This report summarizes the key findings and recommendations from a number of technology roadmaps that define the "Factory of the Future" (circa 2020), and identifies a strategy to assist small- to mid-sized enterprises in identifying digital technologies that can boost productivity within their manufacturing operations.

An Assessment of Technology Roadmaps for Advanced Manufacturing

An Overview for the DTAPP Consultation with Manitoba Industry

Fred Doern
Red River College

Executive Summary

The April 12th, 2012 edition of The Economist includes an article, “The Third Industrial Revolution”, which speaks of modern manufacturing environments that are void of men in oily coveralls but filled with young men and women sitting in front of computer screens controlling the manufacturing process. The author claims that switching from a skills-based economy to a knowledge-based economy forms a critical paradigm shift for the new era of manufacturing.

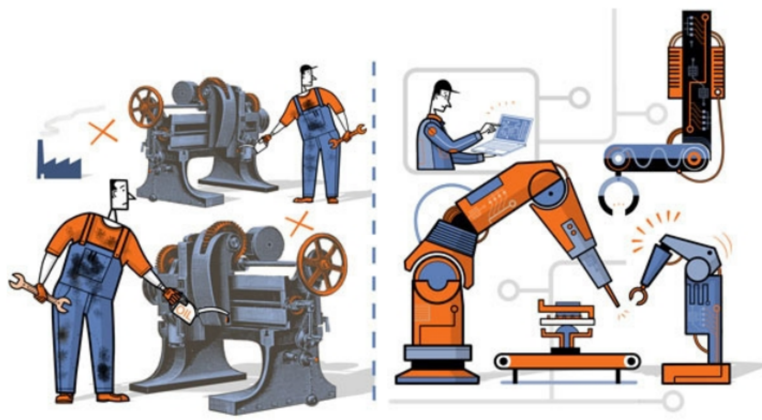

Figure 1 SOURCE: The Economist, April 12th, 2012

Further evaluation of American, Australian, and European technology foresight documents would support this hypothesis, and the purpose of this report is:

(1) to summarize the key findings and recommendations of a number of technology roadmaps that identify emerging trends and technology platforms to define the “Factory of the Future” (circa 2020);

(2) to provide a framework for Manitoba industry to identify emerging technologies that are most likely to impact on their manufacturing capabilities;

(3) to identify a Digital Technology Strategy that will help small- and medium-sized enterprises boost productivity within their manufacturing operations.

Contents

Productivity – Technology – Investment - Training

The DTAPP Program

"The Digital Technology Adoption Pilot Program (DTAPP) is a component of the Government of Canada's overall strategy to boost the productivity of small- and medium-sized enterprises (SMEs) and improve Canada's digital economy. Delivered by the National Research Council of Canada Industrial Research Assistance Program (NRC-IRAP), DTAPP is designed to speed up the rate at which SMEs adopt digital technology and build digital skills."

The emphasis on productivity enhancement for SMEs is part of a global economic theme in many industrialized nations. The next figure from a British study on UK competitiveness reaffirms the importance of worker productivity on economic growth and quality of life for industrialized nations.

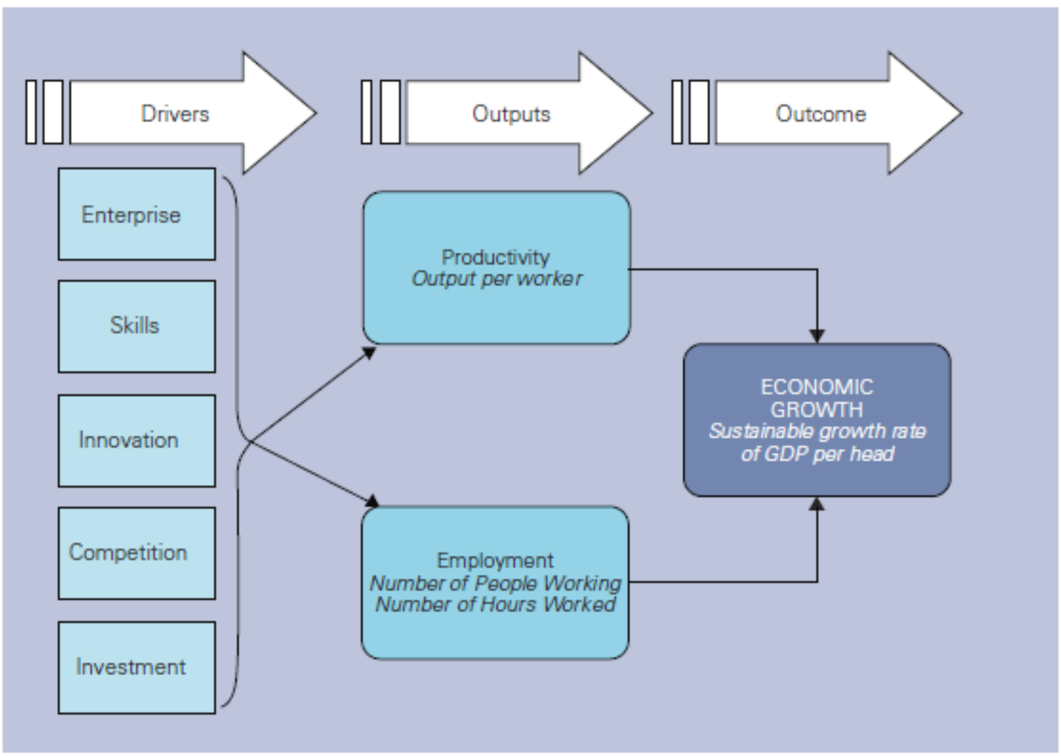

Figure 2 Source: UK BIS "Skills for Growth" 2010

So in keeping with the themes of productivity, digital skills, and innovation, the DTAPP program is focused on:

- supporting and accelerating the adoption of digital technologies,
- improving understanding of the link between digital technologies and productivity, and
- raising awareness of the benefits and importance of adopting these technologies.

The specific areas of technology included in the DTAPP initiative include:

- design (CAD), engineering, and virtual manufacturing
- electronic business systems (ERP, MRP systems)
- robotics and automation, automated inspection
- information and communications technologies (ICT).

The Technology Framework and Technology Roadmaps

The process of technology roadmapping involves consultation with industry experts and other stakeholders to develop a technology framework and proactive strategy to achieve mid-to-long term objectives in corporate and/or industry market positions.

Industry Canada has a long history in the practice and promotion of technology roadmapping activities, and has worked with other Canadian stakeholders to develop a portfolio of technology roadmaps. The best known technology roadmapping experts, however, tend to be the group from the Institute for Manufacturing (IfM) Centre for Technology Management at Cambridge University led by Dr. Rob Phaal[1] and David Probert.

The technology roadmapping process at the Cambridge IfM is always built around the concept of managing technology lifecycles, and is usually described within the context of the ISAEP framework for technology management. Figure 3 is a relatively simple illustration of this framework, while figure 4 illustrates a more "interactive" depiction of the activities within the ISAEP process.

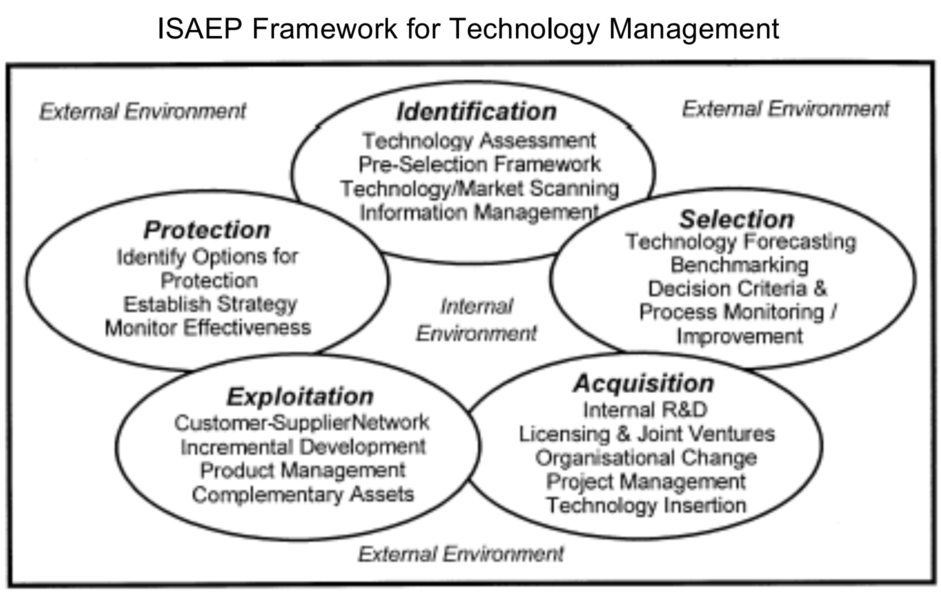

Figure 3 The Cambridge ISAEP Framework - Phaal & Probert 2004

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[1] PHAAL, R. Technology roadmapping - A planning framework for evolution and revolution. **Technological Forecasting and Social Change**, v. 71, n. 1-2, p. 5-26, 2004. Accessed at

[2] UK Technology Strategy Board report on High Value Manufacturing Strategy 2012-2015

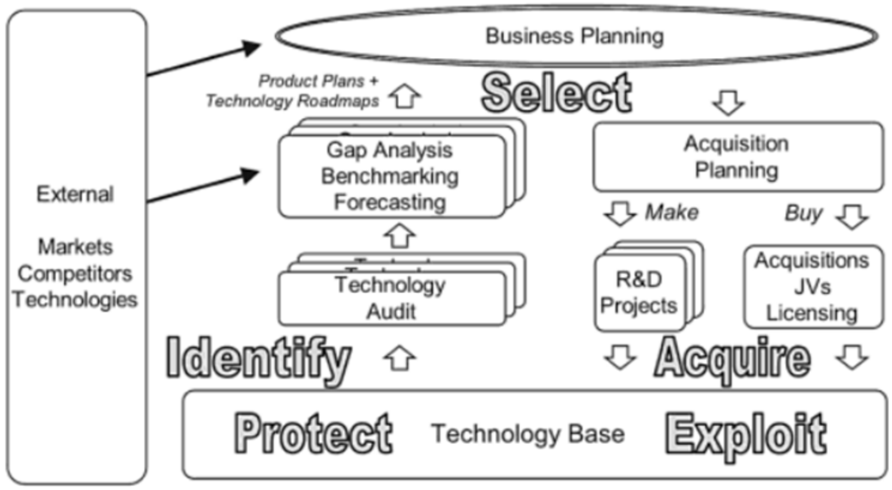


Figure 4 A Variant of the Cambridge ISAEP Framework to Illustrate the Dynamic Nature of Activities within the Model

A concise depiction of the Cambridge technology management model within the context of the ISAEP framework is figure 5 which illustrates the ISAEP activities (focused around a key technology base) spanning between the technological and commercial perspectives, and integrating the operations, innovation, and strategic initiatives of the organization. It also shows the push – pull relationship with new technology adoption.

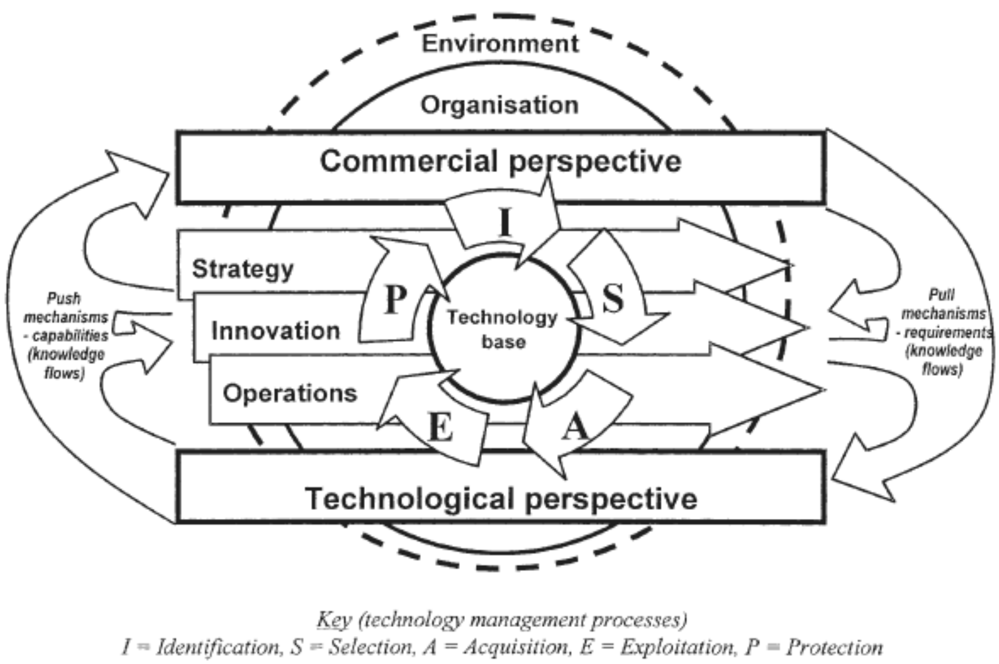


Figure 5 The Cambridge Technology Management Model focused around the ISAEP Framework

The natural progression of this framework starts to differentiate between “market pull” and “technology push” and introduces the idea of creating value for the customer and elements of a timeline (figure 6).

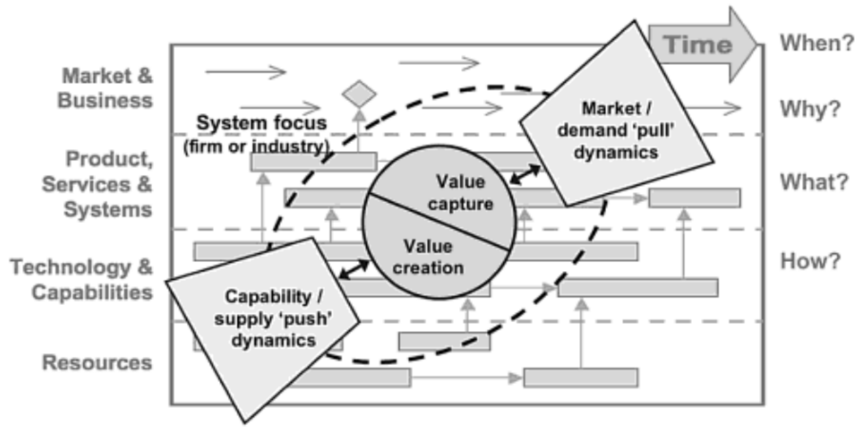


Figure 6 The Cambridge Value Creation - Value Capture Perspective related to Technology Roadmaps

The actual technology roadmap that evolves from this process is usually displayed as a multi-level Gantt chart where specific tasks/milestones are placed along a timeline within their family of operations (figure 7).

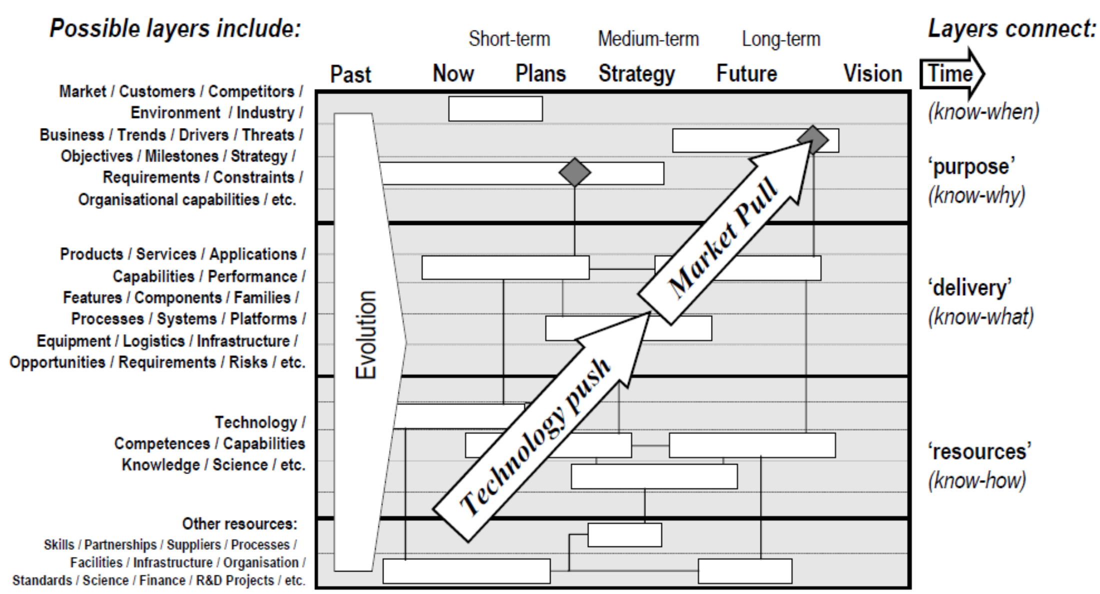


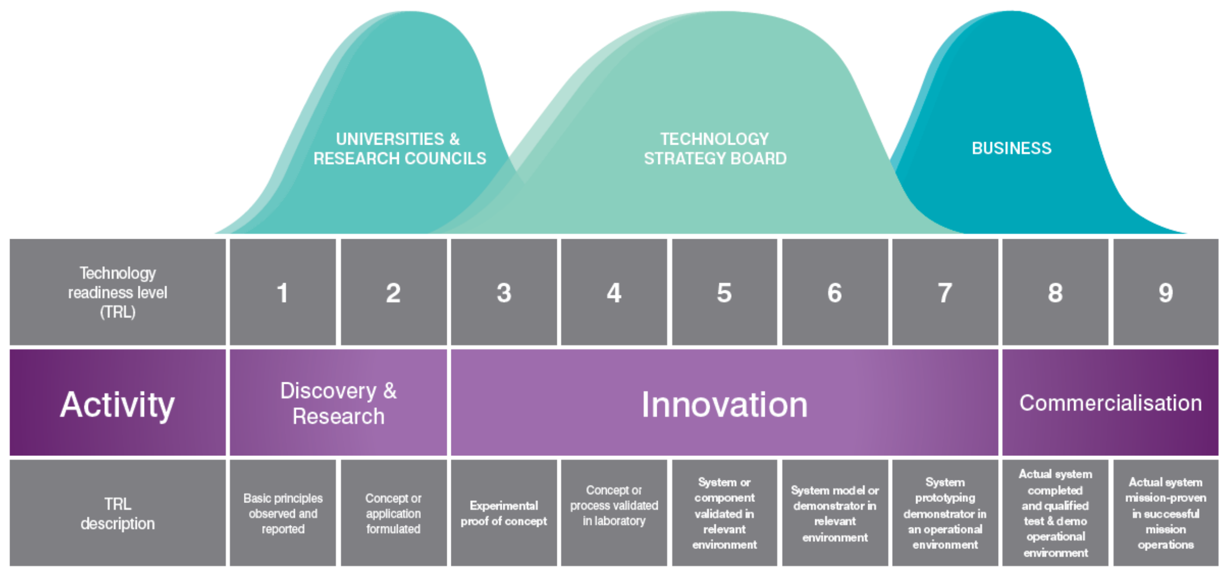
Figure 7 The Cambridge Generic Technology Roadmap Structure

In summary, the technology roadmap (TRM) is really just a technology forecast or a visual depiction of a technology exploitation strategy.

The value of the technology roadmap is inherent in the discipline of the process; the consultation process followed by the explicit statement and progression of technical projects and milestones required to meet the value expectations of the market within the specified time frame. This provides insight on skill gaps, engineering challenges, and other resource requirements that are needed to be competitive within the medium- to longer-term future of the industry or corporation.

Technology Readiness Levels

An ancillary concept to the technology roadmap is the idea of technology readiness levels (TRLs). Originally proposed as a benchmark for the US aerospace and defense industries, the TRL is an effort to quantify the technology "readiness" along the spectrum from ideation to commercial realization.



Source: The NASA-developed Technology Readiness Level model[17]

Figure 8 Technology Readiness Levels and the progression from Discovery through Commercialisation[2]

Within the TRL spectrum there is some debate where Discovery & Research activities may end (TRL 3) and where Commercialisation activities begin (TRL 7), and to the appropriate levels of funding and activity along the TRL timeline.

The aerospace sector spends considerable time and effort to correlate technology roadmaps and technology readiness levels as part of a strategic plan for global competitiveness within their industry.

During the review of American technology roadmap documents, two themes were identified:

(1) the perceived lack of investment for the mid-level TRL (technology development and technology demonstration) region of activities, and
(2) the similarity between technology readiness levels (TRL) and manufacturing readiness levels (MRL).

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[2] UK Technology Strategy Board report on High Value Manufacturing Strategy 2012-2015

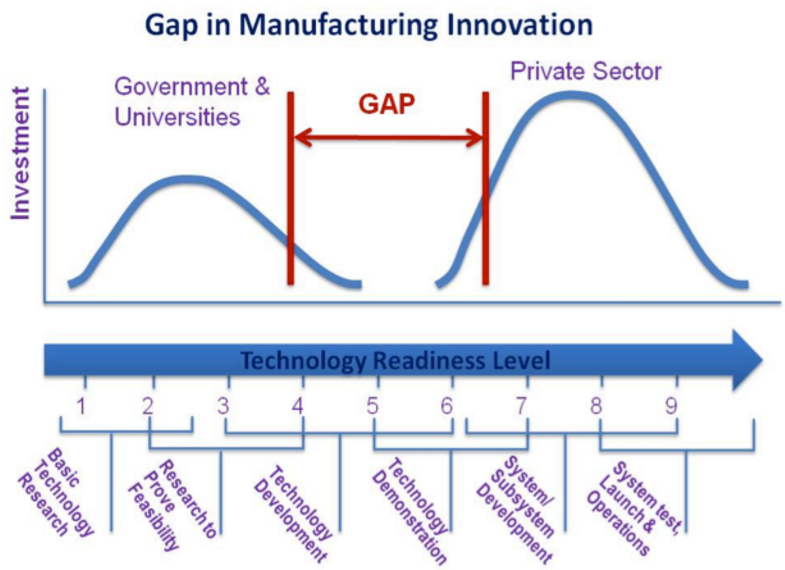

Figure 9 Perceived Investment Gaps at Mid-Level TRLs

This gap in mid-level investment is being recognized in a number of countries: specifically in the USA where there is a major investment (over 1 billion US$) by the federal government to demonstrate additive manufacturing[3] as an emerging technology; numerous activities (worth over 1.2 billion Euros) within Europe using public-private partnerships to develop technology demonstration projects as part of the Factory of the Future[4] initiative; and government support in Australia[5] to support manufacturing with emerging technology demonstration projects.

The American approach to support advanced manufacturing[6] is partially embedded in their government procurement process and US Department of Defense support under the Defence Advanced Research Projects Agency. That forms the basis for correlation between the TRL and MRL (Manufacturing Readiness Level) charts identified in figure 10. There is also a focus on commercializing technology developed at US federal research laboratories[7]. Finally, the US President's Council of Advisors on Science and Technology submitted their report[8] in July, 2012 which prompted commitments of 3.2 billion US$ towards technology development in manufacturing and another 8 billion US$ toward community college education to support the manufacturing sector.

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[3] http://namii.org/about/background/ US announces support for the National Additive Manufacturing Innovation Initiative
[4] http://www.effra.eu/home/about-factories-of-the-future.html
[5] http://www.industry.qld.gov.au/documents/AdvancedManufacturing/Advanced_Manufacturing_-_Action_Plan.pdf
[6] Report to the President on a National Strategic Plan for Advanced Manufacturing available at http://www.whitehouse.gov/sites/default/files/microsites/ostp/iam_advancedmanufacturing_strategicplan_2012.pdf
[7] http://www.nist.gov/director/speeches/upload/Molnar_091211.pdf The U.S. Advanced Manufacturing Initiative
[8] Capturing Domestic Competitive Advantage in Advanced Manufacturing accessed at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_amp_steering_committee_report_final_july_27_2012.pdf

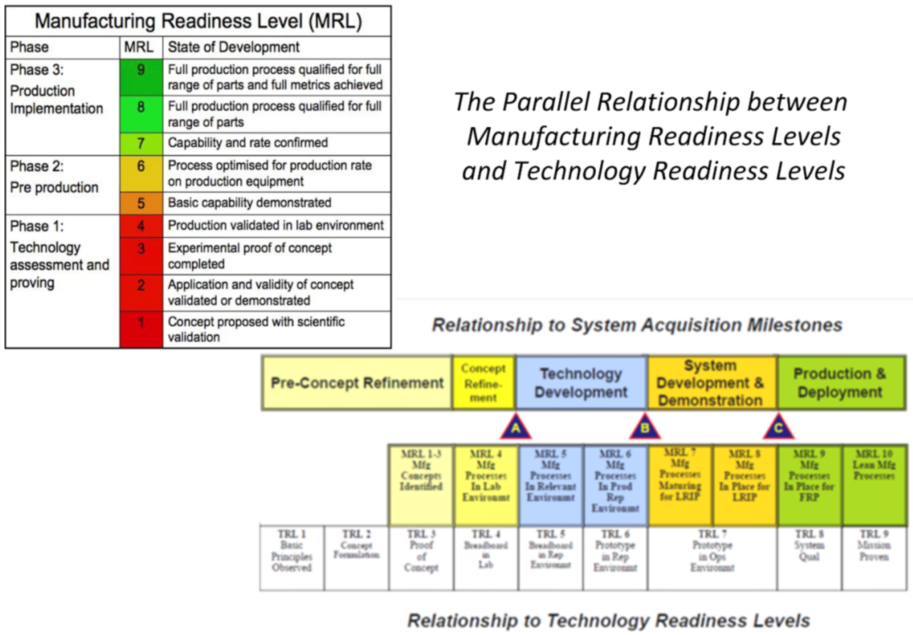

Figure 10 Correlation between MRL and TRL

Within the Defense procurement strategies and the U.S. National Strategy for Advanced Manufacturing, there is also a training and skills component that is based upon the Advanced Manufacturing Competency Model[9].

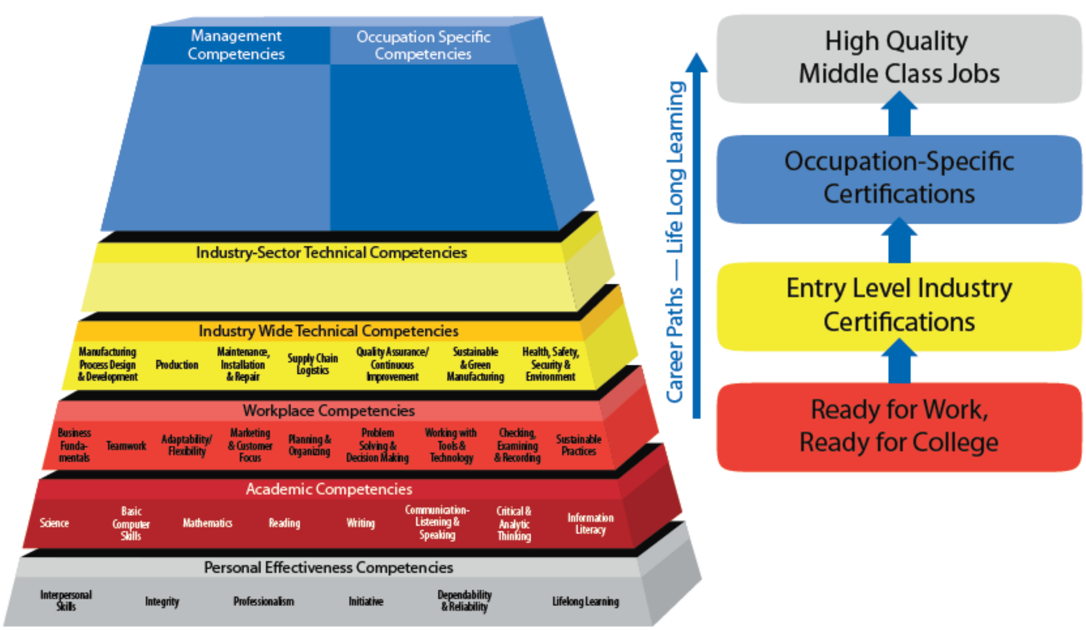

Figure 11 Advanced Manufacturing Competency Model

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9 http://dodmrl.com/2012_workshop/DOL_Manufacturing_Competency_Model.pdf

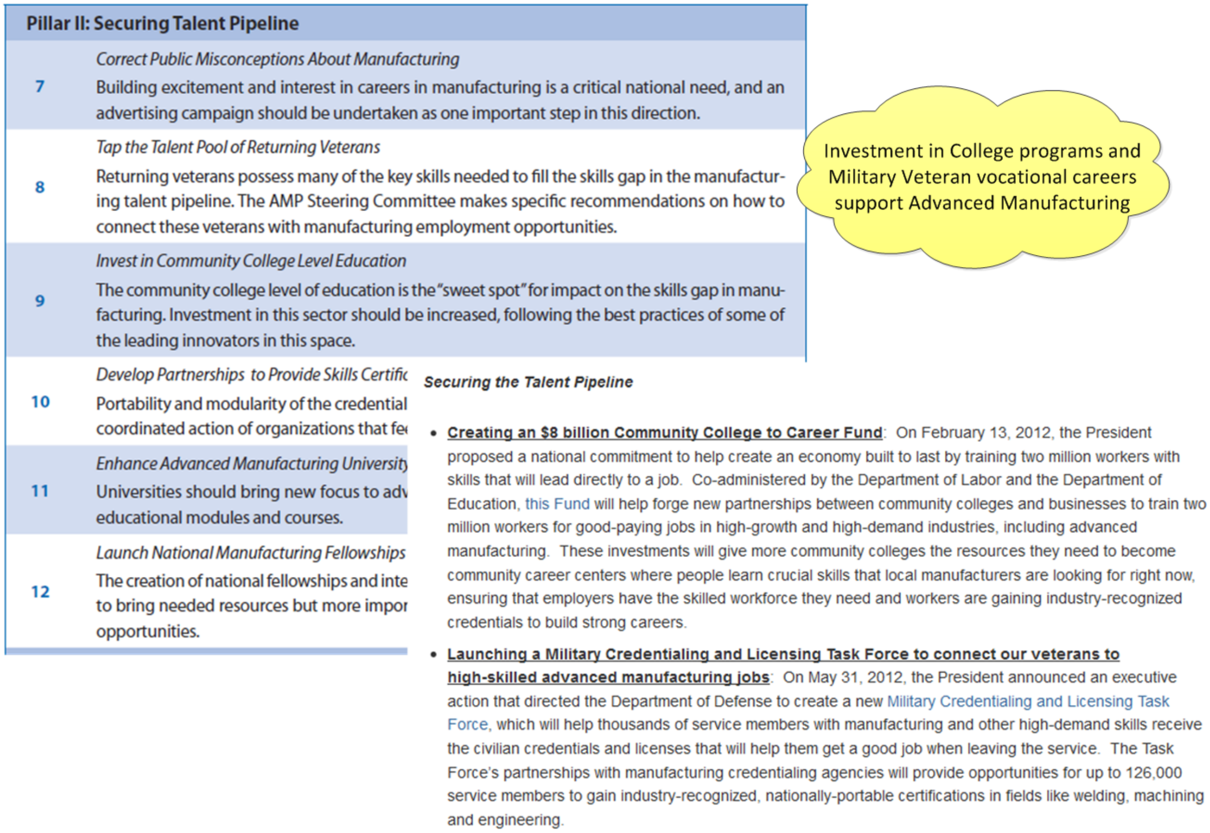


Figure 12 US Investment in Colleges and Veterans to Support Recommendations for Advanced Manufacturing

In summary, productivity as a critical driver for national economic growth is a function of the proper selection of emerging technologies (identified through technology roadmapping activities) x investment in mid-level TRL/MRL technology development and technology demonstration projects (stimulated by some combination of government and private sector programs) x strategic investments in training and skill development to support activities such as the Advanced Manufacturing Competency Model.

A Review of Manufacturing Technology Roadmaps

While the previous section of this document made reference to the technology roadmapping process and a number of international applications of this tool (process) to define or refine strategies to support advanced manufacturing, the actual list of technologies has not yet been discussed.

During the preparation of this review, a large number of technology roadmaps available on the internet were reviewed and highlights from some of the most memorable documents will be summarized along with some of their emerging technologies.

The Factory of the Future PPP Strategic Multi-Annual Roadmap[10]

Figure 13 A Foundation Document for Advanced Manufacturing in Europe

A strategy document was written as part of a public-private partnership and published in 2010.

Key information:

- Launched as part of the European Economic Recovery Plan
- Initiative amounts to 1.2 billion Euros between 2010-2013 equally shared by European Commission and the private sector
- Focus of the initiative is to support collaborative research projects on innovative enabling technologies of multi-sectoral benefit and oriented towards industrial factory applications
- Four major technology groups: sustainable manufacturing, information and computing technologies (ICT) enabled intelligent manufacturing, high performance manufacturing, and exploiting use of new materials through manufacturing
- Sustainable manufacturing focused around four themes: high efficiency and near-to-zero emissions in the manufacturing process; alternatives to energy intensive manufacturing based

[10] http://ec.europa.eu/research/industrial_technologies/pdf/ppp-factories-of-the-future-strategic-multiannual-roadmap-info-day_en.pdf

on advanced production systems; improved use of renewable resources at the factory level; and production using environment-neutral materials

ICT enabled manufacturing differentiated between **smart factories**: agile manufacturing and mass customisation; **virtual factories**: value creation, global networked manufacturing and logistics; and **digital factories**: manufacturing design and product life cycle management.

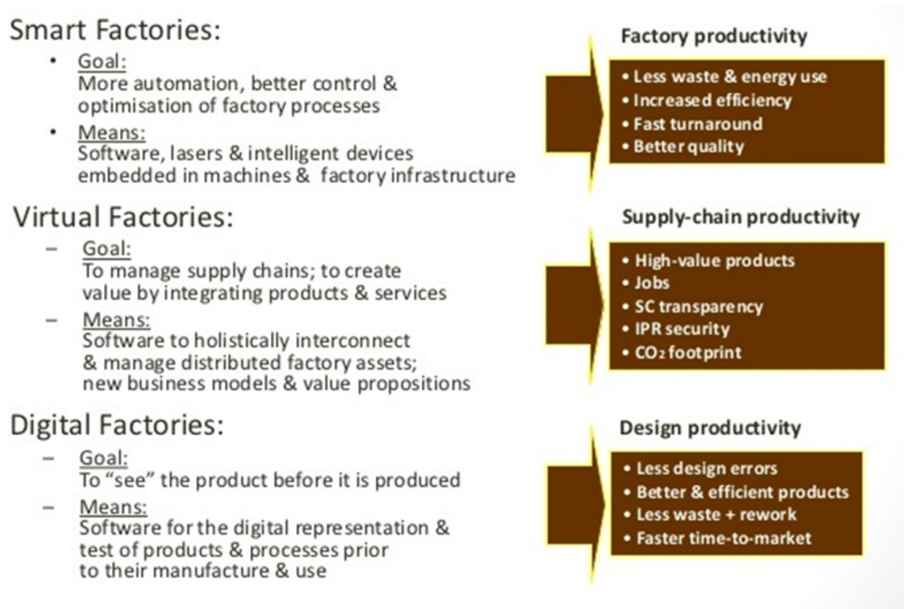


Figure 14 ICT Enabled Factories and their Influence on Productivity

- High performance manufacturing had four strategic areas: flexible adaptive production equipment, systems and plants for rapid (re)configurations and optimal energy use; high precision micro-manufacturing machines and systems; tools for production planning and in-situ simulation for open reconfigurable and adaptive manufacturing systems; and zero-defect manufacturing.
- Exploiting new materials through manufacturing includes: net-shape manufacturing for advanced structural and functional materials; new material functionalities through manufacturing processes; manufacturing strategies for renovation and repair; and product design using sustainable material processing technologies.

The Factories of the Future PPP Strategic Multi-Annual Roadmap served as the launch pad for a number of associated roadmaps.

> *Manufacturing research should focus on the transformation of the present factories, towards re-usable, flexible, modular, intelligent, digital, virtual, affordable, easy-to-adapt, easy-to-operate, easy-to-maintain and highly reliable "Factories of the Future".*

ICT for Manufacturing: The ActionPlanT Roadmap for Manufacturing 2.0

The ubiquitous nature of information and communications technology resulted in two key technology roadmap documents[11,12] within the European community. Inherent to these documents was a vision:

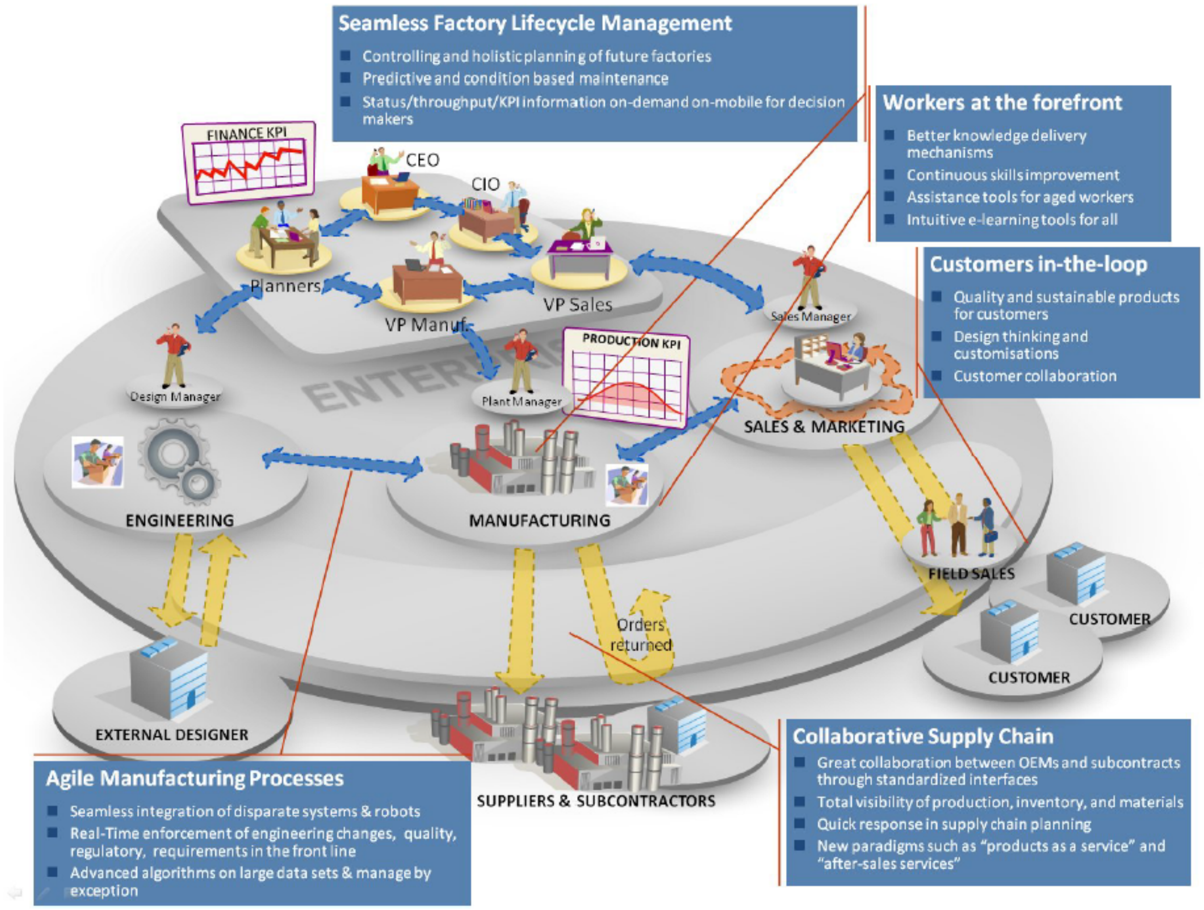


Figure 15 Manufacturing 2.0: A common vision for Europe

The integration of the manufacturing supply chain with marketing, operations, and new product development via ICT products and technologies formed the basis for the ActionPlanT roadmap. Within that vision there was acknowledgement of cloud computing to support corporate Enterprise Resource Planning (ERP) systems, a machine-to-machine (M2M) or Internet of Things concept that allows manufacturing equipment to communicate with ERP systems and also with equipment manufacturers for service operations, and the idea of mobile computing as a platform for both production management and corporate communications.

[11] http://www.actionplant-project.eu/public/documents/vision.pdf The ActionPlanT Vision Document

[12] http://www.actionplant-project.eu/public/documents/roadmap.pdf The ActionPlanT Roadmap for Manufacturing 2.0

Projects within the ICT ActionPlanT portfolio were evaluated on the basis of five criteria (termed Ambitions) that were displayed as part of a second conceptual map.

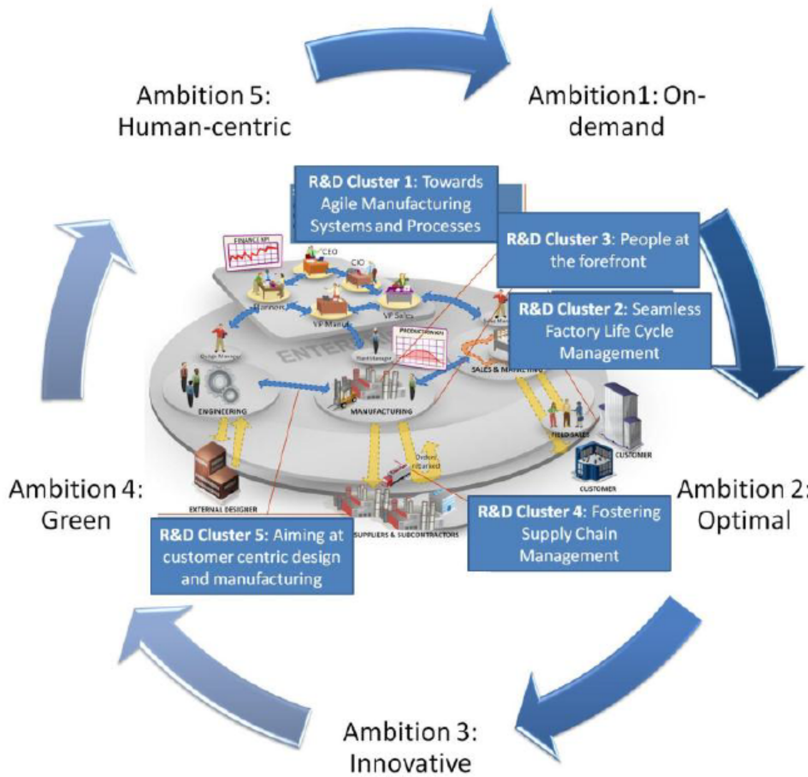


Figure 16 ActionPlanT Manufacturing 2.0 Ambitions (Evaluation Criteria)

These criteria were defined as:

> *"On-Demand: Manufacturing 2.0 should accommodate changing demands from a new customer base and deliver customised products on demand.*
>
> *Optimal: European enterprises need to produce products with superior quality, high security and durability, and competitively priced compared to products from emerging markets.*
>
> *Innovative: Faster introduction of collective innovation.*
>
> *Green: Manufacturing 2.0 needs focused initiatives to reduce energy footprints on shopfloors and increased awareness of end-of-life product use.*
>
> *Human-centred: Manufacturing 2.0 will evolve from being perceived as production centred to human centred with greater emphasis on generating core value for human stakeholders."*

Based upon the vision and ambition criteria, the ICT recommendations identified 15 technology areas:

ICT Recommendations for Manufacturing 2.0

Operational recommendations

- OP1: Cloud-based infrastructure for high-performance manufacturing applications
- OP2: Manufacturing app store for manufacturing solutions

Content recommendations

- CL3: Collaborative service management to tackle complexity and optimize operations
- CL4: Collaborative design and manufacturing for better products
- CL5: Collaborative knowledge management for value creation
- CN6: Connected objects in the Manufacturing By Web (MBW) environment – involves the idea of the Internet of Things and the M2M communications
- CN7: M2M cloud connectivity in the MBW
- CN8: Cloud-based social networks for Human Machine Interfaces (HMI)
- IN9: Big-data analysis and real-time decision making
- IN10: Intelligent visualization for big data
- IN11: High-performance simulation and analysis in the cloud

Consumption recommendations

- CS12: Mobile apps for Manufacturing 2.0 enterprises
- CS13: Mobility infrastructure for MBW apps
- CS14: Timeless manufacturing software with rich user experience
- CS15: Secure software for Manufacturing 2.0 enterprises

Other Factories of the Future Related Roadmaps

The Factories of the Future PPP Strategic Multi-Annual Roadmap spawned a number of noteworthy technology roadmaps including:

IMS 2020 Roadmap on Sustainable Manufacturing, Energy Efficient Manufacturing and Key Technologies[13]

- This document develops a sustainability model for manufacturing based around three major themes: environment, economy, and society.
- Within the roadmap, the Key Area Topics are sustainable manufacturing, products and services; energy efficient manufacturing; and key technologies.
- Following from the 3 Key Area Topics are 13 Research Action themes and 60 Research Topics

[13] http://www.ims.org/wp-content/uploads/2011/10/IMS2020_Action-Roadmap_KAT1-2-3.pdf

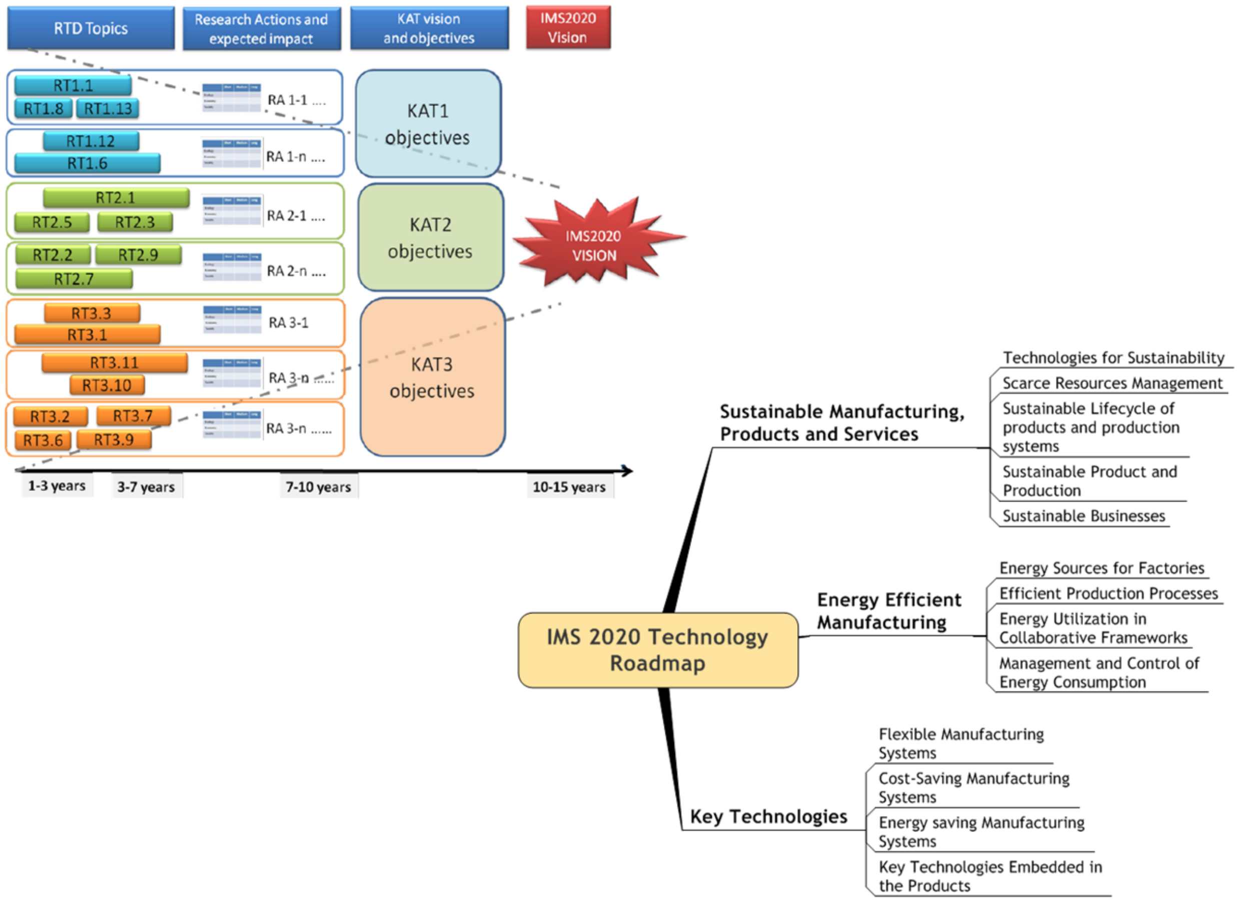


Figure 17 IMS 2020 Key Areas of Technology and Research Action Themes

EuMAT - Roadmap of the European Technology Platform for Advanced Engineering Materials and Technologies[14]

The EU MINAM Micro- and NanoManufacturing Roadmap 2012[15]

[14] http://eumat.risk-technologies.com/filedown.aspx?file=3229

[15] http://minamwebportal.eu/attachments/Micro-_and_Nano-Manufacturing_Roadmap.pdf

Factories of the Future PPP – FoF 2020 Roadmap Consultation Document[16]

While the original Factories of the Future PPP Strategic Multi-Annual Roadmap was part of the European 7th Framework, the successor FoF 2020 Roadmap Consultation Document is part of the European Horizon 2020 initiative. The consultation process was open for public comment until October, 2012. The framework for the FoF 2020 document included sections on three major areas: Challenges and Opportunities, Technologies and Enablers, and Research and Innovation Priorities.

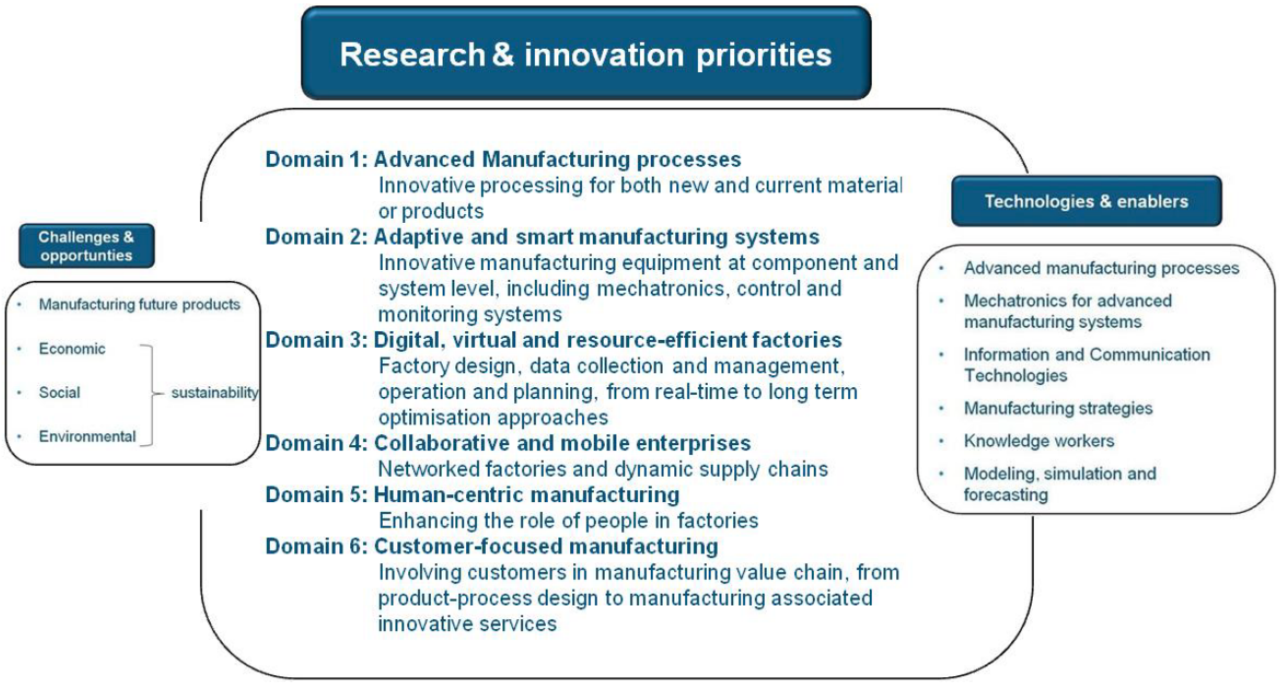


Figure 18 FoF 2020 Roadmap Consultation Framework

Expansion of the FoF2020 Challenges and Opportunities includes:

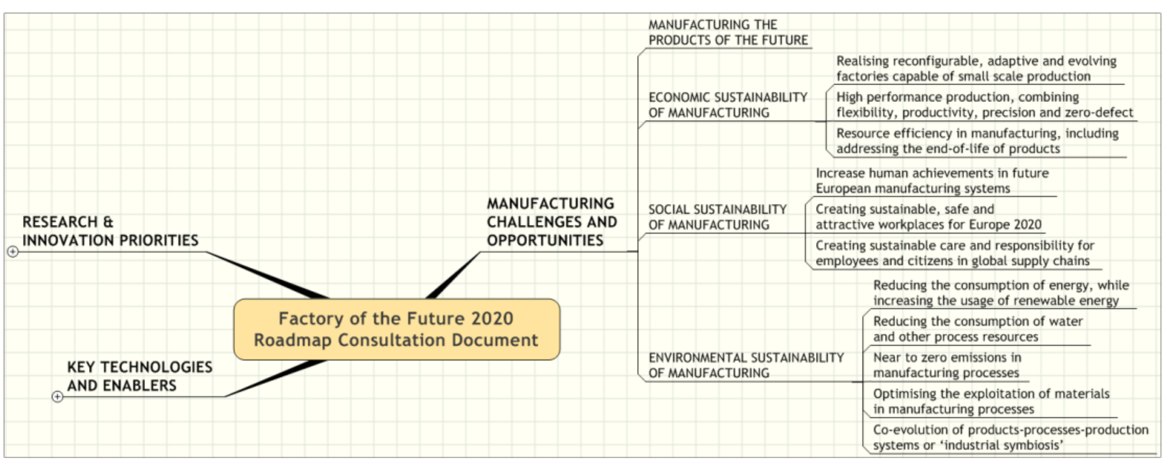


Figure 19 FoF 2020 Manufacturing Challenges and Opportunities

[16] http://www.effra.eu/attachments/article/335/FoFRoadmap2020_ConsultationDocument_120706_1.pdf

An expanded list of the key technologies and enablers included:

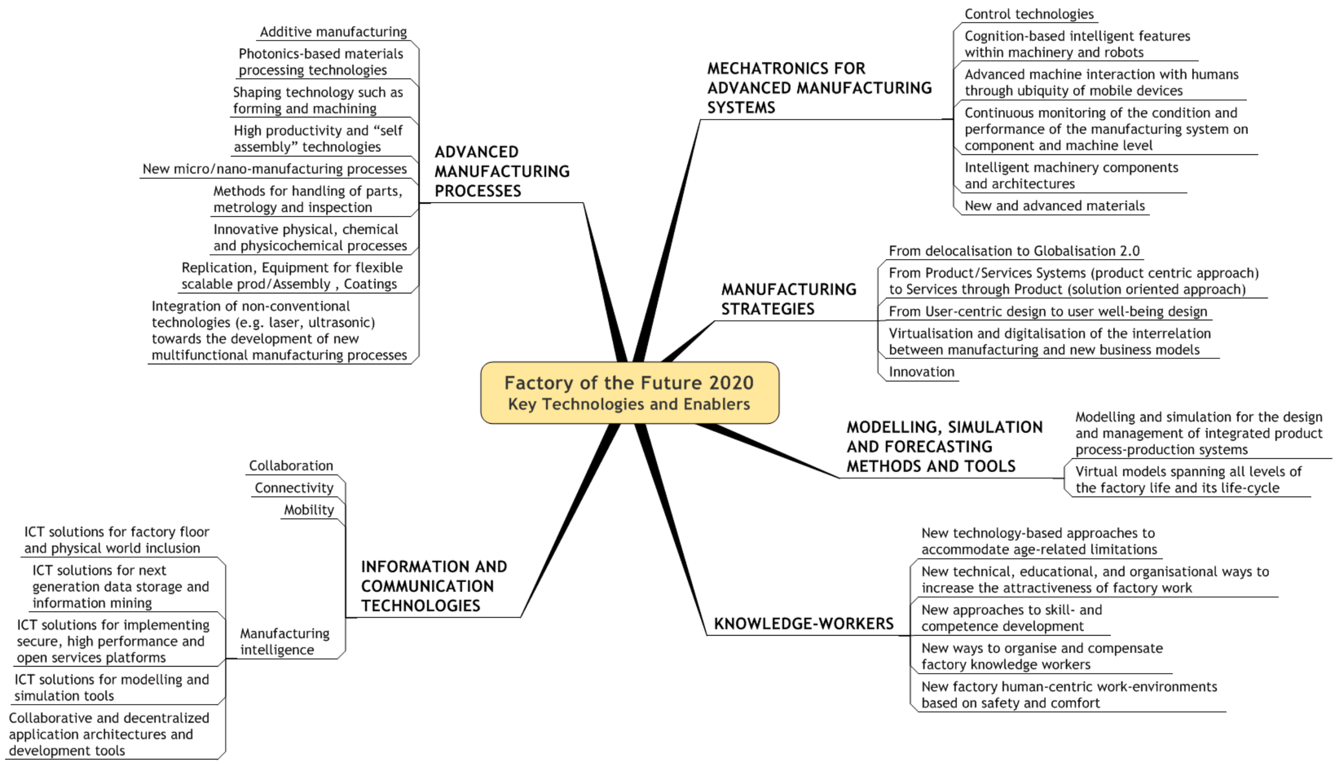


Figure 20 FoF 2020 Roadmap Consultation Key Technologies and Enablers

While the final results of the public consultation process have not yet been posted, it would appear that advanced materials, mechatronics, and information and communication technologies will play dominant roles in the future landscape of European manufacturing.

Capturing Domestic Competitive Advantage in Advanced Manufacturing[17]

As indicated earlier in this report, the U.S. President's Council of Advisors on Science and Technology (PCAST) identified a number of issues and recommendations in their 2012 report on advanced manufacturing. While the major themes in the recommendations focused on enabling innovation, securing the talent pipeline, and improving the business climate, the group also identified a list of key technologies for the future of manufacturing in the American economy. This list included:

[17] Report to the President, July 2012
http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_amp_steering_committee_report_final_july_27_2012.pdf

- Advanced sensing, measurement, and process control (also known as smart manufacturing or advanced automation).
- Advanced material design and synthesis, including nano-materials, meta-materials, metals, coatings, ceramics.
- Information technologies, including visualization and digital manufacturing.
- Sustainable manufacturing.
- Nano-manufacturing (includes micro feature manufacturing).
- Flexible electronics.
- Bio-manufacturing and bioinformatics, including proteomics and genomics.
- Additive manufacturing.
- Advanced manufacturing equipment (including testing).
- Industrial robotics.
- Advanced forming (including near-net-shape manufacturing) and joining/bonding technologies.

Figure 21 US PCAST List of Key Technologies to Support Advanced Manufacturing

As part of the strategy to move forward to capture domestic competitive advantage, the PCAST group also recommended a Manufacturing Innovation Institute (MII) model to foster multi-level research and skill development. The figure depicting this model is included below:

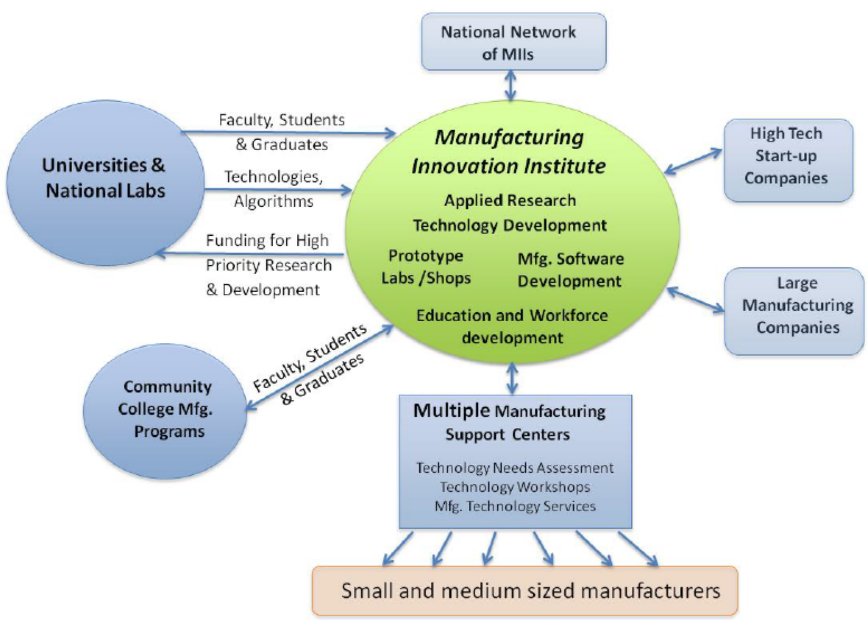


Figure 22 US PCAST recommendation for a Manufacturing Innovation Institute

The inclusion of the small- and medium-sized manufacturers and the community college manufacturing programs as integral components within the MII model is indicative of the need for vocational education and workforce development to sustain an advanced manufacturing sector within the USA.

An example of this MII model would be the recently announced National Additive Manufacturing Innovation Institute (NAMII)[18] created in August 2012.


President Obama Cites NAMII Success in State of the Union Address

POSTED ON FEB 13, 2013

Blairsville, Pa. — February 13, 2013. NAMII, the National Additive Manufacturing Innovation Institute, awarded on August 2012, and driven by the National Center for Defense Manufacturing and Machining (NCDMM), is honored by President Obama's citation of NAMII's success in last night's State of the Union address. "We were tremendously honored to hear President Obama describe the work we are doing in Youngstown, Ohio, with NAMII during his State of the Union address," said new NAMII Director Ed Morris. "It is rewarding to know that...

Figure 23 NAMII cited as a success in 2013 State of the Union Address

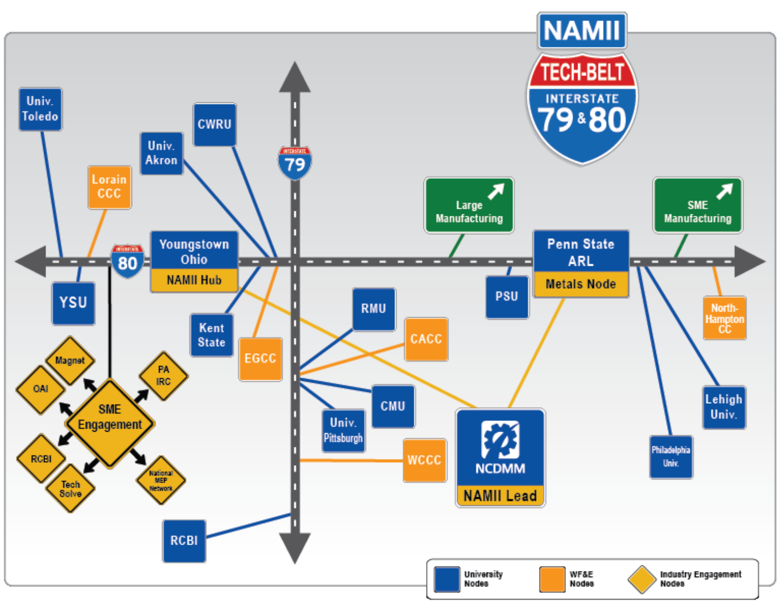


Figure 24 NAMII is a model of Industry - Government - Academic Stakeholders

18 http://namii.org/news/press-releases/

Lead Members listed in ORANGE
Full Members listed in YELLOW
Supporting Members listed in BLUE
List updated on February 8, 2013

- 3D Systems Corporation
- Abbatron
- Allegheny Technologies
- Association of Manufacturing Technology
- APEX CNC Swiss
- AST2
- Automated Dynamics
- Bayer Material Science
- BenFranklin C&N PA
- BenFranklin SE PA
- BioDevice Design
- Boundry Systems
- Case Western Reserve University
- Catalyst Connection
- Concurrent Technologies Corporation
- DVIRC
- Energy Industries of Ohio
- The ExOne Company
- FMW Composites
- Fourth Economy
- GE Global Research
- Greenleaf
- Innovation Works
- IRC Network, Inc.
- JumpStart
- Kennametal
- Kent Display
- Kent State University
- Lehigh University
- Liquid X Printed Metals
- Lockheed Martin Aeronautics
- Lubrizol
- M-7 Technologies
- MAGNET
- Manufacturing Resource Center (MRC)
- Missouri University of Science and Technology
- NE PA IRC
- NorTech
- Northern Illinois Research Foundation
- Northhampton Community College
- Northrop Grumman
- nScrypt
- NorthWest IRC
- Ohio Aerospace Institute
- Optomec
- OSRAM Sylvania
- Oxford Performance Materials
- Pennsylvania State University
- POM
- PTC ALLIANCE
- Robert C. Byrd Institute (RCBI)
- Robert Morris University
- RTI
- Society of Manufacturing Engineers
- Stratonics
- TechSolve
- Thogus/RP+M
- The Timken Company
- Touchstone Research Lab
- University of Akron
- University of Texas – Austin
- University of Texas at El Paso
- University of Toledo
- Westmoreland County Community College
- Wohlers Associates
- Wright State University
- Youngstown Business Incubator
- Youngstown State University

Figure 25 Current Members in the NAMII Initiative

The list of key technologies within the PCAST report reflects both the ICT and advanced materials perspective cited within other U.S., British and Australian roadmaps.

Implementing 21st Century Smart Manufacturing[19]

This document represents the results of a workshop led by the Smart Manufacturing group from UCLA in September 2010. The process followed is similar to that of a technology roadmap and the action plan put forward in the document includes an effective series of forms to represent different strategic thrusts and technologies to enable "smart manufacturing".

[19] https://smart-process-manufacturing.ucla.edu/about/news/Smart%20Manufacturing%206_24_11.pdf

Goals to Achieve Outcomes

- Lower the cost for applying advanced data analysis, modeling, and simulation in core manufacturing processes.
- Lower the cost of pre-competitive infrastructure, including data and information networks, interoperable hardware and software, and shared business data.
- Establish an industry-shared, community-source platform that provides access to customizable open-access software, serves as an applications or "apps" store and clearinghouse and facilitates innovation.
- Create and provide broad access to next-generation sensing technologies and the digital infrastructure for the enterprise application of manufacturing intelligence, (e.g., disposable sensors, data fusion, wired and wireless networks which combine data from different sources to achieve greater measurement accuracy and more intelligence).
- Establish national test beds or accessible user facilities for smart manufacturing concepts and make them available to companies of all sizes.
- Develop virtual factory and supply chain tools (e.g., real-time simulation and visualization, virtual test beds, dynamic risk analysis, dynamic supplier involvement) for real-time planning and point-in-time tracking/traceability of materials and products.
- Apply dashboard performance tools (e.g., key performance indicators, dynamic monitoring, dynamic visualization of critical data, like a car dashboard) across the enterprise to manage dynamic production, use, and storage of essential resources (energy, water, air) sustainability and EH&S.

Figure 26 The 21st Century Smart Manufacturing Goals

Overarching Outcomes

Technology Innovation and Economic Health
Highly integrated smart systems provide pathways for competitively manufacturing materials and products.

Agility
Agile processes in highly optimized manufacturing plants and supply networks enable rapid response to changes in customer demands.

Resource Efficiency
Ready access to manufacturing intelligence allows factories to run more efficiently and minimize use of resources.

Safety and Confidence
Products and processes are guaranteed safe and reliable through tracking of sustainable production and real-time handling of materials.

Next Generation Workforce
A manufacturing workforce with advanced skills and talent maximizes the benefits of manufacturing intelligence.

Sustainability
Smart processes minimize environmental impacts and improve sustainability of critical sectors (clean energy, defense, homeland security).

Figure 27 The 21st Century Smart Manufacturing Desired Outcomes

To achieve the goals and outcomes, the report outlined a series of actions:

Priority Actions:

Industrial community modelling and simulation platforms for smart manufacturing

- Action 1: Create community modelling and simulation platforms for the virtual plant enterprise
- Action 2: Develop next-generation toolbox of software and computing architectures for manufacturing decision making
- Action 3: Integrate human factors and decisions into plant optimization software and user interfaces
- Action 4: Expand availability of energy decision tools for multiple industries and diverse skill levels

Affordable industrial data collection and management systems

- Action 5: Establish consistent, efficient data methods for all industries
- Action 6: Develop robust data collection frameworks (sensors, data fusion, knowledge capture, user interfaces) across the manufacturing enterprise

Enterprise-wide integration: business systems, manufacturing plants, and suppliers

- Action 7: Optimize supply chain performance through common reporting and rating methods
- Action 8: Develop open platform software and hardware to integrate and transfer data between small/medium enterprise (supplier companies) and original equipment manufacturers
- Action 9: Integrate product and manufacturing process models

Education and training in smart manufacturing

- Action 10: Enhance education and training to build workforce for smart manufacturing

Identifying a List of Critical Technologies

US PCAST	FoF 2020 Consultation
• Additive Manufacturing • Advanced Forming and Joining Technologies • Nanomanufacturing • Sustainable Manufacturing • Flexible Electronics Manufacturing • Biomanufacturing and Bioinformatics • Advanced Materials Design, Synthesis, and Processing	ADVANCED MANUFACTURING PROCESSES • Additive manufacturing • Photonics-based materials processing technologies • Shaping technology such as forming and machining • High productivity and "self assembly" technologies • New micro/nano-manufacturing processes • Methods for handling of parts, metrology and inspection • Innovative physical, chemical and physicochemical processes • Replication, Equipment for flexible scalable prod/Assembly , Coatings • Integration of non-conventional technologies (e.g. laser, ultrasonic) towards the development of new multifunctional manufacturing processes
• Industrial Robotics • Advancing Sensing, Measurement, and Process Control • Advanced Manufacturing and Testing Equipment	MECHATRONICS FOR ADVANCED MANUFACTURING SYSTEMS • Control technologies • Cognition-based intelligent features within machinery and robots • Advanced machine interaction with humans through ubiquity of mobile devices • Continuous monitoring of the condition and performance of the manufacturing system on component and machine level • Intelligent machinery components and architectures • New and advanced materials
	INFORMATION AND COMMUNICATION TECHNOLOGIES • Collaboration – Connectivity - Mobility • ICT solutions for factory floor and physical world inclusion • ICT solutions for next generation data storage and information mining • ICT solutions for implementing secure, high performance and open services platforms • ICT solutions for modelling and simulation tools • Collaborative and decentralized application architectures and development tools
• Visualization, Informatics, and Digital Manufacturing Technologies	MODELING, SIMULATION AND FORECASTING METHODS AND TOOLS • Modeling and simulation for the design and management of integrated product process-production systems • Virtual models spanning all levels of the factory life and its life-cycle

While each of the technology roadmaps might emphasize a different group of technologies or technology clusters, a comparison of the American (US PCAST) and European (FoF2020) perspectives indicate a number of common topics (additive manufacturing, industrial robotics, mechatronics) indicated by the red font in the table.

The European approach is more explicit in defining an implementation plan for their TRM activities, and the use of public private partnerships to select, fund, and execute individual projects within their predefined topic areas appears to provide a successful strategy. The US approach tends to focus more on private sector entrepreneurs to develop technology, although the PCAST document was careful to point out the lack of funding for the TRL 4-6 technology demonstration phase as a weakness in their national program. The US federal investment in the NAMII initiative is more closely aligned with the European approach of a public-private-academic partnership to provide large-scale technology demonstration/technology validation activities. This approach appears to be a critical step in a strategy to repatriate manufacturing to the USA.

A Digital Technology Strategy to Support SME Productivity Enhancement

Many Manitoba manufacturers look to process improvement (lean, lean – six sigma, or theory of constraints) as a first step to improve production. This is a crucial step to identify their value streams and eliminate waste activities where possible, however, 70 percent of companies surveyed during a series of focus group/workshops indicated that process improvement was NOT sufficient to maintain growth and that they were looking to new technology to support their manufacturing operations.

Based upon “clicker surveys” during workshops in Winnipeg of Factory of the Future technology trends, the technology priorities for small- and medium-sized enterprises in Manitoba include:

1. the integration of mechatronic (automation) and industrial robotics solutions to enhance quality, safety, and productivity;
2. the integration of ICT within the factory to improve production and supply chain management activities;
3. the adoption of advanced manufacturing technologies (such as additive manufacturing, advanced joining and bonding technology, and micro- and nano-manufacturing processes) or new materials (composites, biomaterials) to promote new process and product development opportunities;
4. the adoption of advanced product life cycle management (PLM) software to provide a virtual factory simulation for enhanced computer-assisted manufacturing solutions.

The cost and productivity improvement for the different technology insertion elements will differ from company to company, however, the DTAPP process could act as a catalyst for many of these enhancements.

Insertion of new technology within companies involves more than capital investment in hardware or software. Discussion with SME respondents during the RRC DTAPP workshops or during additional meetings with general managers or production managers from a number of these companies identified an implementation strategy that must include:

1. build awareness of emerging technology,
2. provide demonstration sites - preferably with "hands on" accessibility,
3. identify early adopters and/or systems integrators to facilitate technology adoption, and
4. identify skills-upgrading opportunities for staff and/or new hires.

Additional technology roadmap documents of note

Australia, Trends in manufacturing to 2020 - A foresighting discussion paper

Australian Institute for Commercialisation, Enabling Technologies Roadmap Study

Manufuture-EU, Manufacturing Research and Innovation in Horizon 2020

ProMexico, Designed in Mexico – Roadmap for design, engineering and advanced manufacturing

UK Technology Strategy Board, Concept to Commercialisation: A strategy for business innovation, 2011-2015

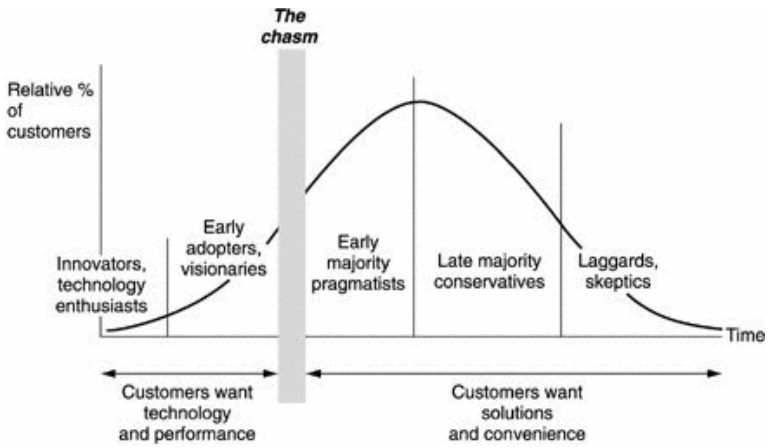
UK Technology Strategy Board, Shaping our National Competency in Additive Manufacturing

Wohler Associates, Additive Manufacturing Technology Roadmap for Australia

World Economic Forum, Redesigning Business Value: A Roadmap for Sustainable Consumption

World Economic Forum, The Future of Manufacturing Opportunities to drive economic growth

Technology Adoption and SME Culture/Readiness



	Time to Adoption (years)				
Manufacturing Processes & Strategies	In house for over 5 years	Recently (<5 yrs)	Soon to adopt (within 2 yrs)	Expect to adopt (2-5 yrs)	No Interest – Not Applicable
ERP, MRP systems					
Lean, Lean – 6 Sigma, ToC					
Current Technology	In house for over 5 years	Recently (<5 yrs)	Soon to adopt (within 2 yrs)	Expect to adopt (2-5 yrs)	No Interest – Not Applicable
CNC or adv. Machining					
Basic automation (PLC)					
Adv. Materials forming – superalloys, composites, ceramics					
RFID materials mgmt					
Welding Robots					
Emerging Technologies	Recently (<5 yrs)	Soon to adopt (within 2 yrs)	Expect to adopt (2-5 yrs)	Longer Term (5-10 yrs)	No Interest – Not Applicable
Additive Manufacturing					
Machine Vision					
M2M Communications					
Robotic Assembly					
Cloud computing for Supply Chain transactions					

Presentation Summary of Emerging Technologies in Advanced Manufacturing