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BETWEEN LABORATORY AND FACTORY:
A British Model for Innovation in Manufacturing and Applied Technologies

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ABSTRACT
In late 2009, the University of Virginia Foundation consulted with Perkins+Will to help develop a program brief for a different kind of research facility: a hybrid of laboratory and factory that would offer a new model of collaboration between universities and industry that would be called the Commonwealth Center for Advanced Manufacturing, or CCAM. The CCAM initiative envisioned a non-profit institution, housed in a purpose-built facility, which would promote faster and more effective translation of laboratory discoveries into products and processes for commercialization.

One of these new collaborative models has been innovated in the United Kingdom. These centers, generally called "Technology Innovation Centres," each focus on a particular research "theme" that, though specialized, has relevance across a wide range of aerospace, power systems, electronics, and other technology-intensive industries. This study aims to provide an understanding of the "British Model" for university-industry collaborative research centers at several levels—development history and government policy; business and operations; and planning and design, in order to understand this important emerging building type. The objective of the article is also to provide applicable lessons that may empower U.S. universities and companies to collaborate under similar organizational principles as the British Technology Innovation Centres and its new American counterpart, CCAM.

KEYWORDS: collaboration, research and commercialization, building typology, manufacturing processes, hybrid facility

1.0 INTRODUCTION
The competitiveness of U.S. high technology manufacturing in the global marketplace has become an increasingly serious topic in current political and economic debate. Meanwhile, while still ranking number one in many measures, U.S. universities see declining trends in research grant funding, and are urgently searching for new models of collaboration with private industry.

We worked closely with CCAM's founding partners—the University of Virginia, Virginia Tech, and the Rolls-Royce Corporation--in programming and eventually designing the new facility for such collaboration. As the project developed, we were made aware of an important precedent to the CCAM concept – not in this country, but in the British city of Sheffield.

The Advanced Manufacturing Research Centre (AMRC) became operational in 2008, and pioneered the model of a membership-based research institution that bridges the gap between laboratory and factory. In the British model, universities and companies commit to becoming dues-paying members in an independent research consortium, equipped with purpose-built facilities to accommodate investigations jointly agreed by the membership. We also learned that the AMRC would soon be joined by several other "Technology Innovation Centres" (TIC's) to establish a network of similarly organized facilities, all pursuing complementary themes in materials science and engineering, product development, and manufacturing technology. CCAM will informally associate with these centers, as its primary research themes in surface engineering and manufacturing systems are intended to complement the research efforts of its British cousins. The aim of these centers is to accelerate the transition of laboratory discoveries into manufacturing techniques and processes in an environment that has attributes of both laboratory and factory.

In helping the Technology Innovation Centres achieve this goal, a common planning and design approach has evolved, which draws from a shared programmatic kit of parts and a consistent strategy for assembling these elements into a coherent architectural statement. In short, we are seeing the emergence of an important new building type.

In order to gain a deeper understanding of the British TIC's, key Technology Innovation Centres were visited in February 2012 in order to conduct an observational study. The study consisted of touring the facilities and conducting interviews with the senior administrative staff as well as with the architects who designed them (see Figure 1). Preceding the visits, a detailed questionnaire was submitted to each of the centres, which set the agenda of the interviews and facilitated the discussions.

Figure 1: Location map of British TIC's that were part of this study.

From these interviews, this study aimed to answer the following:

- Where is the gap between research and commercialization, and how did certain key universities, private companies, and public agencies come together to bridge this gap with the Technology Innovation Centres?
- How are the organizations of the centres structured, and how do they conduct the business of research?
- What are the planning and design commonalities—and differences—between the centres as well as CCAM? Is this an emerging building type that begins to set a standard for such buildings around the world?
- What is the U.K.'s policy moving forward in supporting these centres, and enlarging the network and the types of technologies that they address? How does this policy compare to that in the United States?

2.0 THE TECHNOLOGY INNOVATION CENTRES: A BRIEF HISTORY

In the world of high-tech industry, somewhere between basic discoveries in the laboratory and full-scale production of profitable and reliable products, lays a graveyard of promising ideas that lacked the right resources for successful translation into commercial reality. Meanwhile, production difficulties plague the manufacturing of high-tech products because problems were not solved at a smaller scale before massive investments in the equipment and processes of commercial-scale production.

The metrics of how basic research evolves into commercializable reality has long been identified, and has developed into such sophisticated rubrics as the Manufacturing Readiness Level (MRL) scale, the Technology Readiness Level (TRL) scale, and its variants. These frameworks describe the attributes of each step along the way as processes are defined, refined, and scaled up to production levels (see Figure 2).

MRL 4-6 is the zone of development that institutions such as the British Technology Innovation Centres, and its American counterpart at CCAM, are targeting. They aim to achieve this goal by creating purpose-built facilities where universities and private sector companies can collaborate on shared problems of translating laboratory discoveries into technological innovation.

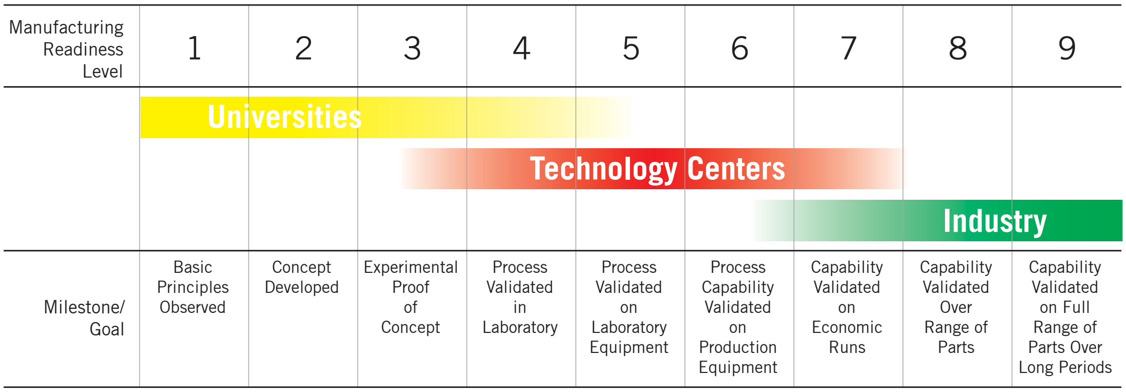


Figure 2: Manufacturing Readiness Scale.

2.1 Advanced Manufacturing Research Centre (AMRC)

At the beginning of this century, on a reclaimed brownfield near the city of Sheffield, England, a novel experiment began in how universities and industries could collaborate in manufacturing research. The Boeing Corporation sought new breakthroughs in machining technology; the University of Sheffield was particularly renowned in research in machining and metallurgy, owing to centuries of expertise that made the Sheffield region famous for metalworking. Boeing and the University partnered in the traditional way in the 1990's, with Boeing directly funding research projects, but, set out in an ambitious new direction in 2001. Working at a larger political scale, and gaining funding and support from regional development agencies (Yorkshire Forward) as well as the European Union (European Regional Development Fund), the founding partners created the Advanced Manufacturing Research Centre (AMRC), a new institution that would be housed in a purpose-built facility where multiple industrial companies and the university could collaborate on projects within the general theme of machining technology.

The organizational breakthrough was the membership model: participants would be members of a research "club", paying annual dues that would cover the operational costs of the centre. All research conducted at the centre would fall into one of two categories: "generic" (projects of common interest amongst the various members, funded by the membership dues) or "directed" (projects of particular interest to a particular member or subset of members, funded by the participants). Another key aspect of the model would be the disposition of intellectual property (IP): all members would share in the IP resulting from generic research, while the results of directed research would become the IP of the particular sponsors. This approach to intellectual property within a collaborative environment ensures continued interest in shared research and also incentivizes investments in directed research; indeed, it is the fundamental key to the financial success of the centre.

The AMRC completed its initial 1200 m^2 (13,000 SF) facility in 2004, on the reclaimed site of a former coking works just outside of Sheffield. Very quickly, the increasing roster of members and projects began to outgrow this modest first building. About that time, Rolls Royce, as a member of AMRC, championed the development of a much larger facility, dubbed the "Factory of the Future", that would more capably support the potential of the AMRC model. Understanding the level of ambition for this project, the members carefully set the vision and goals for the facility, an effort that included a charrette facilitated by the Rocky Mountain Institute. The programming effort pointed towards a building almost four times the size of the original, at 4,500 m^2 (48,500 SF).

The functional realities of collaborative research in machining technology demanded a very large high bay space; the relatively small available site area suggested that any program areas that did not need to be on slab-on-grade—that is to say, virtually everything besides the high bay, certain specialty laboratories, and the entrance lobby—needed to be elevated. The solution was “the office over the workshop”—all the office and meeting areas are on top of the high bay, resulting in the equivalent of a three story building. Acknowledging the functional demands, and honoring the idea of “factory” as a theme for the project, Bond Bryan Architects embraced a simple, rectangular box as the outward form of the building, but developed it with great sophistication in its detailing.

The founders desired a workplace culture that would reflect and support the collaborative mission of the centre; the design supports this goal by an open and airy office floor with a flexible workstation environment interspersed with glass-walled team meeting rooms (there are very few private offices). At the same level, on the other side of the high bay, is a conference area with meeting rooms of various sizes as well as the main employee canteen. Connecting the office and the meeting areas are bridges that cross over the high bay, which, together with generously large windows from offices and meeting rooms that look down into the space, visually link the activities on the office level (computational research, analysis, administration, meeting) with the “factory floor”, where research is applied in actual processes with real factory equipment.

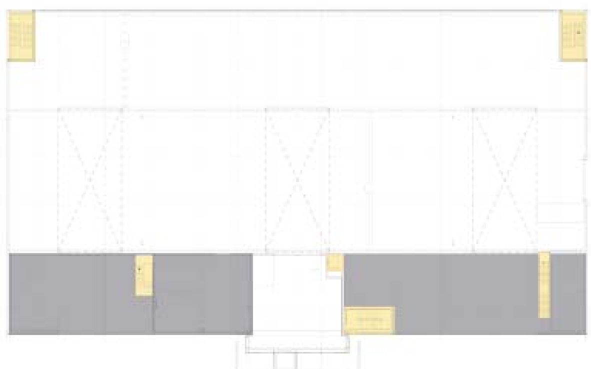
The theme that links the functional and cultural goals of the project is sustainability, which was a very high priority from the inception of the project. Features include ground source heat pumps, and effective daylighting strategies (Buro Happold confirmed 98% of the floor area is naturally lit), natural ventilation in most areas, and solar shading. Most iconic is an 86 meter wind turbine, which offsets approximately one third of the building’s annual electricity usage. The building was awarded the highest Building Research Establishment Environmental Assessment Method (BREEAM) rating, “Excellent”.

Opened in 2008, the AMRC “Factory of the Future” is a showcase building in at least three ways – as a venue for putting the latest technologies in machining processes on display for the large number of visitors who tour the building every year, as an architectural expression of “industrial elegance” that pays homage both to its factory roots as well as to the progressive goals its mission, and, finally, as a demonstration that industrial progress and sustainability are not necessarily contradictory goals.

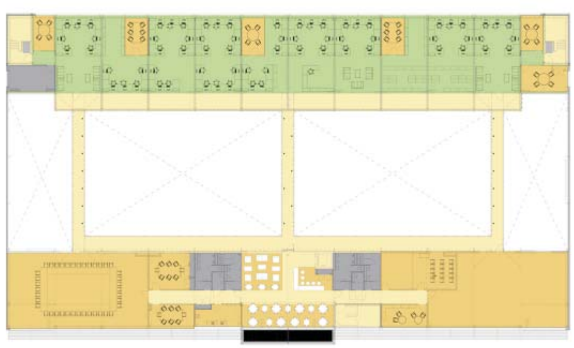
Figure 3: AMRC "Factory of the Future."

Figure 4: AMRC high bay.

AMRC ground floor plan



AMRC mezzanine floor plan



AMRC first floor plan

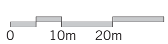


Figure 5: AMRC floor plans.

2.2 Advanced Forming Research Centre (AFRC)

Recognizing the success of AMRC, other partnerships of regional development agencies, universities, and high-technology companies (many of whom were already members of AMRC) began initiating projects modeled after this new building type. The first of these was the Advanced Forming Research Centre in Glasgow, Scotland. The synergy here was the strength of the University of Strathclyde in metallurgy and manufacturing technology (a talent that draws from Glasgow's historic leadership in shipbuilding and other heavy industries), and the innovations sought after by Rolls-Royce, Boeing, Mettis, and other companies having an interest in forging and forming of precision components for critical applications in diverse fields such as aerospace, marine propulsion, and oil exploration.

Like AMRC, the third leg of the stool was participation by a regional development agency, in this case, Scottish Enterprise. With their commitment of public funds for the construction and the initial equipment, the AFRC project could move forward, beginning with the development of the functional program in 2008 (about the time the AMRC Factory of the Future was coming online).

Although the research theme was different, the functional considerations for the AFRC were broadly similar to those at Sheffield: a high bay where very large tools and equipment could be moved with relative ease; laboratories that could support sensitive specialty activities such as surface characterization and metrology; and an open, flexible office environment. However, program and budget pointed to a building only approximately half the size of its sister facility in Sheffield, on a larger site—thus, a single-story solution made the most sense. Hypostyle Architects, of Glasgow, gave the building a memorable form by bifurcating the building with a central "street" feature that functions as entrance lobby and break-out space from adjacent meeting rooms, and (using some specifically aeronautic imagery for inspiration and deliberately avoiding the appearance of a box) endowed the office and high bay zones with expressed shed roofs that are as striking on the exterior as they are on the interior.

Sustainable features included enhanced air tightness and insulation in the exterior envelope, maximization of natural light and natural ventilation, and sophisticated energy control systems. The project achieved a BREEAM "Very Good" rating. The AFRC opened its doors in the summer of 2010.

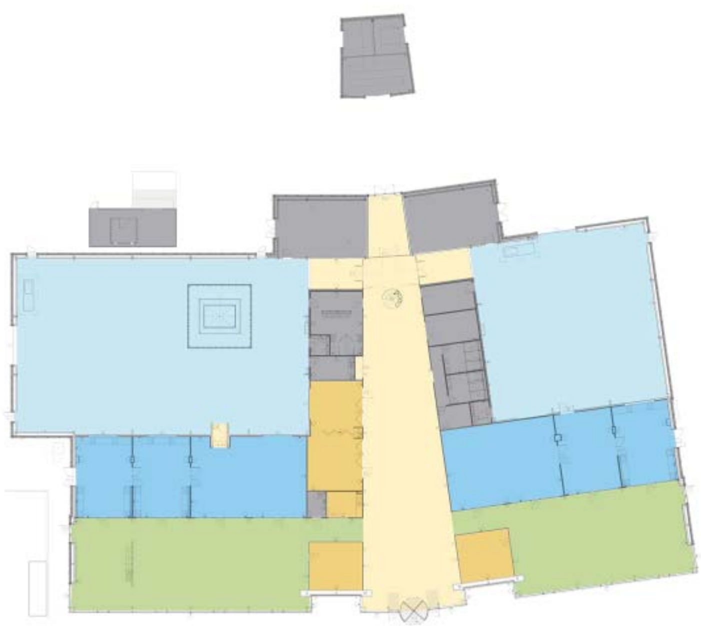


Figure 6: AFRC ground floor plan.

Figure 7: AFRC exterior (Photograph courtesy of Hypostyle Architects).

Figure 8: AFRC office & break Area (Photograph courtesy of Hypostyle Architects).

2.3 Manufacturing Technology Centre (MTC)

While the AFRC project was just getting underway in Scotland, two other partnerships in England formed to develop institutions that would explore other distinct themes in materials engineering and manufacturing innovation. In Coventry, three regional universities, together with Airbus, Rolls-Royce, and the East Midlands Development Agency, founded the Manufacturing Technology Centre (MTC), whose main mission would be to explore advancements in assembly and joining technologies. At 12,000 m^2 (129,000 SF), it is by far the largest of any of the centers that are the subject of this study. The expansive floor area was in part driven by the requirement for three very large high bay spaces, each capable of accommodating complete production-scale assembly cells (indeed, one of the high bays was

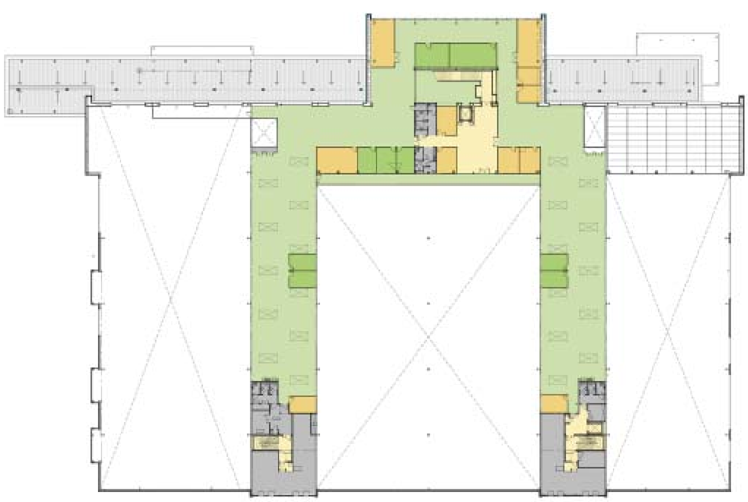
Figure 9: MTC public exterior.

Figure 10: MTC lobby concourse.

required to be able to accommodate the wing of an Airbus A-380 super-jumbo airliner). Broadly similar to the AMRC in the arrangement of the major functional pieces, the MTC was also programmed with an exceptionally spacious and architecturally memorable "public" space, a 3-story high concourse that connects most of the major program elements including the employee café and large meeting rooms. The investment in this amenity reflected a realization, based on the experience of the AMRC, that these centers will host large meetings and see a surprising amount of visitors—everyone from elementary school field trip students to political leaders—and that significant break-out space is a critical necessity.

Although lacking something as conspicuously iconic as AMRC's wind turbines, the Manufacturing Technology Centre achieved a BREEAM Very Good rating. The MTC began research operations in the summer of 2011.

MTC ground floor plan



MTC first floor plan

Figure 11: MTC floor plans.

2.4 National Composite Centre (NCC)

Meanwhile, the University of Bristol, with its noted reputation in composites research, teamed with the Southwest Regional Development Agency and with additional funding from the European Union, launched the National Composites Centre (NCC). For this project, the critical founding industrial member was Airbus, who was outgrowing its existing composites research facility nearby and was anxious for additional research capacity as efforts for its first all-composites airliner, the A-350 XWB, were ramping up.

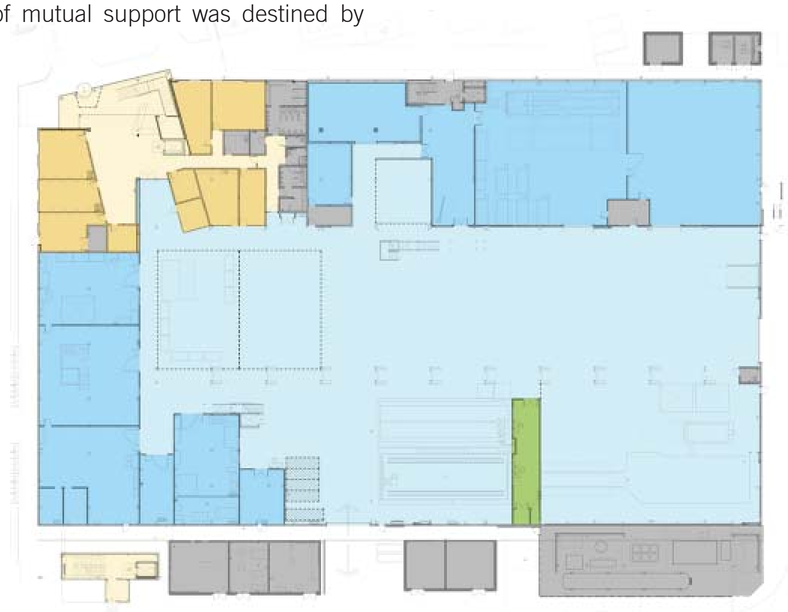
At 8,500 m^2 (91,000 SF), the NCC is physically organized along similar lines as its cousins in Sheffield and Coventry, but with a somewhat larger proportion of the program given over to closed-wall dedicated special-purpose rooms having unique requirements for cleanliness and controllability of environmental conditions, appropriate to the nature of composites production and assembly.

Consistent with the precedent set by the AMRC, the National Composites Centre achieved a BREEAM Excellent rating. Notable sustainable design features include an aggressive daylighting scheme in the high bay, photovoltaic arrays, and rainwater harvesting. Like the MTC, the NCC began research operations in the summer of 2011.

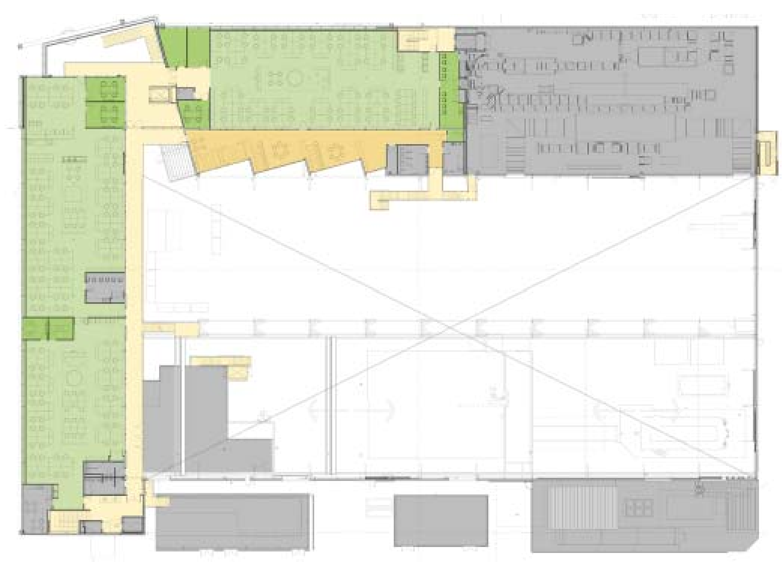
Figure 12: NCC main entrance.

Figure 13: NCC high bay.

Far from being isolated institutions, the AMRC and the four other U.K. research centers that followed in its path quickly evolved into an informal association regularly taking counsel with each other on recruitment of new members what projects would be pursued at the respective centres, and other topics of joint interest. This atmosphere of mutual support was destined by two important facts: first, several key companies (most notably Rolls-Royce) are members of many or all of the centers, and second, at the behest of these members, the research themes of each centre were chosen to be complementary with, rather than duplicative of, the themes of the others.



NCC ground floor plan



NCC first floor plan

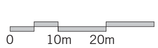


Figure 14: NCC floor plans.

2.5 Commonwealth Center for Advanced Manufacturing (CCAM)

Certain key industrial members of the TIC's in the UK recognized, given the nature of their global supply chains, the importance of expanding the TIC model to other countries including the United States. Building on particular strengths of the affiliated universities, University of Virginia and Virginia Tech, the new center in the U.S. would have a theme that none of the U.K. centers had yet emphasized: surface engineering, a specialty in materials science that pertains to coatings and other surface manipulations of materials that alter their fundamental properties. This center, called the Commonwealth Center for Advanced Manufacturing (CCAM), is located near Petersburg, Virginia, not far from the recently completed Rolls Royce North American Rotatives Factory, which manufactures jet engine disks.

CCAM had its first programming effort in the fall of 2009; the project was completed in October of 2012. This 62,000 SF facility has a similar mix of basic program components as has been described for the AMRC and its cousins; but, in organizational strategy, more closely resembles the AFRC (the diagrams in the latter part of this study illustrate the relationship). Drawing on reported lessons from the operational life of the AMRC, a deliberate visitor pathway ("parade route") is hard-wired into the planning of the building. Like the NCC, the design offers plenty of closed-wall laboratory spaces to accommodate processes that will need unique environmental conditions, a consequence of the surface engineering research theme. Like the MTC, a generously sized lobby that offers independent access to a dedicated conference area anticipates the center as a busy venue for meetings, seminars, and presentations.

Figure 19 illustrates the commonalities and differences among the five centres observed as part of this study. Notable factors include private or university ownership of the centre; 100 percent funding of construction cost from the government for examples in the U.K.; complementary (not duplicative) research themes; and a mostly 1:1 ratio of general to directed research.

Figure 15: CCAM west exterior (Photograph by Alan Karchmer).

Figure 16: CCAM high bay (Photograph by Alan Karchmer).

Figure 17: CCAM east exterior (Photograph by Alan Karchmer).

CCAM first floor plan

CCAM second floor plan

0 10m 20m

Figure 18: CCAM floor plans.

	AMRC	AFRC	MTC	NCC	CCAM
Location	Sheffield, England, U.K.	Glasgow, Scotland, U.K.	Coventry, England, U.K.	Bristol, England, U.K.	Petersburg, Virginia, U.S.A.
Building Owner	University of Sheffield	Strathclyde University	Manufacturing Technology Centre, Ltd.	University of Bristol	University of Virginia Foundation
Construction Cost (£)	£6.5m (2008)	£6.3m (2010)	£23m (2010)	£11m (2011)	£8.1m (2012)
Construction Cost (2012 adjusted)	£5.8m	£6.2m	£22.8m	£11.3m	£8.1m
Construction Cost (2012, in U.S. $, ($1.60/£)	$9.3m	$9.9m	$36.5m	$18.1m	$13m
Building Gross Area (m^2)	4,500 m^2	2,600 m2	12,000 m^2	8,500 m^2	5,700 m^2
Building Gross Area (gsf)	48,500 gsf	28,000 gsf	129,000 gsf	91,000 gsf	62,000 gsf
Construction Cost / sf	$192	$353	$282	$198	$210
Public Funding of Construction Cost	100% (Yorkshire Forward RDA, European Union)	100% (Scottish Enterprise)	100% (East Midlands Development Agency, Advantage West Midlands)	100% (Southwest RDA, European Union)	28% (U.S. Economic Development Agency)
University Members	University of Sheffield	University of Stratchclyde	University of Birmingham, University of Nottingham, Loughborough University	University of Bristol	University of Virginia, Virginia Tech, Virginia State University
Research Themes	• Machining & Milling • Composites	• Forming • Forging • Tool design	• High integrity fabrication • Net shape • Intelligent automation • Tooling • Manufacturing simulation & informatics	• Composites manufacturing • Preform technologies	• Surface engineering & coatings • Manufacturing systems
Ratio of Generic to Directed Research	1:4	1:1	1:1	1:1	1:1

NOTE: Adjusted construction cost based on Faithful & Gould construction Inflation Reports of March 2010, April 2011, and October 2011, reflecting annual construction cost deflation/inflation of -10% in 2009, -3% in 2010, and +2% in 2011.

Figure 19: Technology Innovation Centres – comparison at a glance.

3.0 THE TECHNOLOGY INNOVATION CENTRES AS A BUSINESS PROPOSITION

The TIC's, along with their American cousin CCAM, share the same basic organizational scheme that was established at AMRC in Sheffield. In summary, private sector companies are dues-paying members of a non-for-profit research organization; this organization is affiliated with one or more research universities; and, most critically, the member companies share in ownership of the intellectual property that results from generic research projects.

All of the centers have at least two tiers of membership. Members at the top level typically pay between £200,000 and £300,000 in annual dues ($320,000 - $475,000). These members are typically large, well-established Original Equipment Manufacturers (OEMs) with a wide range of technological interests. Their membership includes a seat on the board of directors, which, besides having oversight on the operations of the center, also determines which projects will be pursued as generic research. These Tier I members share in the ownership of the intellectual property (IP) stemming from the generic research.

Second (and in some cases, third) tier memberships are generally aimed at smaller companies, or companies whose interests are focused on a single area of technology. Benefits for the lower tier members are correspondingly more limited; for example, they may not share in the IP of generic research outside of their particular project involvement.

Members typically must commit to a minimum time duration for their membership, for example five years for Tier I, three years for Tier II, etc. In some cases, a member may provide in-kind donations, such as major equipment, to satisfy its dues to the center in whole or in part.

Major OEM's such as Boeing, Airbus, and Rolls-Royce were major players in the establishment of the centers; however, beyond the founding members, a center's financial success relies on having a critical mass of Tier I members. Thus, recruitment is a critical activity, particularly in the first few years of a center's existence. While many members consist of companies with an aerospace focus, the research themes tend to cut across all industries that rely on innovations in materials science and engineering and their related manufacturing technologies. Thus, the membership profiles of the centers can be rather ecumenical: besides aerospace, members are coming from fields as diverse as electronics, imaging, medical equipment, robotics, industrial tooling, and power generation, to name a few.

The founding of all of the Technology Innovation Centers had roots in existing relationships between certain major OEMs and particular universities. For example, Boeing's collaboration with the University of Sheffield, building upon that university's noted accomplishments in machining technology, paved the way for the establishment of the AMRC. In some cases, the relationship can be with multiple universities – for example, with its multi-themed research agenda, the MTC involves a consortium of universities in the East Midlands region, each bringing different talents to the centre including the University of Birmingham (net shape manufacturing), the University of Nottingham (advanced tooling), and Loughborough University (electronics manufacturing).

The structural relationship between the universities and the centers is variable. In some cases, the Centre is a wholly owned subsidiary of its affiliated university (as is the case with the AMRC and the University of Sheffield). The MTC, on the other hand, is an independent non-profit corporation (in the U.K., a "Company Limited by Guarantee", roughly equivalent to a 501(c) organization in the United States).

AMRC established the concept that collaborative and proprietary research could co-exist in the same institution. In fact, the business model depends on the additional revenue that proprietary research brings, in addition to the annual dues paid by the members. As mentioned previously, "generic" research are those projects jointly agreed by the top-tier members to be of interest to all; the cost of this research is part of the operating expenses of the center; and the intellectual property accrues to all the top-tier members.

"Directed" research are those projects commissioned by an individual member, or group of members, who pay additional fees for the research and enjoy exclusive rights to the I.P. Similarly, an entity completely outside the membership of a center may commission research, and pay fees to the center for this effort.

Directed and commissioned research are a substantial revenue stream for all the centers, and can comprise anywhere from 50 percent to 80 percent of the research volume at the centers.

The presence of proprietary research poses a dilemma in buildings that are otherwise intended to be hotbeds of collaboration, with physical transparency as an architectural goal across all the centers. However, the centers seem to have had few challenges in being able to create necessary security – physical and or visual – in certain areas where particularly sensitive work is in progress. Occasionally, a "room-within-a-room" may be constructed to provide the necessary barrier. More challenging, in some cases, has been the setting up of the information technology infrastructure in the buildings to allow secure data to be handled and stored within what is otherwise a collaborative network.

4.0 AN EMERGING BUILDING TYPE: LABORATORY AND SHOP FLOOR UNDER ONE ROOF

Although these five technology Innovation Centres were designed by separate architectural firms, with limited awareness of each other while the program briefs and designs were being developed, it is remarkable how a comparison of the centers reveals many more similarities than differences. Partially, this is a result of the example set by the AMRC. It is also a result of all firms embracing the functional logic of the building as a giver of form, and of having separately arrived at a common set of goals.

The high bay (or bays) are the most critical program element, needing at once to be both like a true factory floor, but also not setting up obstacles for change. Once set up, a factory floor may remain unchanged for many years; in a research environment such as at these centers, large equipment gets moved in, moved around, and moved out with much higher frequency. Thus, the high bays generally feature large undifferentiated floor space with at least 8m overhead clearance, large access doors from the exterior, generous daylighting, a modular approach to delivering utilities, and (in most cases) a very strong floor slab capable of supporting extremely heavy equipment. Most of the high bay spaces in these centers are equipped with traveling bridge cranes.

Laboratory spaces supplement the high bays, providing enclosed environments for specialty and sensitive work that requires acoustic separation from the generally noisier high bay, or that have unique environmental requirements. Mechanical systems serving high bays generally recycle some proportion of the high bay air, and these spaces can have a relatively large range of temperature and humidity. Sensitive instrumentation and activities such as metrology (precision measuring), surface characterization (involving very sensitive tools such as scanning electron microscopes), metallurgy, chemistry, and many other specialty activities usually require air systems meeting laboratory criteria in terms of temperature and humidity range, air change rate, and ability to handle heat loads. In these spaces, all air once exhausted from the lab is not recycled.

Office areas are open plan; private offices are very rare. A variety of teaming and meeting spaces are distributed in the office areas to provide venues for collaborative project work. In all cases, open workstation areas are positioned to allow views into the high bay area, or the labs, or both.

In the U.K., conditioned air and power and data cabling are provided by a raised flooring system, thus allowing higher ceiling heights and advantages in energy efficiency.

In most of the centers, some of the large meeting rooms are separated from the office areas and are more directly connected to the building lobby. Together with the lobby, which serves as break-out space, these meeting rooms create a miniature conference venue for lectures, seminars, and symposia that have become commonplace in the centers.

All of the centers recognized that despite the very practical and functional imperatives of these buildings, the image of the building and the visitor's experience would be critical for successfully conveying the mission of the centers to the broader public. This was recognized at the AMRC, but even they did not anticipate the volume of visitor traffic that would eventually be flowing through their facility. The designers of the subsequent centers took this lesson to heart, carving out more generous lobby spaces and sometimes incorporating "parade routes", i.e., designated walking routes that choreograph the experience of typical visitors who are escorted through the building.

In every case, the founding partners of the various centers requested their designers to develop an "iconographic" image of the building, recognizing the importance of these new institutions in their literal as well as political landscapes. The designers, including Perkins+Will at CCAM, found an architectural voice that while unique to each center, were all within a certain bandwidth of formal simplicity and what one might call "industrial elegance".

Finally, as mentioned in the individual descriptions of the centers in previous sections, all of these projects recognized the resonance between sustainability and fundamental goals of the research that the centers are meant to support: striving for manufacturing techniques and processes that are more efficient, less energy intensive, and less wasteful of materials. To that end, all of the projects employed an array of energy efficiency strategies, some of which were imaginatively leveraged into becoming a part of the building image (for example, the wind turbine at AMRC, or the serrated profile of the clerestory windows at the NCC). All of the U.K. projects achieved either of the top two ratings available under the BREEAM system.

Together, as the following diagrams and floor plan comparisons show, the Technology Innovation Centres have invented what is essentially a new building type, not quite resembling a typical engineering lab at a University, nor a factory either, something that, quite appropriate to the research it supports, is somewhere between the two.

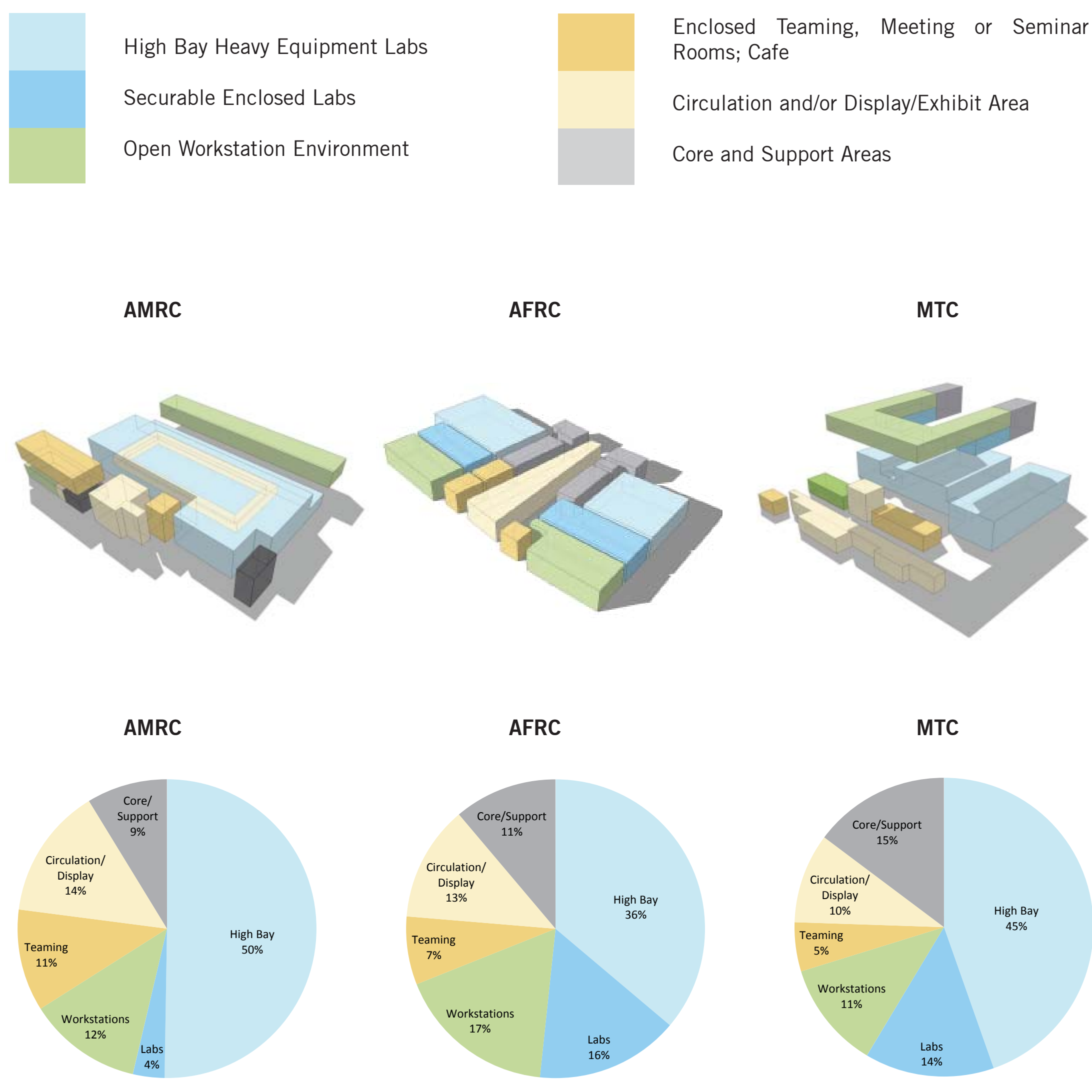


Figure 20: Massing and location of program areas in proportion to other centres.

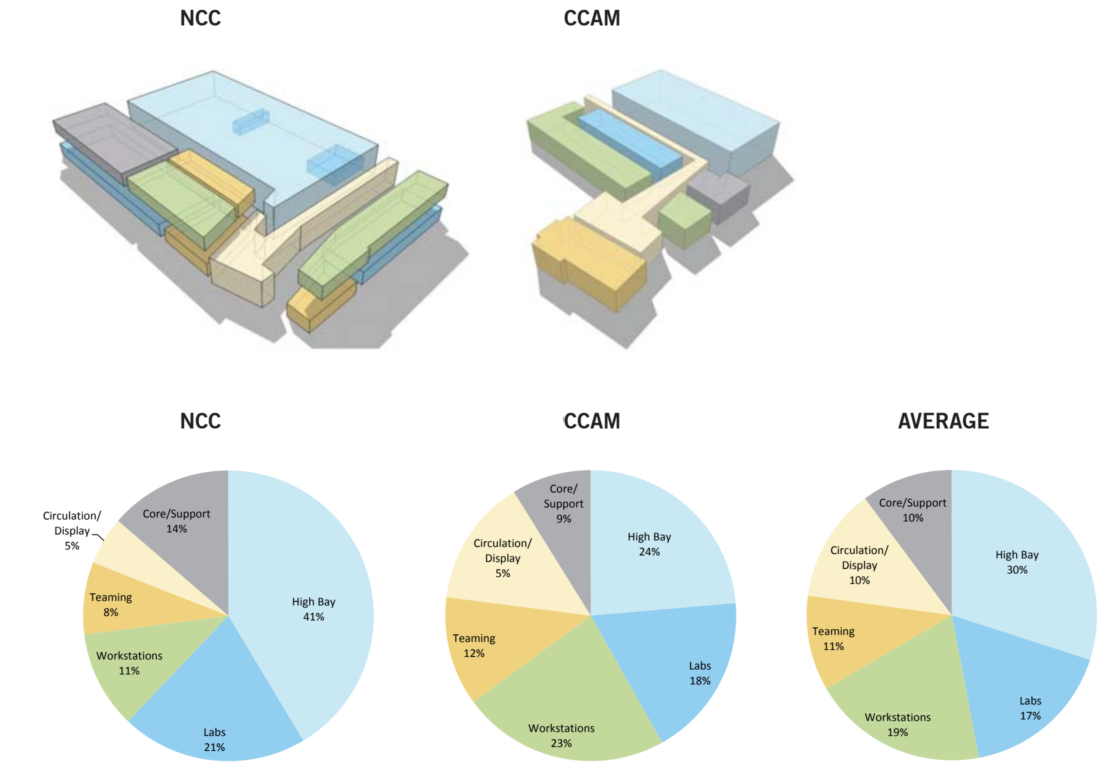


Figure 21: Massing and location of program areas in proportion to other centres.

5.0 U.K. GOVERNMENT POLICY AND INDUSTRIAL REVOLUTION: THE CATAPULT CONCEPT, AND IMPLICATIONS FOR THE UNITED STATES

5.1 The Rise, Fall, and Recovery of Manufacturing in the U.K.

Recent years have seen a decline of the UK's share of manufacturing in the world economy, as summarized in the following points extracted from the House of Commons Library report International Comparisons of Manufacturing Output (updated January 2014)[1]. As of 2011 the UK ranked:

- 7th in terms of manufacturing output ($233 billion),
- 26th in terms of manufacturing output per head ($3,700),
- 108th in terms of manufacturing output as a share of national economic output (11 percent).

While statistical evidence was piling up that the U.K.'s competitive world advantage in manufacturing was beginning to erode, particularly in the high-value, high-technology industries that had been its traditional strength, there was attendant concern that shifting the economy more towards financial and service industries would not realistically solve long-term unemployment problems. As Lord Mandelson, Business, Innovation and Skills Secretary in the Labour governments of Tony Blair and Gordon Brown, remarked in late 2009, the UK needed "less financial engineering and more real engineering", recognizing that broad-based prosperity could not be achieved without a healthy, growing manufacturing sector.

5.2 Diagnosing the Problem: The Hauser and Dyson Reports

Earlier in 2009, Lord Mandelson had commissioned a report to identify what the U.K. could be doing better to compete more effectively in high-value manufacturing. Dr. Hermann Hauser, a noted entrepreneur and venture capitalist in Britain, was asked to lead the effort; the resulting report, The Current and Future Role of Technology and Innovation Centres in the UK, focused on research and development as the key area needing improvement[2]. Dr. Hauser succinctly framed the global competitiveness situation:

> *". . . it has become clear that the leisurely translation of scientific discoveries into new industries has been replaced by a race between nations to take advantage of these discoveries and translate them into economic success stories before others do so."*

The Hauser Report identifies current UK policies regarding public support of scientific and technological innovation and commercialization including a variety of national and regional boards and agencies, but concentrates on a specific aspect of these policies, the Technology Innovation Centres (TICs). At that time, TICs such as the AMRC existed in several technological arenas with various measures of government support and guidance. The Hauser Report recognized the importance of the existing TICs in promoting the activities that characterize the financially risky middle ground of the Manufacturing Readiness scale: providing a setting for companies to share the cost and risk of applied research and process scale-up, co-locating access to equipment and skills that might otherwise be beyond the reach of individual universities or companies, and matching technologies to markets.

The Hauser Report goes on to compare the British Technology Innovation Centres with peer institutions in a dozen other countries, such as the Industrial Technology Research Institute (Taiwan), the Carnot Institutes (France), and the National Institute for Advanced Industrial Science and Technology (Japan).

The most cited point of reference, however, both in the Hauser Report as well as elsewhere, is the network of TICs in Germany known as the Fraunhofer Institutes, consisting of more than 80 research units operating in 60 institutes across a broad range of topics in science, engineering, and medicine. Founded in 1949, the Fraunhofer Institutes are by far the most developed network of TICs in any country, and are often credited with a key role in the success of the German economy and its extraordinary share of high-value manufacturing in the world economy. In the Hauser survey of TICs around the world, it is noted that the Fraunhofer system is in the median range in terms of direct government funding of operations, at about 30 percent, with the remainder of their budget coming from government-funded research grants, usually won on a competitive basis, and from privately commissioned research projects.

In contrast, the UK TICs were generally expected to be financially self-supporting, without any direct contribution of public funds to operations, within a few years of their founding. The Hauser Report saw this as unrealistic expectation that promoted short-term thinking in setting the research direction of the centers. The Report also noted that, to the extent the UK had been investing in its TICs, it did not have "clear prioritization, long term strategic vision, or coordination at a national level." The Report concluded with a series of recommendations, such as better networking of existing and future TICs, criteria for establishment of new centers, and, most importantly, establishment of a consistent funding program that could help ameliorate financial uncertainty and promote long-term, strategic planning amongst the centers.

Almost simultaneous with the Hauser Report was a report commissioned by the conservative party from Sir James Dyson, noted industrial designer and inventor of, amongst other things, the eponymous cyclonic-separation vacuum cleaner. Dyson's report, Ingenious Britain: Making the UK the Leading High-Tech Exporter in Europe, took a more sweeping look at the challenge of effective technological innovation, including cultural and educational factors[3]. The Dyson report, citing the AMRC as a positive example, reached a similar conclusion as Hauser in recognizing the importance of the Technology Innovation Centres and recommending a firmer policy and funding structure to support them.

5.3 The Catapult Program

In 2010, the conservative government under David Cameron acted upon the recommendations of the Hauser and Dyson reports, and established a national program to guide and support the development of TICs in the U.K. Favoring the brand name of "Catapult Centres", the program largely follows the roadmap put forth in the Hauser Report. The stated mission of the Catapult Program is to develop "centres of excellence that bridge the gap between business, academia, research and government."

Administered by the U.K.'s Technology Strategy Board, the Catapult program encompasses the existing TICs discussed in this report – AMRC, AFRC, MTC, and NCC – under the title "High Value Manufacturing Catapult", with an annual funding contribution of approximately £4m annually to each center. It also is launching "catapults" in other topic areas including cell therapy, offshore renewable energy, satellite applications, connected digital economy, future cities, and transport systems.

5.4 The Future of Technology Innovation Centres in the United States: the National Network for Manufacturing Innovation

Meanwhile, recent developments in the political and policy arenas here in the United States reflect an increasing awareness of the importance of high-value-added manufacturing in a vibrant, growing economy. For decades, as in the U.K., conventional wisdom had rationalized the decline of manufacturing in the United States with the concept that the economy's shift of emphasis to services would be a higher and better use of the talent of the citizenry, and assure the preeminence of the U.S. economy on the world stage. A corollary to this reasoning was the belief that while low-tech and commodity manufacturing might be moving to foreign countries, the U.S. would always maintain dominance in the production of high-tech, high-value-added goods. However, the experience of the first decade of this century tells a different story: the U.S. share of high-technology exports declined from around 20 percent of the world total in the late 1990s to about 11 percent in 2008, as illustrated in Figure 22.

Trade balance in high-technology goods for selected regions/countries: 1995-2008

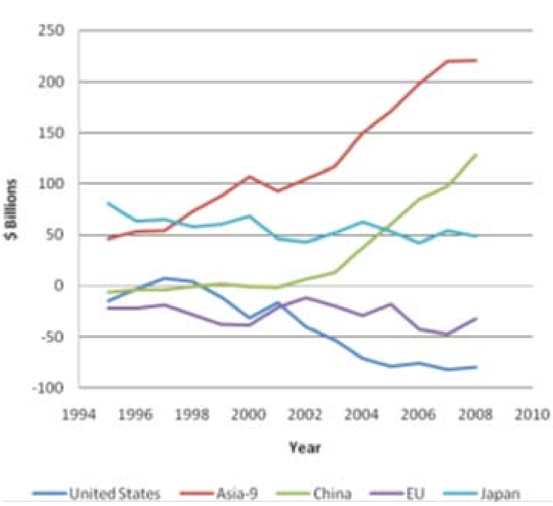


Figure 22: Trade balance in high-technology goods for selected regions/countries: 1995-2008 (Source: National Science Board's Science and Engineering Indicators 2010).

In response to this and other statistical evidence that a fundamental and disturbing shift is occurring in the competitiveness of U.S. technology, the President Council of Advisors on Science and Technology (PCAST) released a report in June 2011, Ensuring American Leadership in Advanced Manufacturing, which presents the following three points to make the case of why high-tech or high-value manufacturing matters[4]:

- "Manufacturing, based on new technologies including high-precision tools and advanced materials, provides the opportunity for high-quality, good-paying jobs for American workers;
- A strong manufacturing sector that adapts to and develops new technologies is vital to ensure ongoing U.S. leadership in innovation, because of the synergies created by locating production processes and design processes near to each other; and
- Domestic manufacturing capabilities using advanced technologies and techniques are vital to national security."

The over-arching concern is that as high-value manufacturing moves overseas, with it goes the innovation chain: basic research, primarily from universities; applied research, proof-of-concept, and scale-up (the middle part of the MRL scale); and the feedback of the commercial sector back into the research stages. Like the Hauser and Dyson reports, a key recommendation of PCAST is to improve, with federal participation, the research infrastructure that supports the middle levels of the MRL scale.

The United States does not lack programs that support R&D and innovation in manufacturing technology; however, as Figure 23 shows, these programs tend to be either focused on earlier or later stages of the MRL process, or are relatively small-scale programs.

In March 2012, President Obama announced the implementation of the key recommendation of the PCAST report, a national-level infrastructure of manufacturing research comparable to the Catapult centers in the U.K. With a somewhat less poetic, but typically American name, the National Network for Manufacturing Innovation (NNMI) is envisioned as establishing as many as fifteen CCAM-like centers across the country. Appropriately, the president chose as the setting for the NNMI announcement the new Rolls Royce manufacturing facility at Crosspointe, Virginia—which is, not coincidentally, also the home of CCAM. The president also cited CCAM as a model of the sort of university-industry collaboration that the government expects to be typical of NNMI; few may realize that, as this report shows, the

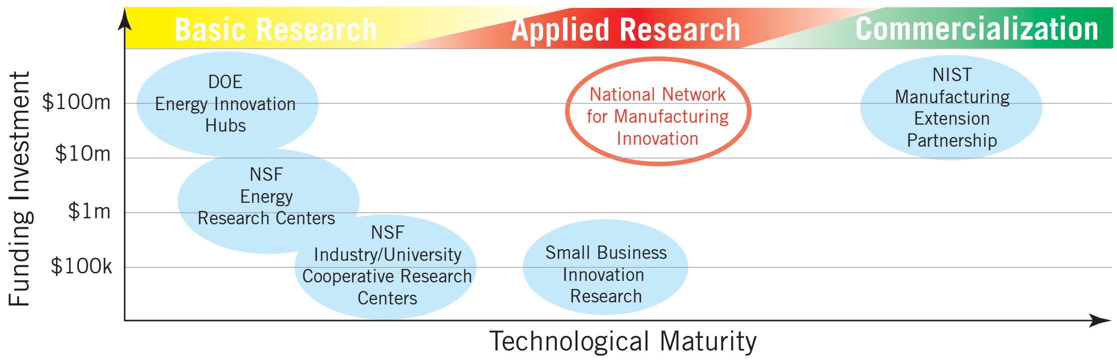


Figure 23: The National Network for Manufacturing Innovation fulfills a role similar to CCAM and other centres between laboratory and factory.

model owes much to forward-thinking academics, business people, and policy makers in Britain.

6.0 CONCLUSION

As universities in the U.S. struggle to find new mechanisms for supporting research in the face of stagnant or declining governmental funding, high technology industries are actively looking for and investing in new pathways for innovation in a time of fierce global competition. Centers dedicated towards advancing technology through a collaborative hybridization of laboratory and factory, such as the British TIC's and America's CCAM, provide a solution.

By bringing together both private industry and university research programs, a group of such centers having specialized, but complementary research themes promotes faster and more efficient translation from research to commercial application than the typical model of industry-funded university research because the resulting innovations are simultaneously leveraged across multiple technologies and market sectors. These Technology Innovation Centers provide an unprecedented hybrid building type, a mix of laboratory and factory, to support these new pathways from discovery to application.

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REFERENCES

[1] Rhodes, C., (2014). "International Comparisons of Manufacturing", Retrieved on 2/2014 from http://www.parliament.uk/briefing-papers/SN05809/international-comparisons-of-manufacturing-output.

[2] Hauser, H., (2010). "The Current and Future Role of Technology and Innovation Centres in the UK", Report, Retrieved on 2/2014 from http://webarchive.nationalarchives.gov.uk/20120703103713/http://www.innovateuk.org/_assets/pdf/other-publications/hauser-review.pdf.

[3] Dyson, J., (2010). "Ingenious Britain: Making the UK the Leading High Tech Exporter in Europe", Report, Retrieved on 2/2014 from http://webarchive.nationalarchives.gov.uk/20110305010507/https://www.data.org.uk/generaldocs/news-press/Ingenious%20Britain.pdf.

[4] Holdren, J. et al., (2011). "Report to the President on Ensuring American Leadership in Advanced Manufacturing", President's Council of Advisors on Science and Technology, Retrieved on 3/2014 from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-advanced-manufacturing-june2011.pdf.