REPORT TO THE PRESIDENT

CAPTURING A DOMESTIC COMPETITIVE ADVANTAGE IN ADVANCED MANUFACTURING

Report of the Advanced Manufacturing
Partnership Steering Committee

Annex 1:

Technology Development Workstream Report

Executive Office of the President

President's Council of Advisors on
Science and Technology

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PREFACE

In June 2011, the President established the Advanced Manufacturing Partnership (AMP), which is led by a Steering Committee that operates within the framework of the President's Council of Advisors on Science and Technology. In July 2012, the AMP Steering Committee delivered its report to PCAST, entitled *Capturing Domestic Competitive Advantage in Advanced Manufacturing*. PCAST adopted this report and submitted it to the President. The Steering Committee's report draws on preliminary reports prepared by several "workstreams." These workstream reports have been made available as on-line annexes to the Steering Committee report.

Report of the Advanced Manufacturing Partnership Steering Committee Annex 1:

Technology Development Workstream Report

EXECUTIVE SUMMARY

Background

The Technology Development Workstream had two broad objectives. The first was to determine a sustaining mechanism to be used for identifying and developing key manufacturing technologies, and the second was to set forth a set of top technology areas that would ensure U.S. manufacturing competitiveness.

To meet the objectives, the mechanisms used to gather data were mainly the following:

- Surveys to elicit opinions and feedback from industry and university participants regarding important industries for the future, and key technologies that will be needed, as well as private-public partnership best practice examples and models.
- Workshops with industry and university participants to identify the top technologies required for manufacturing competitiveness.
- Desk research of comparable mechanisms used in other countries and regions to identify and nurture technologies.
- Whitepaper solicitations from select experts.

The research and innovation ecosystem of a nation is highly dependent on the presence of a manufacturing base that provides constant feedback in terms of problems and challenges to be solved. Also, product innovation cannot exist without intimate knowledge and control over the manufacturing process. In other words, design of the product also inherently involves design of the manufacturing process by which the product will be made. Historically, the United States has had a vibrant manufacturing base and active programs in both basic and applied research. The distinguishing feature of U.S. research activity has been the sheer breadth and vitality at various levels.

A review of mechanisms used in other countries indicate a use of more hierarchical, systematic planning systems that are explicitly aligned to national strategies– often necessitated by their lack of resources, as opposed to in the United States, where much more bottom-up innovation flourishes and much larger bets are made with respect to research. But in 2011, the world shifted. For the first time in history, total R&D spending in Asia Pacific exceeded total R&D spending in the U.S., with the largest increases occurring in China from government sources. This trend is forecasted to continue at even a higher rate. The use of a structured planning process at a national level has the advantages of both aligning and allocating national resources more efficiently into U.S. efforts to revitalize planning, as well as creating a platform to better address competing national strategies from other countries (that are often government led and therefore difficult for U.S. industry participants to counter by themselves). Therefore, we have incorporated this kind of a hierarchical planning process into our recommendations.

Findings

- A number of model programs have excellent best-practices that can be adopted.
- Greater industry participation is required to identify and nurture technologies—whether in determining the national strategy, developing technology roadmaps, or creating and managing programs. Industry-university-government advisory boards and consortia can work well in this regard.
- An analysis of mechanisms used in other countries and regions suggests that key differences exist in the use of national foresight mechanisms, as well as higher involvement of industry and university stakeholders.
- A broad list of crosscutting technologies that are critical for establishing U.S. manufacturing competitiveness has emerged. This list can help kick-start the sustaining mechanism for identifying and developing advanced manufacturing technologies.

High-Level Recommendations—Sustaining Mechanism for Identifying and Developing Technologies

A technology life-cycle process is proposed, using the following main steps:

- **Use a national foresight mechanism to generate a national strategy on the set of important future needs and broad technology areas of focus.** Incorporate inclusive and multiple methods to gather as much input as possible from various industry and university stakeholders and subsequently arrive at a consensus.
- **Use industry-government-university consortia (where possible) to generate detailed roadmaps for industries of strategic importance and based on the broad technology areas laid out in the national strategy.** These roadmaps should include guidance on key performance metrics. For example, if sustainability is an important objective, then there should be a common understanding of what is included in a set of sustainability metrics and how they should be measured. For the cases where industry maturity is low, the federal government has to drive the research and infrastructure development agenda. In fact, many mature industries with a strong U.S. manufacturing base are also under competitive threat, and roadmaps and investment to keep these “crown jewels” profitable are also needed.
- **Create and manage programs to carry out the research and eventually help commercialize technologies.** Industries need to have strong participation in terms of funding, setting program goals and carrying out the project-management activities. Programs need to have long-term goals (essentially run over a few years) and have

stable sources of funding. Rigorous, metric-oriented analysis and review of proposals (to award projects) and performance have to be carried out.

- **Conduct periodic review of program results and strategic analyses of the portfolio of projects.** Adjustments need to be made to funding allocations in the portfolio. Consortia also need to periodically reevaluate their missions and reset their goals depending on changing external conditions.

Successful development and commercialization of advanced manufacturing technologies require that several needs be met, namely:

- The need for effective programs in universities for generating a pipeline of engineers who are engaged in applied research and early stage commercialization, and go on to be future manufacturing and R&D leaders.
- The need for policy support in the area of R&D tax incentives as well as trade incentives to ensure export competitiveness.
- The need for shared infrastructure accessible to industry members, including subject-matter experts (SMEs), for their research and development needs and in enabling commercializing of technologies.

*Top Technology Areas of Focus**—Cross-cutting Technologies Selected as a Starter List for Advanced ManufacturingPartnership (AMP) Focus***

- Advanced sensing, measurement, and process control.
- Advanced material design and synthesis, including nanomaterials, metamaterials, 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.

CHARGE TO THE WORKSTREAM

The Technology Development workstream was given two main objectives. The ***first objective*** was to define the best permanent mechanism for identifying and nurturing the set of technologies that will have the greatest impact on the retention and future growth of manufacturing in the United States, enabling differentiation and competitiveness for U.S. manufacturing from an end-to-end supply-chain perspective over a sustained period of time. The ***second objective*** was to recommend the top manufacturing technology areas from an industry and university perspective and to analyze some of the supporting/enabling factors and constraints that affect U.S. manufacturing competitiveness.

PROCESS FOLLOWED

The following actions were taken to define the sustaining mechanism:

- A qualitative survey was carried out with key industry personnel who have extensive experience working in joint programs with Federal agencies, national labs, and universities. They were asked for their experiences on best run programs, opinions on best practices for program management, and views on best practice partnership models from other countries and regions.
- Research of public-private partnerships and technology-development mechanisms in other countries and regions was carried out to determine alternative models.
- An analysis of the key factors that should be taken into account to identify and develop technologies was carried out.
- A white paper was solicited from a joint industry-university expert panel to analyze and lay out recommendations on improving public-private partnerships.

The results from the actions above were synthesized into defining an ideal technology lifecycle process, finding gaps in current practice, and developing specific recommendations accordingly.

To establish the list of key advanced manufacturing technologies, three separate surveys were carried out. The first was a pilot survey with an initial set of industry and university participants. The aim was to identify the manufacturing industries that will have the greatest economic and national impact on the United States now and into the next decade and then identify the set of leading advanced manufacturing technologies required. A set of interim findings was created. Feedback was elicited from broader group of universities (APLU), manufacturing members (MAPI), and small and medium enterprises (NCMS) in terms of the interim findings. Based on the results of the previous steps, a more comprehensive survey was then carried out with a broader set of industry and university respondents on the key technology areas for the future.

The team then compared these technology areas with the FY11 and FY12 Federal agency advanced manufacturing programs to verify alignment to needs and to identify technologies that would benefit from stronger public-private partnerships. Interactive workshops were held in universities to further gather input on key technology challenges for manufacturing, as well as the top technologies on which stakeholders should focus.

A high-level analysis was carried out of some key megatrends and drivers for manufacturing to determine whether the technologies selected had sufficient coverage, and a final list of top technology areas to enable U.S. manufacturing competitiveness in terms of enhancing tradability and differentiation was then synthesized from the outputs from the previous steps. This formed the starter list that could be used in the strategic-planning process.

KEY FINDINGS

Sustaining Mechanism for Developing Technologies

The survey of U.S. industry participants on public-private-partnerships elicited the following qualitative inputs:

- The best run programs have the requisite amounts of applied research and business focus and are thus often led by industry-government-university consortia.
    - The semiconductor industry is an excellent case study of consortia running applied and basic research programs over a long period of time with fairly good historic results. SEMATECH and SRC have been cited as good role model consortiums with very well run programs. Roadmapping has also been a highlight of these consortia, with the ITRS being a good example.
    - Consortia have a goal of driving pre-competitive technologies that can benefit all companies involved to move the industry forward.
- There are also excellent examples of outstanding government-led programs—for example, the National Institute of Standards and Technology Advanced Technology Program (NIST-ATP), Defense Advanced Research Projects Agency (DARPA), various Department of Energy – Energy Efficiency and Renewable Energy (DOE-EERE) programs, Department of Defense (DOD) ManTech program—that have been cited by respondents.
- Stakeholder participation and transparency are key. Industry partners need to be involved in the process of determining programs goals and strategies.
- Programs need to have long-term goals and stable funding commitments. All respondents noted that the best programs were always multiyear programs with clear funding commitments.
    - Because of the longer term view, partnerships need to periodically examine their missions and goals and make periodic adjustments.
    - A longer term perspective does not imply a purely theoretical effort; programs need to have a strong focus on (ultimately) reducing research to industrial practice.

- Partnerships require industry participants to co-fund initiatives. This brings the necessary focus on applied research and drives a results-oriented approach due to strong return-on-investment (ROI)-driven incentive.
- The prevailing view is that the government should not pick product technologies for the future (i.e., try to make big bets on specific technologies unilaterally), but rather define the problem statement fairly tightly and let the partnership work out the technologies. An example would be the Nanoelectronics Research Initiative (NRI), which has as its mission, "Demonstrate novel computing devices capable of replacing the CMOS FET as a logic switch in the 2020 timeframe."
- Partnerships need sufficient longevity and breadth to establish and pursue overall objectives that extend across multiple Federal funding agencies while remaining responsive to individual agency objectives.
- Universities are, and need to be, a key focal point for research and education mechanisms. This has worked well for some of the best run programs and, more important, is a key mechanism through which a pipeline of research and leadership talent for the manufacturing industry has to be built. An important point to note here is that federally funded programs have played a key role in supporting industry internships/graduate fellowships and generating this pipeline (e.g., the Air Force Research in Aero Propulsion Technology [AFRAPT] fellowship program).
- From a specific program-management perspective, the following are some of the key requirements:
    - Program management should involve the industry/university participants. Applied-research programs should in fact be run by program managers from industry as they have high stakes involved (i.e., their own funding and ROI).
    - The need for unbiased technology oversight committees to double-check the technologies selected in the roadmap.
    - Rigorous, metric-based project selection/reviews and portfolio management.
    - NIST-ATP's gate-based proposal practice, which begins with concept papers, followed by technical proposals and finally business proposals, has often been cited as a best practice, well-defined, gated proposal process. Early feedback on concepts helps companies unfamiliar with the process to quickly learn it and be more efficient with resources
    - Contracting or award agreements should be simplified and flexible. A key requirement is to ensure that intellectual property (IP) availability is easy for the industry partners.

The comparative study of other country/region mechanisms for identifying and developing technologies uncovered the following key findings:

- Germany, Japan and Korea are examples of high-cost economies that have focused on, and successfully managed to retain, their manufacturing bases. The following are some of the key points related to the processes and policies utilized by these countries:
    - All have clear national objectives and strategies for retaining manufacturing excellence. They use hierarchical planning mechanisms incorporating technology-foresight processes. The foresight processes themselves are highly inclusive, inviting participation from numerous industry and university experts, whether through white-paper solicitations, Delphi forecasts, brainstorming workshops, or other mechanisms. The German model also makes extensive use of data mining and bibliometrics.
    - Manufacturing still retains its prestige as a career path in these countries. Students carry out applied research in universities and institutes and go on to become manufacturing leaders in industry.
    - Government supports student internships, enabling critical hands-on learning
    - In Germany, universities and institutes are deeply involved in solving industry problems. There is a large component of applied research that is carried out in the various educational institutions in the ecosystem. German universities acknowledge and reward applied-research contributions to a greater extent than U.S. universities.
    - In Japan, applied research is driven more by government and industry consortia than universities, though that has been changing over the last decade.
    - In these countries, SMEs are considered an important part of the ecosystem, and research programs and infrastructure exist to specifically benefit them.
    - They have retained a strong grip over capital-intensive equipment globally. In other words, although a lot of the commoditized manufacturing operations have moved to low-cost economies, the high-cost capital equipment (utilizing advanced manufacturing technologies and quality) needed in the factories are often sourced from these countries.
- The European Union’s 7th Framework Program (FP7) is an inclusive mechanism for identifying and developing technologies. The goals of the program are to achieve growth, employment creation, industrial competitiveness, and technological leadership. Extensive community consultation through events, workshops, and conferences is employed in finalizing the research areas of focus.
- In the semiconductor industry outside the United States, a number of consortia of government and industry have developed technologies and built industrial competitiveness. Among these are SELETE in Japan, IMEC in Belgium, LETI in France, and ITRI in Taiwan.

Advanced Technology Areas

The top industries identified through the industry survey were the following:

1. Advanced materials **(75%).**
2. Agriculture chemicals, biotechnology, chemicals, and communication equipment **(50%).**
3. Aerospace/defense, automotive, appliances, building materials, health care, consumer products, renewable energy **(38%).**

The industry respondents identified the following technologies as most critical to retaining and growing a manufacturing base in the United States:

1. Advanced sensing and measurement technologies **(88%).**
2. Sustainable manufacturing **(75%).**
3. Process control and nano-scale materials **(60%).**
4. Nano-manufacturing, lightweight materials, information technology, flexible electronics, coatings, and continuous process control **(50%).**

Additional insights gained from the in-depth industry interviews also revealed the following industrial priorities and interests on potential game-changing technologies:

- **Materials genome.** Industry believes this is a game changer, particularly for nano-scale materials. A number of the advanced materials companies are already investing in this area; however, all agree that further improvements in materials modeling and optimization, scientific data sharing, and information management are required to enable the full potential of in-silico materials design and accelerated delivery of next-generation materials and processes.
- **Lightweight materials.** Industry is heavily investing in advanced materials and composite processing technologies to enable development of lightweight batteries, building materials, auto components, etc. Most programs are aligned to energy drivers—enhanced energy efficiency, energy storage, and energy generation.
- **Nano-manufacturing.** Breakthrough advances are required to consistently and economically manufacture game-changing nano-materials and chemicals. Advances in this area are tightly coupled with materials genome, advanced sensing and measurement, visualization, and process control.
- **Information technology.** Every respondent noted the critical importance of information technology and data management. It is the foundation for enabling advanced manufacturing from product and process design, to adaptive-process control- to supply-chain management.
- **Adaptive design and processes.** Industries are interested in enhanced methods for rapid design and modularization of flexible, adaptive products and processes.

The university respondents deemed the following technologies as critical:

1. Nano-manufacturing **(60%).**
2. Advanced sensing and measurement technologies **(60%).**
3. Information technology **(50%).**

The respondents also identified additional early-stage technology areas that have the potential to be future game changers:

- **Advanced material design capabilities (material genome, integrated computational materials engineering).** Advanced materials will play a huge role in future products, and developing the ability to discover and manufacture them efficiently is critical.
- **Additive manufacturing.** The ability to inexpensively produce highly customized or personalized products is the ultimate goal of manufacturing technology and will be a true disrupter. A related, but more highly developed, set of concepts would be those from DARPA's AVM (Adaptive Vehicle Make) portfolio, which aims at "a bitstream-programmable manufacturing facility that can be rapidly configured to produce a new design or design variation with nearly zero learning curve. We call this large-scale manufacturing in quantities of one."
- **Bio-manufacturing.** Because bio-products will likely play a significant role in the future, it is imperative that the right foundations are laid in this area to drive viable economics.
- **Industrial robots.** These have the potential to increase the productivity of the workforce.

A systematic analysis of the various factors that influence the evolution of manufacturing technology from the perspectives of differentiation and tradability identified six key factors:

1. Energy efficiency
2. Sustainability/green
3. Productivity
4. New technology
5. Globalization
6. Customization/personalization

A study of the megatrends that are likely to play a big role over the next decade or two—energy, health care, food security, resources management (water and minerals), safety and security, smart world—overlaid on the factors enabling differentiation and tradability, leads to a broader list of manufacturing technologies that also includes the early-stage and future game-changing technologies that emerged from the industry and university surveys:

- Bio-manufacturing.
- Additive manufacturing.
- Micro-manufacturing.
- Advanced manufacturing equipment.
- Industrial robotics.
- Advanced forming (including near-net-shape manufacturing) and joining/bonding technologies.

Combining the information gathered above, we get a final list of technologies:

- 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.

This cross-cutting set of technologies has wide applicability across many industries. These technologies will also play a critical role in addressing national strategic needs (such as defense and food security). Note that there is considerable interplay between these technologies, and their effects and benefits can really be realized when they are applied in an integrated fashion.

Additional Considerations

The survey responses also uncovered other significant factors that drive investment decisions on whether to manufacture within or outside the United States. It is essential that improved policies are set up in terms of tax incentives, investment support, and trade policies to make the United States a competitive manufacturing destination.

The following are the top factors that contribute to the decision to manufacture outside the United States:

1. Proximity to customers **(90%).**
2. Cost **(50%).**
3. Regulations **(40%).**
4. Tax policies **(40%).**

The following are the top factors that contribute to the decision to bring back manufacturing to the United States:

1. Cost **(50%).**
2. Regulations **(50%).**

3. Proximity to customers **(40%).**
4. Tax policies **(40%).**
5. Investment required **(40%).**

Based on the responses, the biggest reason for manufacturing outside the United States is proximity to customers. This reflects the growing importance of markets outside the United States, especially in the emerging economies. This is why technologies for optimization of the overall global supply chain need to be included in our focus on manufacturing. For the decision to manufacture in the United States, the end-to-end supply-chain costs, as well as financial and regulatory factors, play a critical role. We have to ensure that we improve both:

- Differentiation, that is, have better products than competition.
- Tradability, that is, the ability to manufacture in the United States and export anywhere competitively.

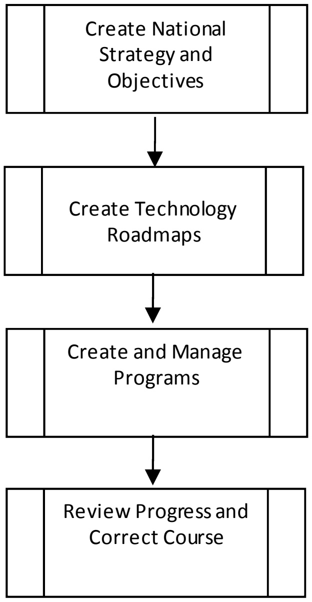
In addition, two more factors are critical for successful development of advanced manufacturing technologies:

- A pipeline of trained engineers carrying out research in universities, who then go on to become manufacturing leaders.
- A network of shared infrastructure for carrying out the research needed by industry

RECOMMENDATIONS

Sustaining Mechanism for Technology Development

The sustaining mechanism is modeled as a process in the figure below.



The specific recommendations are as follows:

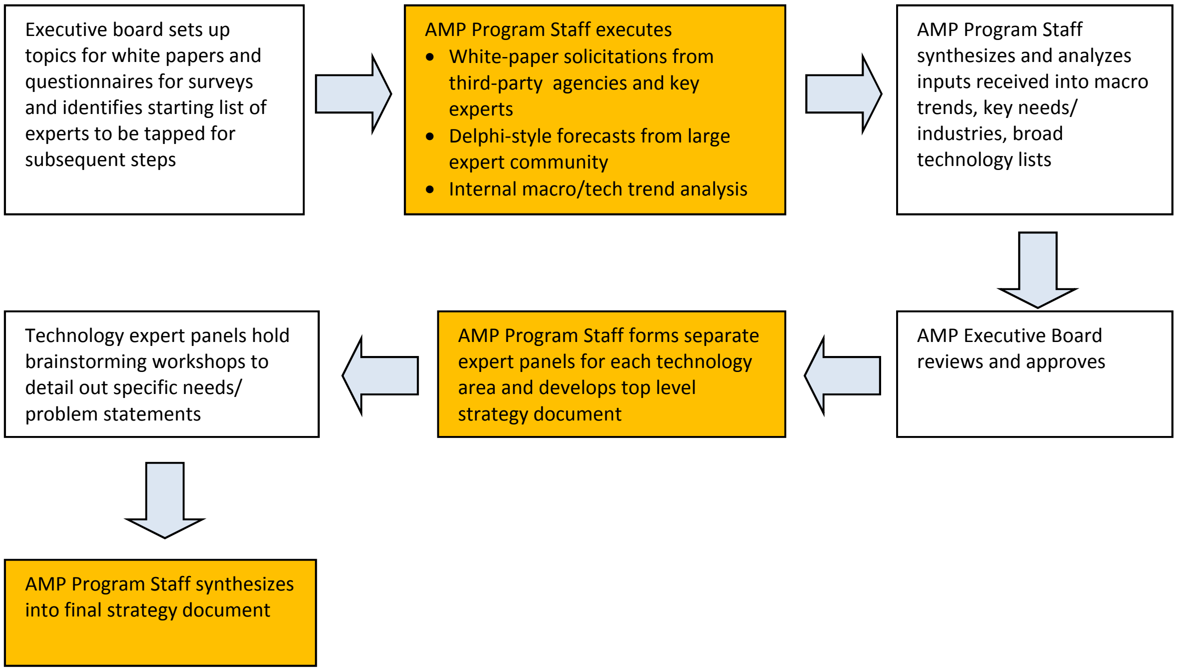
1. The Advanced Manufacturing National Program Office should establish and coordinate the first step of creating the national strategy and objectives, that is, to set up a national foresight process. This activity needs to be completed over the next 3 months or so. The foresight process itself will be an infrequent task done once every 4 or 5 years. The next steps of the technology life cycle are highly dependent on the results of the first step, so the subsequent owners and time lines have to be determined after the completion of step 1.
2. This step of creating the national strategy and objectives needs to analyze strategic national and global needs, identify macro trends that will likely play out, and create future scenarios and forecasts. The table below lays out a guideline framework and a directional view of the nature of the analysis required. Strategic choices will be outlined in terms of the key factors (i.e., industry maturity, national need [defense, energy, infrastructure, food, economic security], global demand and technology maturity) and specific industries. Estimating the specific categorization of industries or technologies (e.g., in terms of high-, low-, or medium-technology readiness or global market demand) is not a straightforward exercise, but qualitative estimations should be carried out. The "Don't do it" scenarios below are those where public-private-partnerships are not advised (note that this is a broad, directional view of how the strategic analysis and decision-making may proceed).

   The final output will be a document that lays out the strategic national needs (and associated industries), future scenarios, and broad technology areas of strategic interest.
3. Multiple mechanisms are needed to make the national foresight process step as inclusive as possible and to drive consensus. Among these are expert panels involving industry/academic fellows, white-paper solicitations from research institutes/consortia, Delphi-style forecasts, brainstorming workshops, surveys, etc.

Framework for Priorities for Federal investments in Advanced Manufacturing Technologies

US National Needs	Global Market Demand	US Manufacturing Competitiveness	Global Technology Readiness	Implication	Technology Required to Drive US Manufacturing Competitivenss	Role of US Government	Role of Industry	Role of University
High	High	High	High	Mature field. US strong global exporter.	Applied research & development to maintain leadership	Strategic demand requires capability.	Leads research & production investment	Conduct applied research
High	High	High	Low	US positioned for strong global leadership. Technology not available.	Basic to applied research	Strategic demand requires capability.	Defines roadmaps, develops technologies and establishes manufacturing capabilities & facilities.	Conduct basic research
High	High	Low	High	US lags. Net importer.	Big investment required to close gap.	Strategic demand drives establishing US manufacturing base.	Establish globally competitive manufacturing capabilities & facilities.	Breakthrough technology
High	High	Low	Low	New field. High export potential. No global Leader. New technology & infrastructure required.	Basic research	Strategic demand drives research & infrastructure build.	Partner with universities & national labs to conduct basic & applied R&D & establish required infrastructure.	Conduct basic research
High	Low	High	High	US specific need. Technology mature. Government roadmap drives infrastructure investment.	Infrastructure investment	Strategic demand requires capability & drives future infrastructure investment.	Establish infrastructure to meet national demand	Breakthrough technology
High	Low	High	Low	US specific demand. Government roadmap drives research and infrastructure investment.	Basic to applied research	Strategic demand sets requirements.	Establish infrastructure to meet national demand.	Conduct basic research
High	Low	Low	High	US needs; others produce. Low global demand. US vulnerable.	Big investment required to close gap.	Strategic demand drives infrastructure build & incentives.	Only establish capability if government funds.	Breakthrough technology
High	Low	Low	Low	US needs; no one produces; invention required.	Basic research	Strategic demand drives research	Establish infrastructure to demonsrate technology & meet national demand	Conduct basic research
Low	High	High	High	US leads; strong exporter. Industry drives research based on global demand.	Applied research	Incentivize exports	Industry leads research & invests in production.	Breakthrough technology
Low	High	High	Low	US leads; strong exporter. Industry consortium leads future roadmapping.	Basic to applied research	Incentivize exports	Industry defines roadmaps, develops technologies and establishes infrastructure.	Conduct industry funded basic & applied research
Low	High	Low	High	US not global leader. Commoditized market.	Big investment required to close gap.	Unless US vulnerable, no action required.	Only invest if breakthrough enables global competitiveness.	Breakthrough technology
Low	High	Low	Low	New field. High export potential. No global Leader. New technology & infrastructure required.	Basic Research	Incentivize exports	Drives research & infrastructure investment. Partners with universities to conduct basic research.	Conduct industry funded basic research
Low	Low	XXX	XXX	No demand. Don't do it.				

The sequence of steps proposed is given below:



4. The next step in the process is to create roadmaps in the broad technology areas identified in the national strategy. Two scenarios are considered for creating technology roadmaps:

    a. For mature industries, the preferable mechanism is to drive the roadmapping exercise through industry-government-university consortia.

    b. For nascent industries, since consortia will likely not exist, or will not have the scale needed to drive this exercise, the Federal Government will need to set up working organizations with broad participation.

    This also has to be an inclusive process utilizing collective intelligence as much as possible, with the aim of driving consensus. Here again, different mechanisms—such as expert panels, technology white-paper solicitations, surveys, competitive analyses white papers, data mining, workshops, etc.—have to be used. A process similar to the one outlined for the foresight process may be used, though face-to-face brainstorming workshops will probably play a larger role.

5. There are a number of recommendations in the area of program management:

    a. Programs need to be multiyear with stable funding because a certain mix of basic research goals has to be set, which requires time to yield results.

Moreover, practical results and business impacts also take a few years to manifest themselves.

b. It is critical that a co-funded model is used where both industry and government bring in the necessary components—the specific percentages will depend on the nature of the roadmap objectives—so that industry has the necessary participation and incentives to drive commercialization of technologies.

c. For mature industries, consortia should create and manage programs. For nascent industries where the government plays a larger role in driving research and infrastructure and is therefore the primary stakeholder, programs will have to be managed by dedicated program managers from Federal agencies. Overall, many ongoing programs already exhibit best practices. For example, the DARPA practice of using short-tenure professional program managers may be a model worth emulating.

d. As is largely done today, competitive-bidding processes need to be used for disbursing research funds for projects. Utilizing the gate-oriented approach of NIST ATP is recommended. In addition, clear metrics for proposal evaluation and award need to be set up. Broad criteria are recommended across all programs:

    i. Novelty of the approach

    ii. Impact of the approach in terms of enhancing manufacturing competitiveness by enhancing tradability and differentiation (e.g. in terms of reducing end-to-end supply-chain costs, reducing capital investments and risks, enhancing product features with significantly reduced costs).

    iii. Degree of addressing pre-competitive technologies, which should enable the industry and not a single player.

    iv. Degree of usage of educational and shared-research infrastructure.

    In addition, applied research programs should also include the following criteria:

    i. Business case in terms of time line of commercialization, potential market revenues, and ROI.

    ii. Technical readiness of proposed approach (should be sufficiently mature).

    iii. Sustainability of the approach.

    Basic research programs can include the following additional criteria:

    i. Potentially transformative nature of outcome (game changer, or opens up completely new areas of application).

e. Program policies also need to clearly lay out IP access rights for industry. Since industry co-funding is mandated, either exclusive-use or shared-use privileges need to be provided to all industry participants (depending on how the funds are actually allocated to individual projects).

f. Periodic reviews of the portfolio of projects need to be carried out by key stakeholders. Funding for programs need to be stable, but allocations within the portfolio need to be reviewed and adjusted. Portfolio allocations need to take care of the right mix of:

    i. Near-term benefits perhaps connected strongly to brown-field opportunities.

    ii. Longer term possibilities to create entirely new manufacturing opportunities—whether they are for products or manufacturing processes—as well as to help protect brown-field competitiveness.

g. Reviews need to ensure research has not been preempted by market forces and that it remains relevant to market needs. Rigorous, metric-based portfolio analysis needs to be incorporated by the program. Some suggested metrics are:

    i. Number and extent of "insertions" of research into products (or at least adoption into development programs in industries or as venture capital/private equity (VC/PE) funded investments).

    ii. Revenue and global market share generated by research (in terms of product revenues), which are more applicable for applied programs.

    iii. Number of patents.

    iv. Number of publications in important peer-reviewed journals.

    v. Number of students trained on the technology developed.

    vi. Number of SMEs benefited, or new startups spawned by, technologies.

    vii. Number of jobs created.

6. Programs need to leverage community colleges, universities, national labs, intermediate technology institutes (e.g., manufacturing innovation institutes) and independent research institutions (e.g., EWI) to carry out research and develop the talent pipeline for industry. Universities and national labs will typically be engaged by larger companies (and consortia) and for a larger component of basic research. The distinctions between universities and national labs should also be worked out to emphasize their complementary and partner roles and to avoid competitive concerns. In any case, it is critical that clear and sufficient goals of commercialization be set down in program objectives. In general, early-stage technologies need to leverage universities and national labs as shared infrastructure, whereas applied research has to revolve around the intermediate institutes and nonprofit research centers. In terms of the technology areas that have been explored as part of this study, some good areas that can be taken up by intermediate institutes/independent research institutes are sustainable manufacturing, digital manufacturing, information technologies, additive manufacturing, advanced forming and joining/bonding technologies, advanced manufacturing equipment, industrial robotics and some aspects of flexible electronics. These fields already have a high percentage of applied research opportunities that need to be commercialized.

7. It is critical that SMEs and elements of the extended value chain are also involved and gain the required access to research infrastructure. Here, the intermediate institutes (MII) and EWI-like research institutes can play a vital role. Each institute will typically focus on a set of specific technologies. A mix of contract-based (i.e., for-fee project research for individual companies) and Federal funds needs to be deployed. The NIST-MEP program can play a vital role in connecting SMEs to the requisite research resources in their areas of interest. State and regional involvement is also critical.
8. Industry further needs to co-fund internship and fellowship opportunities in universities and intermediate technology institutes to incentivize students to take up a manufacturing career path and provide them the right exposure to applied problems. Funding members or consortia need to be involved on advisory boards of universities/institutes to drive curricular changes to include new technologies that are developed. In general, early-stage technologies (low-technology readiness) will be present primarily in university curricula. Technologies that are intermediate in terms of their readiness level will typically be covered in both university and intermediate institutes as part of their applied-research programs. Very mature technologies will typically be the domain of community and technical training colleges as part of their curricula.
9. Finally, to ensure continuity through the whole technology life-cycle process and to be able to measure strategy through to execution, the National Program Office has to set up dedicated tracking teams for each broad technology area. The teams will need to link up the various activities and resources listed above and will essentially track progress and issues until the next cycle of the national strategy process. The teams also need to ensure sufficient cross-integration of the technology areas. All of this will facilitate a much-needed PDCA (i.e. Plan-Do-Check-Act) cycle. In fact, this “tracking” mechanism can be broadened to also function as a resource “web” that can speed up connections across all the different players in the value chain associated with the broad technology area, such as allowing SMEs to locate research resources, connecting early-stage technology developers with commercialization entities, etc.

Top Technology Areas

Based on the inputs and analysis carried out by this workstream, 10 technology areas have been selected as a starter list on which the stakeholders can focus:

- **Advanced sensing, measurement, and process control (including cyber-physical systems) also known as smart manufacturing, also known as advanced automation.** This set of cross-cutting technologies has applicability across almost all industry domains. These technologies are critical for enhancing tradability by way of end-to-end supply-chain efficiency (e.g., low-cost and pervasive sensors in plants and logistics systems, automatic control and coordination of systems of systems). In addition, megatrends of energy/resource efficiency and better safety/quality also depend highly on advances in sensing and automatic process control. Finally, emerging technologies such as nano-manufacturing or bio-manufacturing need their own specialized sensors and control models.

- **Advanced material design and synthesis.** This area covers design and synthesis of small molecules, nano-materials, formulated solutions, polymers, metals, fibers, coatings, composites, and integrated components (e.g., photovoltaic [PV] devices). This design and synthesis entails integration of computational modeling, state-of-the-art synthesis tools (e.g., high throughput), and advanced research analytics. Almost all the megatrends depend heavily on advanced materials, whether for energy efficiency, alternate energy devices, new materials to counter current resource shortages, next-generation consumer devices, or new paradigms in safety and security. Advanced materials will fuel emerging multi-billion dollar industries.
- **Visualization, informatics and digital manufacturing technologies.** This area includes integrated, enterprise-level smart-manufacturing methodologies (e.g., moving directly from computational/digital design to materials planning/purchasing to manufacture of customized formulated solutions for coatings to electronic materials). One aspect deals largely with manufacturing competitiveness through end-to-end supply-chain efficiency—reduced manufacturing cycle time, lower worker injury and illness rates, higher process yields, and higher energy efficiency, brought about by more networked information, control, and management across various entities in the value chain spanning across enterprises. The other aspect deals with the speed with which products are brought to market, which will be a key differentiator. It entails research focused on embedded sensing, measurement, and control systems for highly corrosive, high temperature processes affecting everything from PV to lightweight materials to polymer synthesis. It also entails control systems enabling manufacture of high-performance, highly controlled structures and devices. It also entails simulation and visualization technologies that can optimize the product and its manufacture in the virtual space (therefore bypassing time-consuming and expensive physical testing and experimentation) before actual physical production is started.
- **Sustainable manufacturing.** A key national need, this area covers high-performance catalysis, novel separations (including smart solvents), fluid mechanics, reactor design, etc. A major area of focus will be energy-efficient manufacturing, where high energy-consuming manufacturing processes need to be replaced with lower energy-consuming alternates. Areas such as remanufacturing (i.e., using recycled components to manufacture) also need to be researched. In addition to savings in energy consumption and higher profitability, many accompanying benefits can aid the competitiveness of industry. For example, an important mechanism to achieve energy efficiency would be to achieve a lossless process, which has quality benefits.
- **Nano-manufacturing (includes micro-feature manufacturing).** Nano-materials will most likely play a game-changing role in most future megatrends. Applications range from higher efficiencies in solar cells and batteries, to environmental control through nanotech-based filters, to nano-biosystem-based medical applications, to next-generation electronics and computing devices, to significantly enhanced material

properties with nano-scale additives. Similarly, microstructures on devices will play a key role in delivering new features or enhancing current functionality. The challenge will be to scale up volumes and reduce costs.

- **Flexible Electronics.** These technologies will be major differentiators in the next generation of consumer and computing devices. Some application industries such as photovoltaics and flexible displays are slated to be among the fastest growing ones over the next decade.
- **Bio-manufacturing.** Health care is going to be a key megatrend worldwide, with requirements for newer, more effective and less expensive molecules. Food security is also going to be a key concern of the future, where again bio-manufacturing will play a critical role. In addition, this technology has the inherent potential to enable energy efficiency in manufacturing. For instance, it offers room-temperature synthesis routes that can possibly replace current high-temperature processes. Innovations in the Bio–Nano-interface such as bio-inspired manufacturing using self-assembly have the potential to simplify and scale up many complex/expensive nano-manufacturing technologies and make them economically viable. According to MIT's Industrial Performance Center (IPC), bio-manufacturing "is a technologically advanced, innovative industry that requires highly skilled workers with commensurately high pay," and this industry can therefore play a vital future role in the economic value chain.
- **Additive manufacturing.** A possible megatrend for the future may be the production of highly customized/personalized products. Additive manufacturing ("3D printing") is the main technology that holds this promise. The technology also has several characteristics that enable other unique capabilities. For example, multiple materials can be processed, enabling smart components to be fabricated with embedded sensors and circuitry. Internal features can be produced that significantly enhance performance and therefore differentiate products, such as internal cooling channels optimized for thermal performance not possible with current manufacturing techniques. Also, materials can be processed efficiently with little waste, enhancing the sustainability of organizations that adopt additive-manufacturing technologies.
- **Advanced manufacturing equipment (including testing).** The national innovation ecosystem requires continuous feedback from challenges and new-requirements manufacturing. Securing a hold on the market for manufacturing equipment required in different industries (which is always highly capital intensive) ensures this feedback in a sustained fashion. In other words, even if specific plants are set up overseas, ensuring they have U.S. equipment ensures the necessary connectivity with ongoing manufacturing to close the feedback loop for continued innovation. In addition, these are advanced technology areas requiring significant research activity and funding, where maintaining differentiation is relatively easier for U.S. manufacturing.
- **Industrial robotics.** Automation and use of industrial robots in labor-intensive manufacturing operations such as assembly, product inspection, and testing can enable high endurance, speed, and precision. This has great potential to enhance productivity

of the U.S. workforce and enable it to compete with low-cost economies, both for domestic and export markets.

- **Advanced forming (including near-net-shape manufacturing) and joining/bonding technologies.** Most current mechanical manufacturing processes continue to largely depend on traditional technologies such as casting, forging, machining and welding. These technologies will most likely be the mainstay of future production processes for some time to come. But new needs for greater energy efficiency, resource efficiency, and greater performance require continued innovation and the search for disruptive technologies that will in turn help maintain U.S. competitiveness.

To summarize, a starter list of technology areas has been identified that can be used to kick-start the national strategic-planning process. These technologies address key national needs such as defense, energy independence and efficiency, food security, homeland security, and health care, and will have great bearing on ensuring U.S. manufacturing competitiveness in terms of both differentiation and tradability of products. Because of the interplay beetween these technologies, they need to be developed in tandem to ensure greatest impact.

Current support from an illustrative set of Federal programs for these technology areas is shown in the table below. Although a number of these programs are well aligned with industrial needs, it likely that gaps remain in the Federal portfolio. Steps should to be taken to carry out a complete analysis of the portfolio and to ensure additional investment in the areas where alignment is lower than required.

Advanced Technology	**Agency**	**FY11 and FY12 Programs**
Advanced sensing and measurement technologies	NSF	Cyber physical systems
Nano-manufacturing	NSF	Nano-manufacturing
Information technology		
Sustainable manufacturing	DOE EERE ITP	Industrial energy efficiency ($120 MM/ 3 years)
Nano-scale materials	DOD	Alternate energy
Continuous process control		
Flexible electronics	DOE, NIST	Flexible electronics for batteries and solar cells, NITS (TIP)
Process control		
Visualization		
Adaptive control		
Coatings		
Bio-manufacturing	DOD/ DOE/NIST	Bio-manufacturing; low-carbon biosynthesis of industrial chemicals (% $500 MM), TIP program (NIST)
Biofuels	DARPA	Synthetic biology ($35 MM)
Lightweight materials	DOD/ DOE	Small, high-powered batteries; cost-effective, ultralight, ultra-durable materials for autos (% $500 MM)

Advanced Technology	**Agency**	**FY11 and FY12 Programs**
Material genome	DOD/DOE NIST/NSF	Materials Genome Iniative ($100MM)
Optoelectronics		
Precision machining	DOD	Metal fabrication
Recycle waste-management technologies		
Simulation/test infrastructure	NSF	Cyber physical systems—smart buildings and bridges
Additive manufacturing	NSF	Advanced manufacturing (manufacturing machines and equipment)
Advanced ceramics		
Composite assembly	DOD	Advanced composites
High-temperature processing		
Industrial robots		
Nano-technology medical diagnostics devices and therapeutics		
Ceramics	DOD	Transparent armor, stealth technology ($24MM)
Conductive inkjet technology		
High-speed mixing		
Mobile robots	SBIR/NSF	National Robotics Intiative ($70MM)
Reaction engineering		
Separation technologies		
Metal-jet technology		
Ultra-efficient waste heat recovery		
Advanced forming (including near-net-shape manufacturing)	NSF	Advanced manufacturing (manufacturing machines and equipment)
Advanced joining/bonding technologies	NSF	Advanced manufacturing (manufacturing machines and equipment)

SUPPORTING MATERIALS

Sustaining Mechanism for Technology Development

Best-practice public-private partnership programs: Survey findings

		GUIde	**AFRAPT**	**NRI**	**FCRP**	**SEMATECH**	**MAI**	**NREC**	**ATP**	**DARPA**	**ARPA-E**	**DOE-EERE**	**TARDEC/NAC**	**CAPD**
Objective		to improve bladed disk forced response and high cycle fatigue prediction in aircraft engines	Talent pipeline - advanced engineering degrees in areas such as aerodyne., combustion, and the structural dynamic sciences	Alternative computing devices to CMOS FET	enable ultimate CMOS technology scaling and enable highly complex designs	enable ultimate CMOS technology scaling and enable highly complex designs	Develop low cost metals for US airforce	To develop and mature robotic techs. from concept to commer-cialization	early stage, high-risk technology dev. that would otherwise go unfunded	pursue and exploit fund. science and innovation for National Defense	To focus on creative "out-of-the-box" transform.l energy research that industry by itself cannot or will not support due to its high risk but where success would provide dramatic benefits for the nation	invests in clean energy technologies that strengthen the economy, protect the enviro., and reduce depend. on foreign oil	deliver the most advanced technology solutions to improve the Nation's ground vehicle fleet	Under. and aid complex design and operation issues faced by industry Develop and advance modeling and solution methods for process systems eng.
University participant?		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Consortium		GUIde	N	SRC	SRC	SEMATECH	MAI	N	N	N	N	N	N	CAPD
Best practice criteria														
Funding Period		15 yrs	Multi-year	Since 2005	Since 1999	Multi-year	Annual	Multi-year	Multi-year	Multi-year	Multi-year	Multi-year	Multi-year	Multi-year
Clear mission		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Industry role	**Program Mgt**	N	N	Y	Y	Y	Y	N	N	N	N	N	N	N
	Research direction	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y
	Project steering	Y	N	Y	Y	Y	Y	N	N	N	N	N	N	Y
	Practical experience		Y	N	N	Y	Y	N	N	N	N	N	N	Y

	GUIde	AFRAPT	NRI	FCRP	SEMATECH	MAI	NREC	ATP	DARPA	ARPA-E	DOE-EERE	TARDEC/NAC	CAPD
Co-funding	cost shared exper. hardware and on projects	Summer internships at engineer salaries	Cost shared	Cost shared	Cost shared	Cost shared	N	N	N	N	Cost shared	N	Cost shared
Research type	Applied rather than basic research	Applied research	Basic	Applied	Applied + basic	Applied	Applied	High risk - applied + basic	High risk - breakthru	High risk - breakthru	demo + basic	Applied + basic	Applied
IP provisions for industry	?	NA	Pre-comp.	Pre-comp.	Pre-comp.	Yes, with govt getting nonexcl. license	Licensed from NREC	Yes - companies retain them	Yes (but with FAR clauses)	Yes, with govt getting nonexcl. license	Yes, with govt getting nonexcl. license	inventing party retains IP	?
Other success criteria		Paid students 30% higher than average				Business case oriented. Independent Technical oversight committee		Already had some proof of concept in place, gate based selection, biz case oriented	Strong program managers		expert panel to provide steering inputs,		

Comparative Study of Technology Development Mechanisms in Other Countries

Germany

Germany continues to maintain a visible national strategy on manufacturing overseen by the government. The German Federal Ministry of Education and Research (BMBF) uses a foresight process:

- The BMBF develops a High-Tech Strategy (HTS) that lays out the key areas of research.
- Based on the broad fields derived from the HTS, a number of qualitative and quantitative methods are used (e.g., data mining, workshops, expert interviews, bibliometrics) to determine new areas of research.
- An international panel consolidates these ideas into a set of topic candidates.
- The BMBF then generates a set of white papers on these topics.
- These white papers and topic candidates are eventually distilled into a research agenda using a series of expert workshops and conferences, online surveys, and a comparative study of other innovation systems.
- Other more specific studies (also typically highly consultative and inclusive) are also initiated from time to time by the BMBF to augment the research agenda.
- The national ecosystem consists of the various universities and applied research institutes (e.g., the Fraunhofer institutes), as well as private companies and institutions.

German funding for research is mainly administered by the BMBF through the German Research Foundation (DFG). Most German government manufacturing research funds flow through the technical universities. But note that the Technical Universities carry out a high degree of applied research for industry clients. In addition, the Fraunhofer Institutes are solely applied-research institutes and mainly get their funding through contract work from industrial clients as well as state and federal agencies.

One additional key point is the importance of the SME segment (Mittelstand) and its inclusion in the national strategy on manufacturing. The ecosystem and research/funding mechanisms ensure that SMEs have access to applied research resources.

Japan

The Ministry of Economy, Trade and Industry (METI) generates the National Strategic Technology Roadmap (STR) every few years (with annual updates). A Delphi forecasting process is used where multiple rounds of input are carried out with a wide net of experts from government, industry, and universities, and the areas of research are gradually distilled to the final set. For the 2010 STR, over 800 experts were involved in the process.

Korea

South Korea also follows a Japan-like model where a National Technology Roadmap (NTRM) is created once every few years. This process is led by the Ministry of Science and Technology (MOST). The first instance of this national foresight process was carried out in 1994.

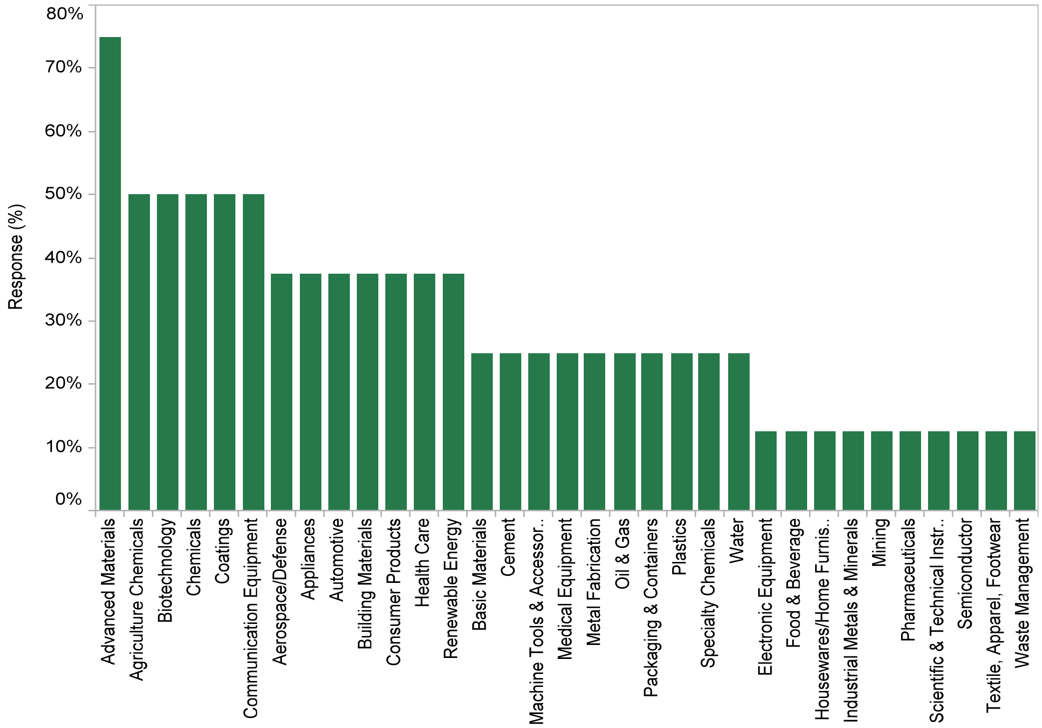
This was a much broader exercise where blank-slate inputs from more than 30,000 experts from industry, government, and academia were invited on research topics of importance. A main expert coordinating committee as well as 12 expert subcommittees were set up to coordinate the process and distill ideas from the huge set of responses and to create the main questionnaire for the Delphi forecast. The Delphi was carried out over 2 rounds with more than 4000 experts being involved.

Top Technology Areas

First Survey with Industry and Universities

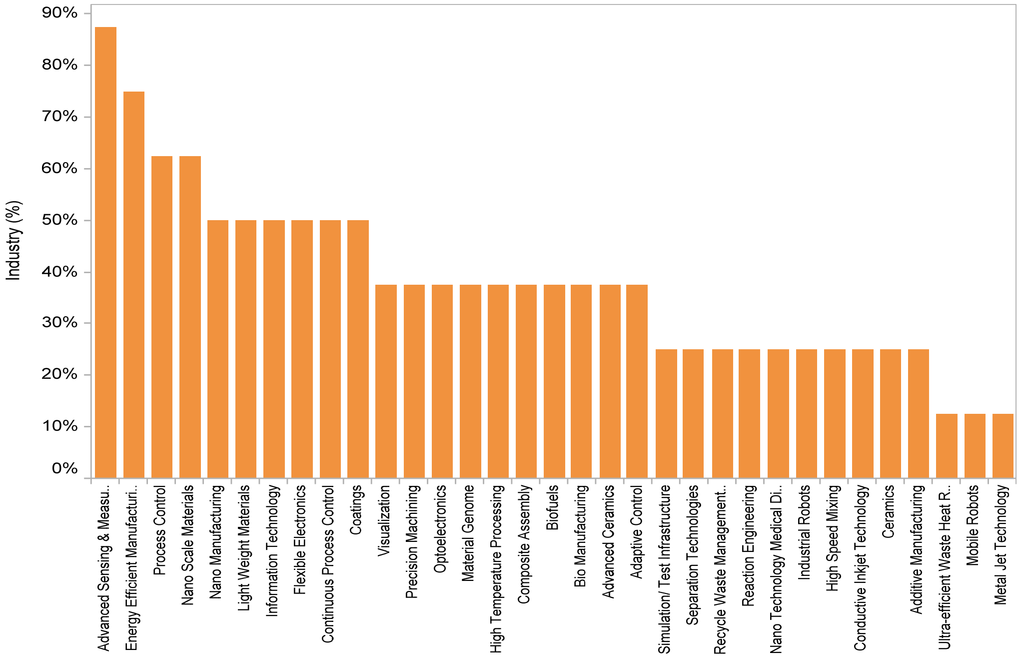
The chart below describes the percentage of industry respondents who selected each industry as critical for maintaining U.S. manufacturing competitiveness.

Industry Survey Results: Industries Targeted to Retain and Grow U.S. Manufacturing



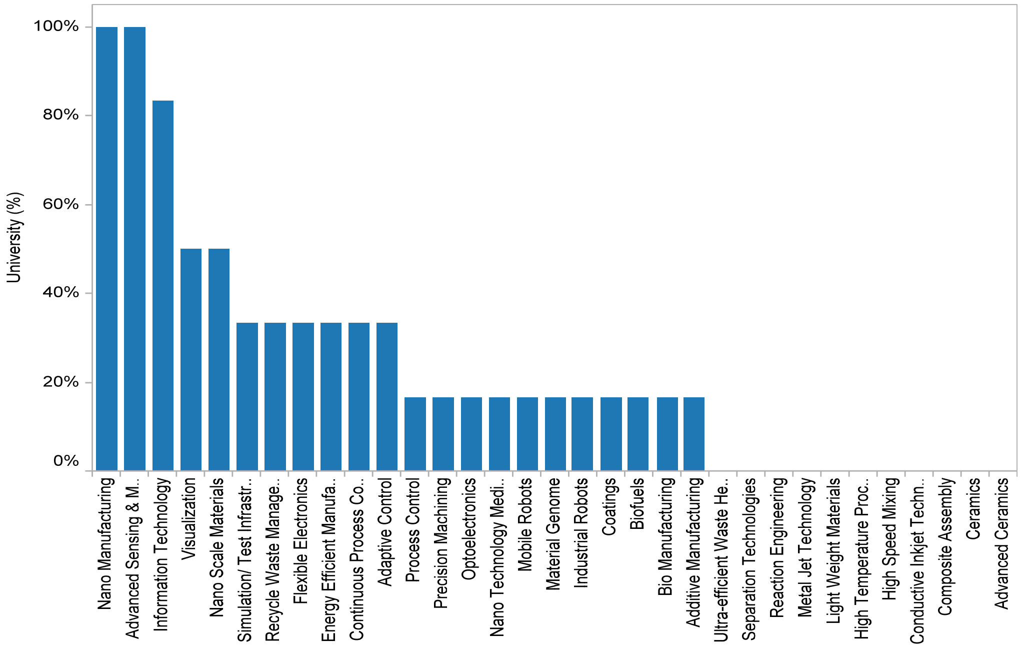
The chart below depicts the percentage of industry respondents who selected each advanced manufacturing technology as being critical for U.S. manufacturing competitiveness.

Industry Survey Results: Advanced Technologies Required to Retain and Grow U.S. Manufacturing



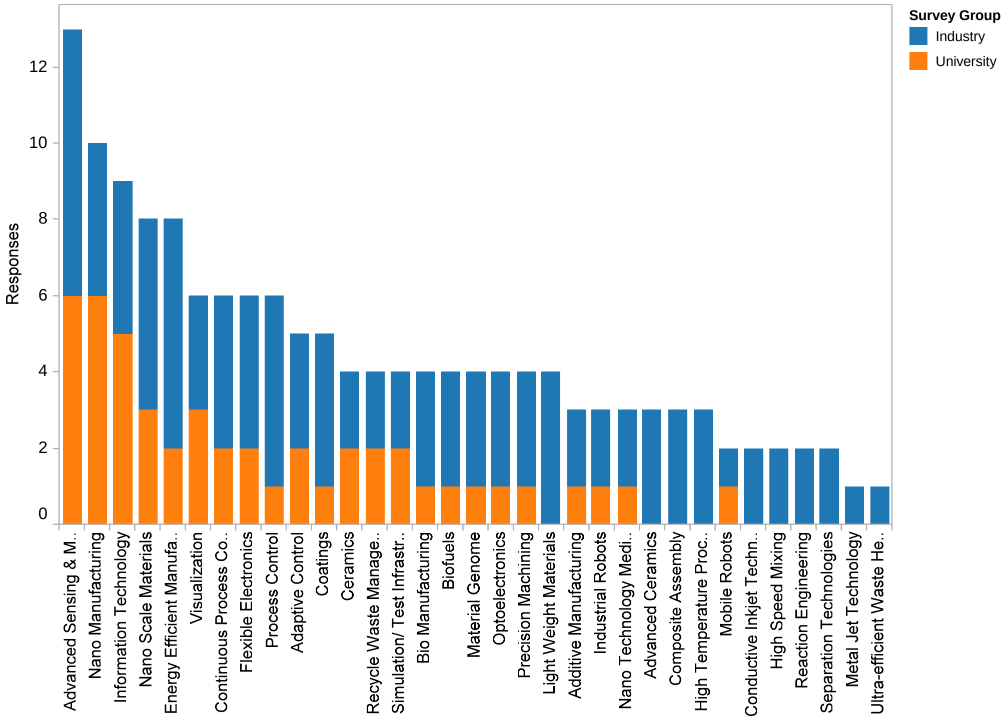
The chart below depicts the percentage of university respondents who selected each advanced manufacturing technology as being critical for U.S. manufacturing competitiveness.

University Survey Results: Advanced Technologies Required to Grow U.S. Manufacturing



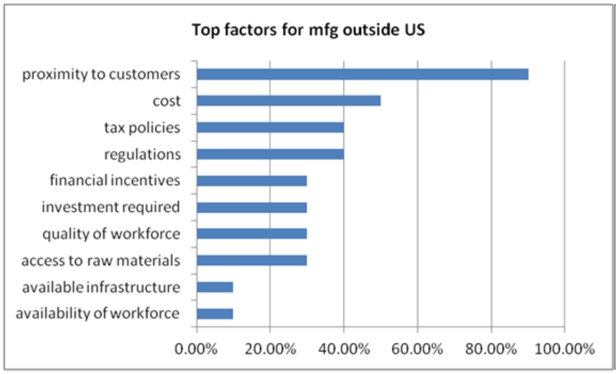
The chart below combines the selections of industry and university respondents for advanced manufacturing technologies that are deemed critical for U.S. manufacturing competitiveness.

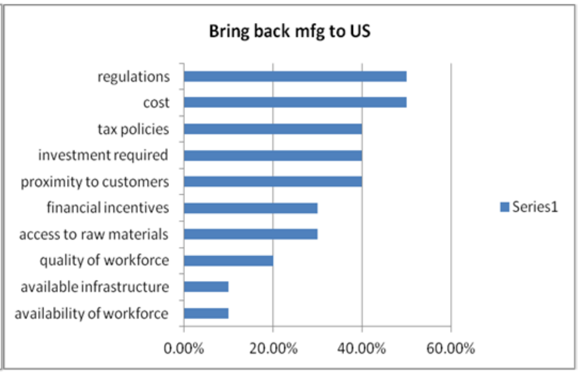
Combined Survey Results: Top Technologies Deemed Most Critical for U.S. Advanced Manufacturing



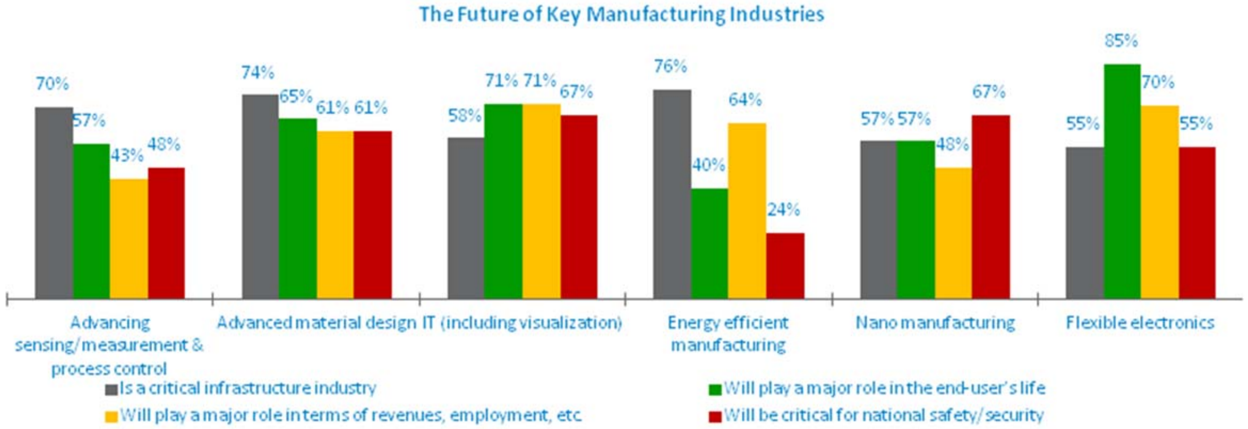
Factors for Manufacturing Outside or Inside the United States

The first chart in the pair below shows the factors driving decisions to manufacture outside the United States, as identified by industry participants. The factors are ranked according to the frequency of selection by the respondents. The second chart of the pair shows the factors driving the decision to bring back manufacturing to the United States

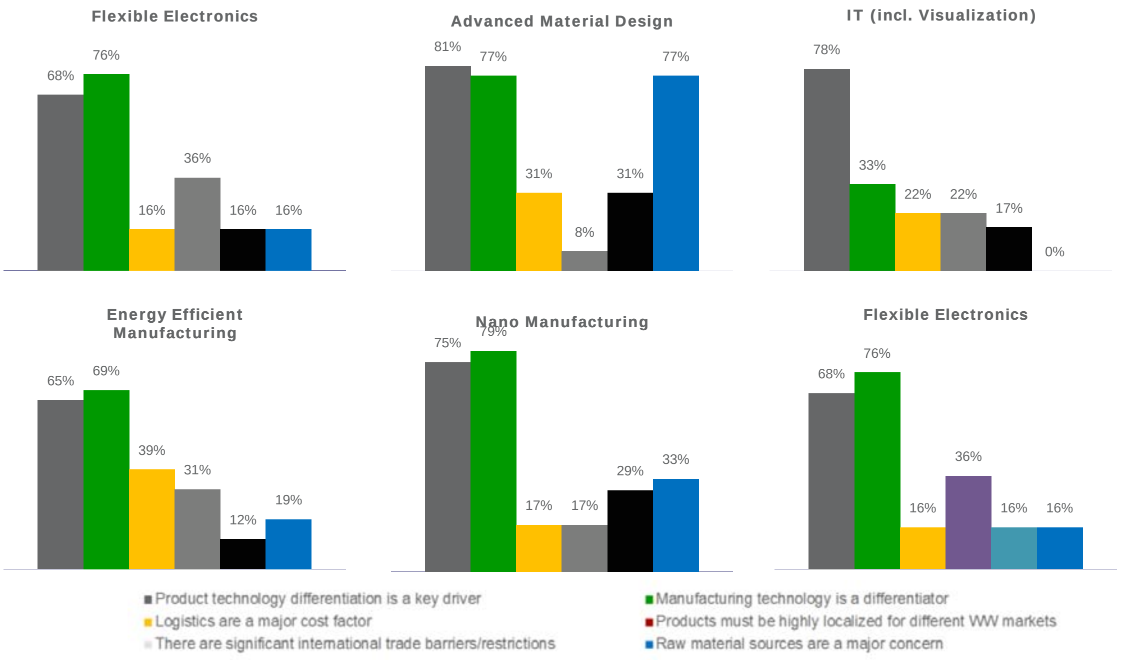




MAPI Council Survey: Excerpts



- Respondents rated advanced material design as critically important across the board.
- Advanced controls and energy-efficient manufacturing were viewed as critical infrastructure industries.
- Information technology (IT) and flexible electronics are both seen as vitally important to end users in terms of revenue and job generation.
- Over two-thirds of those who rated nano-manufacturing expect it to be critical for national safety or security in the future.



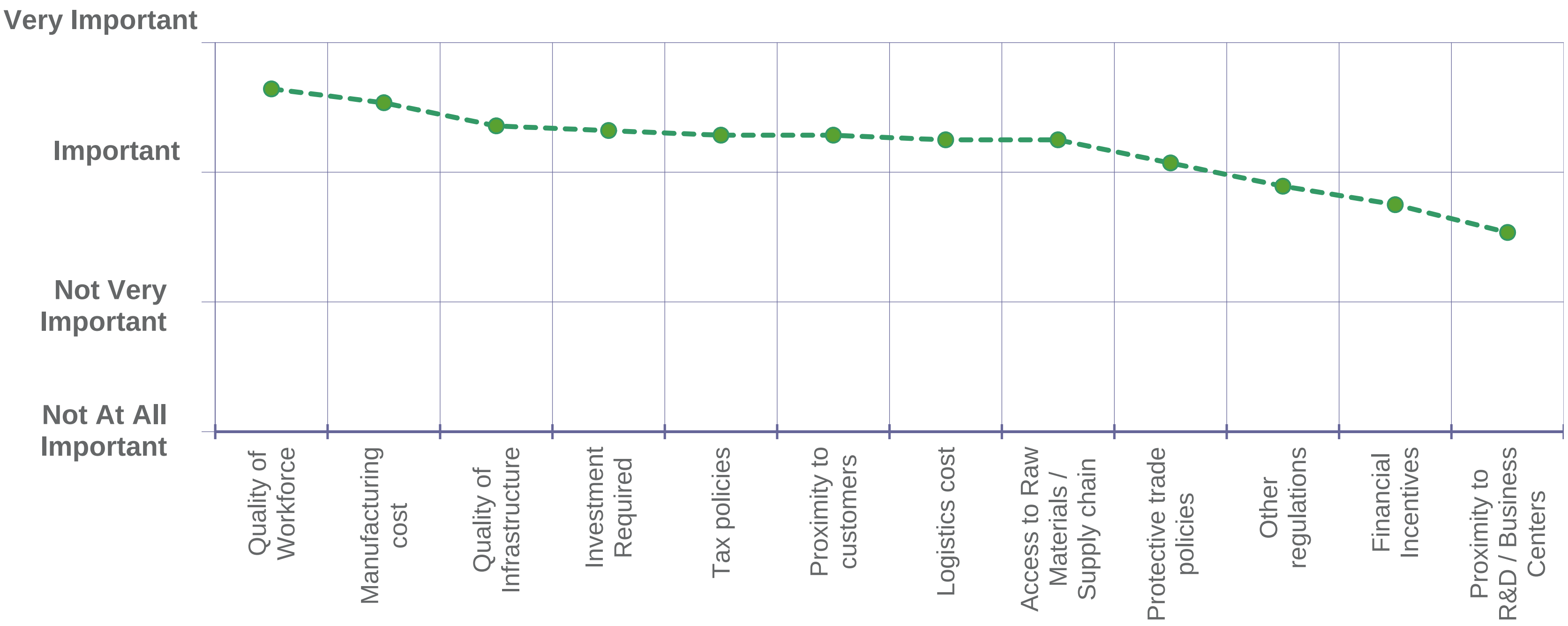
- A very high proportion of respondents identified product technology differentiation as a key driver for controls, material design, and IT.
- With the exception of IT, differentiation of product technologies is expected to be a key driver of success for advanced manufacturing.
- In general, adopting advanced manufacturing technologies is not expected to be seriously affected by logistics costs.
- Other than in energy-efficient manufacturing, the need for localized design is also not expected to play a major role in future development, perhaps because of increasingly globalized standards and consumer expectations.
- At this point, trade barriers are not expected to interfere with dissemination of advanced manufacturing technologies.
- Access to raw materials could present a challenge in the case of advanced material design.

Member Comments:

“Our human resources need to be significantly more competitive. Knowledgeable and productive.”

“Stability of the rules (tax, regulatory) more important than the rules and taxes themselves. These set a framework for the investment case but aren’t drivers of the cases - setting a stable and competitive framework for companies to do business in is the most important failing of recent times.”

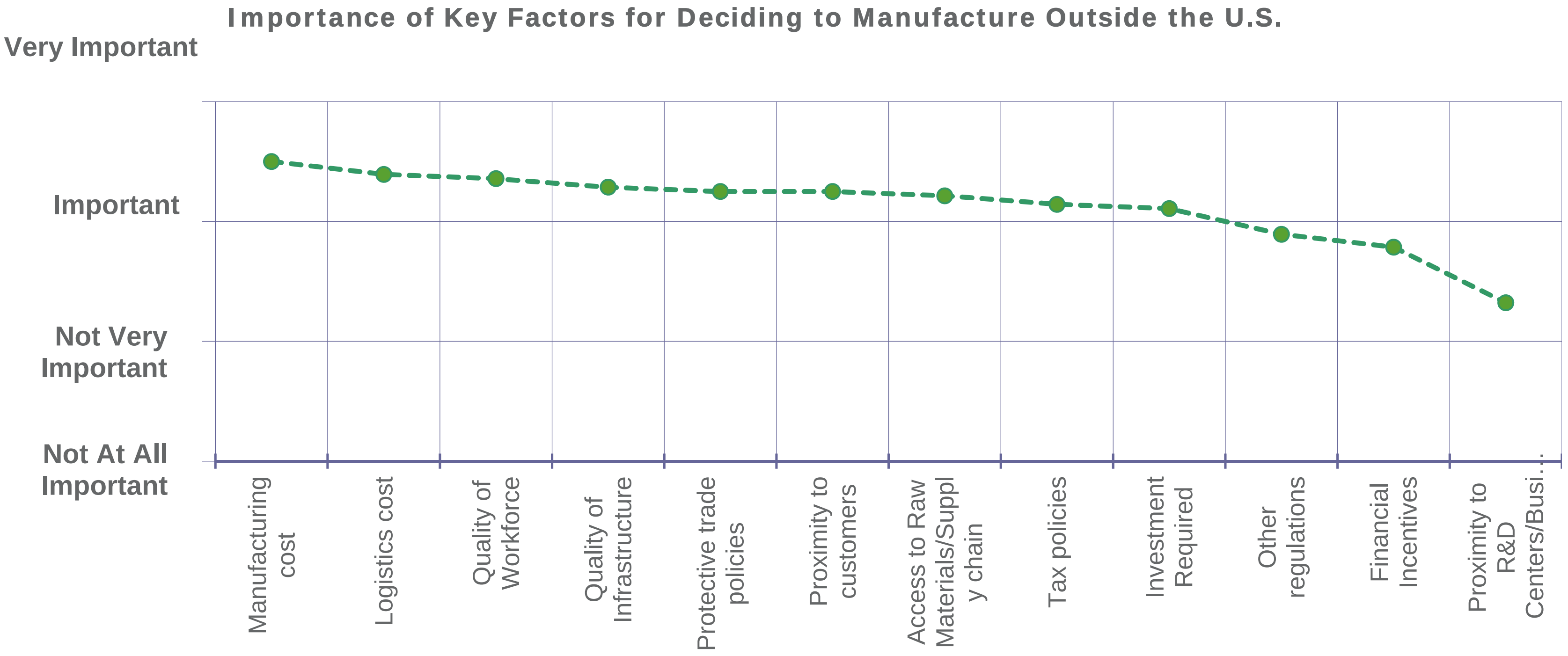
Importance of Key Factors for Deciding to Manufacture in the U.S.



Member Comments:

“Determining your manufacturing footprint is a delicate balance between optimizing your manufacturing costs and your best tax rates. Everyone would prefer to manufacture in the US, but an inflated real wage rate and the 2nd highest corporate taxes in the world make it a bad financial decision.”

“Providing most competitive landed costs at point of use for final assembly is key. If we can offset lower wages offshore with higher efficiencies in our US factories, the only reason for sourcing outside the US would be based on prohibitive regional transportation and logistics costs or market entry barriers or duties brought about by lack of trade agreements.”



Importance of Key Factors for Deciding to Manufacture Outside the U.S.

The two charts above show the MAPI council survey respondents’ ranking of which factors drive the decisions to manufacture inside or outside the United States.

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