage with each Industrial Supplier individually, this is not a practicable approach for small companies as there are too many disparate entities for effective communication and negotiation. To avoid being overburdened with the task, innovators need the opportunity to engage with the Industrial Supplier base as a collective. Based on relationships developed during the SMA project delivery, MTC is able to understand the constraints of each organisation and is well placed to negotiate a smart system collective offering agreement on behalf of the Industrial Suppliers. Once achieved, this will enable innovators to see the commercial proposition through the lens of the single agreement and to secure the whole system benefit.

The availability of a collective offering agreement will make the Industrial Supplier base accessible to the innovators but it may not be sufficient to ensure engagement by the Industrial Suppliers with innovators. As such, the agreement will go part way to addressing the second challenge but is not expected to be sufficient. The purpose of the FIAB demonstrator was to communicate what could be achieved by a smart factory; it did not dictate which features are necessary, or indeed sufficient. It is therefore unsurprising that as each innovator interprets the opportunity presented by the demonstrator for their own business, a range of different features will be considered applicable. Just as the lens of a collective offering agreement provides clarity of the Industrial Supplier base offering for the innovators, a similar approach is needed to simplify and render more attractive engagement by the Industrial Supplier community. As innovation accelerates within the innovation clusters, there will be groups of companies with similar visions for smart factories and broadly common requirements. Negotiation of a set of common requirements for a group of innovators would provide clarity and simplicity for the Industrial Supplier base in engaging with and delivering production solutions for, the innovation community. Multiple groups of innovators, each group having different attributes, would be expected to result in the need for several sets of common requirements. This clarity, by effectively bundling the innovators into groups, will significantly enhance the attractiveness to the Industrial Suppliers of developing smart factories for the innovation community.
A smart system architecture, expected to be a mild adaptation of the FIAB smart system model, must be developed for each set of common requirements. Whilst local variations from a particular set of common requirements could possibly accommodate the needs of an individual innovator, companies would most likely need to accept a resulting premium cost for an additional feature. MTC with its in-depth understanding of the smart factory architectures and technical possibilities is ideally placed to deliver this task. Further, with growth of uptake of smart factories it would be possible for new innovators to become associated with a pre-existing group, or for a new set of common requirements to be formed with an associated innovator group.

> MTC with its in-depth understanding of the smart factory architectures and technical possibilities is ideally placed to deliver this task.

The third and final point to be addressed in order to facilitate commercial FIAB development for clean energy innovators is the availability of technical support during service. Known as system integrators, there are many such companies ranging in size from micro to blue chip, which are capable of providing this service. As such a crucial aspect of a successful smart factory, it is recommended that MTC works with candidate companies to develop a set of preferred providers. Ideally they will have a robust understanding of the FIAB and the SMA opportunity and indeed those who were partners in the project are ideally placed. Such companies will undoubtedly on occasion work in partnership with MTC during the development stages of the smart factories for the innovation community. Indeed, with the MTC being focused on first applications of technology, it must be anticipated that the role of system integrators will migrate upstream within projects to increasingly support initiatives for the development of the FIABs. The framework that emerges from the implementation of arrangements to address the three concerns is depicted in the diagram.

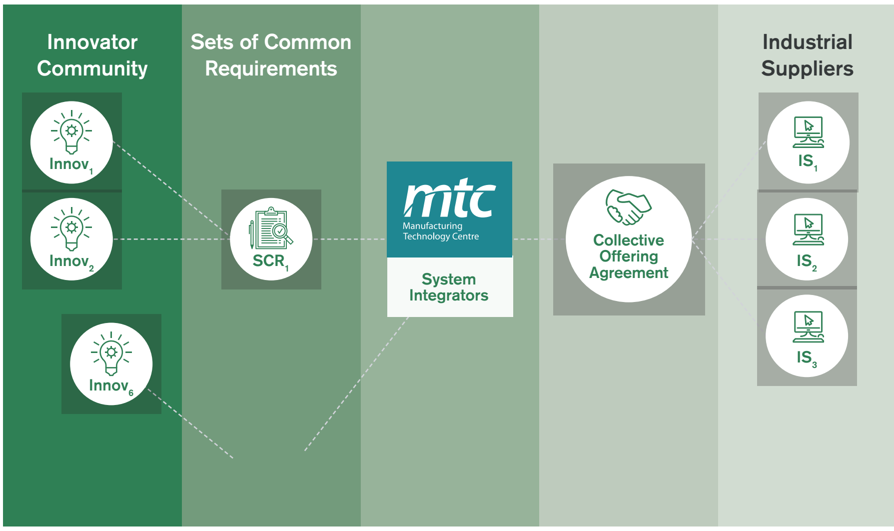


Diagram Showing Framework to Facilitate SMA Exploitation within Clusters

With its pivotal responsibility to ensure the successful animation of smart factory delivery projects for the clean energy innovation community, MTC will document refinements to the already devised methodologies. Promotion and facilitating sharing of the knowledge base amongst all stakeholders within each innovation cluster must be actively pursued in this role.

The sharing of knowledge, deployment of developed methods and refinement of process will greatly enhance innovation within clusters. However, in order to maximize the benefit, MTC must ensure that best practice is documented and maintained and indeed shared across all innovation clusters.

The proposed mechanisms, when implemented, will ensure that cluster based clean energy innovators have the opportunity to confidently scale-up manufacturing operations within a well defined and resourced framework.

5.0

Empowering Innovators: Mechanisms

Section 4.0, The Opportunity for Innovation Clusters describes mechanisms which make smart factory development readily accessible to innovators. The smart factory solution is ideal for scaling a business; factories can be located at multiple sites around the world to meet market needs, each being managed from the same Control Centre.

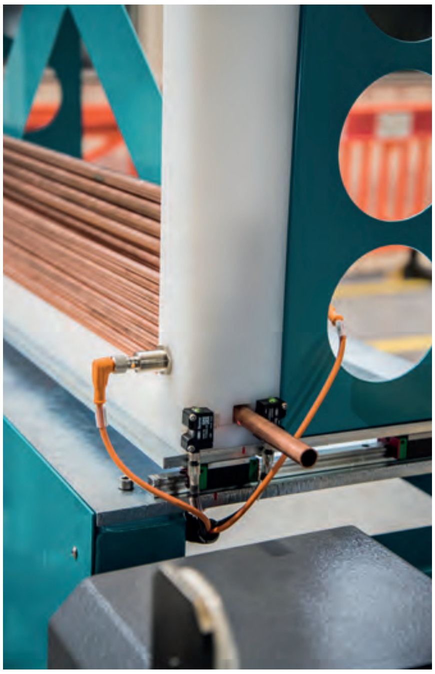
Local economic constraints and pressures can be sidestepped by choice of alternative locations. Further, rapid deployment is possible, with units being built, shipped to location and then undergoing rapid commissioning at the point of use. However, scale-up demands funding, which during the growth phase of an innovative company is likely to require external investment. But Forbes is clear, that the ability to scale is a critical part of a plan for investment, stating:

"Investors hear ideas on a daily basis. While many sound great, they may not be viable. Even a business plan is simply not enough to attract an investor. You must be a business with a model that is scalable, a product or service that has "legs"."

The solution to seeking the funding for growth and indeed acquiring the smart factory solutions on offer may to a large extent be provided by the underpinning of the proven FIAB technology with the framework approach described in section 4.0, The Opportunity for Innovation Clusters. From an investor perspective, the reduction in risk offered to growth companies operating in the innovation clusters with these mechanisms in place will significantly enhance appeal. Businesses will be empowered by the direct benefits of the mechanisms offered within the innovation clusters and the indirect benefits of the de-risked environments drawing in investors, allowing them to embrace growth without sacrificing attention to detail in the day to day running of the business.

In addition to geographic flexibility, the smart factory model offers the opportunity to deploy smart systems to develop wide-ranging and disparate supply chains. The solutions facilitate achievement of high levels of vertical integration operated by a single Control Centre, thus empowering innovators to increase their revenues.

In summary, embedding MTC knowledge and capability within clusters will accelerate the delivery of smart factories by providing excellent opportunities for clean energy innovators and investors, hence facilitating delivery on the urgent need to tackle the climate crisis.



6.0

Conclusion

The Paris agreement was a significant event marking global acceptance of the need to take urgent action to address climate change. There is much embedded energy infrastructure across Europe and beyond and the process of transformation is complex, requiring consensus to be achieved on broad thinking, cascading into layers of detail and culminating in regulation and mechanisms at both national and local levels.

The desired benefits can only be attained through delivery of clean energy solutions by innovators. With innovation being the preserve of private enterprise, the narrative changes from that of rule based implementation to one of creation of an environment of encouragement. However, innovation alone is not sufficient; the energy landscape will only be impacted if scale-up is achieved, demanding that supply chain challenges be overcome.

Whilst there has been much discussion about the potential of such technologies, the Energy Research Accelerator programme has delivered solutions which have the potential to catalyse the urgently needed change – delivery of a full scale working demonstrator has been rightly hailed as a world first.

The key deliverable of the working FIAB demonstrator is accompanied by creation of the SMA methodology articulating the concepts devised during the FIAB research and making them accessible for all types of smart factories. The FIAB concept is a highly automated production cell with embedded intelligence allowing it to be remotely managed through a menu driven app-based Control Centre. With a Digital Twin and Virtual Factory, the technology allows the operator to fully understand the current state of the cell and by exploring options, to evaluate and make optimal choices for future operations and maintenance.

The smart system architecture that underpins the technology was first proven for the manufacture of cryogenic pipes, but its versatility has been established with the delivery of a solution for producing phase change material. Adopters of the technology benefit from the possibility of rapid product introduction with the solution being portable and remotely configurable. This geographic flexibility offers companies the prospect of choosing locations which offer both economic and operational advantages. The ability to remove much of the human decision making within manufacturing units also facilitates vertical integration of the supply chain, enabling operators to extend their financial rewards.

The SMA project was delivered by the MTC in conjunction with University of Birmingham and whilst the team is actively exploiting the results, early traction has been with large companies. To support the innovation required, mechanisms must be put in place within clusters to ensure that benefits are reachable by micro, small and medium sized businesses. The challenges for such companies in developing innovative clean energy solutions are already significant and the adoption of novel manufacturing methods will require support and facilitation to overcome bandwidth constraints. It is proposed that the facilitation is provided in the form of a collective offering agreement between the Industrial Suppliers so that innovators see the proposition through a single lens. Equally, the risk-reward balance for the Industrial Suppliers interfacing with smaller companies is adverse relative to engaging with larger companies. This issue will be best addressed by providing the Industrial Suppliers the opportunity to engage with groups of innovators, through the generation of sets of common requirements that serve their collective needs. It is proposed that MTC, supported by its academic partners where necessary, provides knowledge to the innovation community, facilitates project engagement and negotiates the sets of common requirements and collective offering agreement.

Whilst micro, small and medium sized businesses will require assistance in accessing the SMA solutions on offer, of vital importance to them is implementation of a framework for technical support of the integral system during service. There are many reasons why a company may wish to choose a particular service provider but, being an essential ingredient for project success 'preferred' options must be provided within the innovation cluster environment. There are system integrators who were party to the project and whilst they are candidates for provision of such technical support, MTC is well placed to objectively evaluate options, make selections and negotiate terms.

'The Energy Research Accelerator has delivered a ground breaking supply chain solution that is already being adopted by large companies in the energy, power, transport and defence sectors.'

The high level of system integration and control within the FIAB architecture delivers many benefits. Although project budget and timing prevented optimisation of energy consumption being targeted, the system could be enhanced to provide this capability without radical change. Equally, the smart factory could be interfaced with other neighbouring operating units to create a localized energy ecosystem.

Whilst there are undoubtedly opportunities to extend the capability resulting from the research, the Energy Research Accelerator has delivered a ground breaking supply chain solution that is already being adopted by large companies in the energy, power, transport and defence sectors. With the implementation of some simple mechanisms the opportunity exists to catalyse adoption of this technology within innovation clusters and hence to radically accelerate introduction of a new generation of clean energy products.

7.0

Recommended Next Steps

Creation of an environment in which innovation clusters can capitalise on the developed FIAB and SMA business model and pursue directions that will enhance the benefits of the methodology still further in the future.

Engage with stakeholders, including innovators, investors and business groups, to exploit of the SMA methodology within innovation clusters:

- Hold a series of FIAB demonstrations with associated briefings to explain the opportunity created and how it can be exploited for the advantage of innovation clusters
- Take feedback from participants following the above briefings and create a structured action plan to address any concerns that arise and exploit opportunities identified

MTC, supported by its academic partners, to facilitate uptake of the developed SMA methodology within innovation clusters:

- Use relationships developed during the SMA project delivery to refine understanding of the constraints of each Industrial Supplier and negotiate with the companies a collective offering agreement
- Engage with innovators, partition into appropriate groups and negotiate a set of common requirements for each group so as to provide simplicity and clarity for the Industrial Suppliers
- Objectively evaluate and choose three 'preferred' system integrators to support integrated smart factory systems during service and negotiate headline terms
- Maintain a blueprint of best practice for use of the SMA methodology within an innovation ecosystem
- Lead a steering group to ensure that best practice is understood and adopted by all innovation clusters

In parallel with the deployment of SMA methodology within the innovation clusters, continue research to enhance the technology:

- Research, evaluate and establish optimal methods to further extend vertical integration between smart factories so as to facilitate return of enhanced value to innovators
- Develop a system to predict consumption of energy during service and to optimize for minimal usage
- During introduction of FIABs and smart factories within the innovation clusters explore opportunities to create local energy efficient ecosystems
- Evaluate recommendations made by stakeholders within the innovation clusters for enhancement to the SMA methodology and pursue research directions which are approved by MTC and its academic partners

References

1. Strengthening UK manufacturing supply chains: An action plan for government and industry.

   Technological advances are set to transform modern manufacturing as will increasing consumer demand for bespoke products. These changes have huge implications for supply chain businesses which will need to respond and adapt. Embracing use of robotics, integrated sensors and IT/Cloud Computing central to the 4th Industrial revolution, 1 will impact profoundly on manufacturing supply chain management and customer relationships, bringing greater collaboration and more integrated systems. Flexible processes such as additive manufacturing, advanced joining, and reconfigurable robotics will reduce the importance of economies of scale in some types of manufacturing and so support greater localisation of the supply chain and mass customisation of products. Manufacturers will favour suppliers that are resilient and adaptable to these changes.

   https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/407071/bis-15-6-strengthening-uk-manufacturing-supply-chains-action-plan.pdf

2. **Climate KIC**
   Keeping global temperature rise below 2˚C necessitates unprecedented change: new social dynamics, ways of doing business, capital flows, policymaking, economic models and new ways of living. No one organisation can solve climate change on its own.

   We catalyse the rapid innovation needed across sectors by convening the brightest minds to tackle challenges, empowering leaders through capacity building and seed funding the most promising climate-positive businesses.

   www.climate-kic.org

3. EC Reference to Paris Agreement

   https://ec.europa.eu/clima/policies/international/negotiations/paris_en

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