Strengthening Manufacturing Competitiveness:

Report from the 2010 Conference on the Future of Materials Joining in North America

February 2, 2011

EWI Joining Innovation

AWS

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Preface

There is a growing sense that North American manufacturing is at a crossroads and manufacturing competitiveness is at risk.

The manufacturing landscape has undergone significant change in the past 10 years. Manufacturing still requires advances in materials joining technologies to remain competitive; however, emphasis on materials joining technologies has declined as the manufacturing environment has changed. The "Future of Materials Joining in North America" (FMJNA) was convened in August 2010 to identify opportunities to strengthen the competitive position of the North American materials joining industry and manufacturing in general. In his opening remarks to the conference, Dr. Henry Cialone, CEO of EWI (Edison Welding Institute), summarized the strategic opportunity that the conference represents:

> *"We are living in interesting times. The economy is starting to emerge from the worst recession in 60 years, which has had a profound impact on the manufacturing industry. Coming out of major economic disruptions, industry and markets often transform themselves. The innovators that lead the change often prosper. For example, personal computing business grew rapidly following the deep recession of the early 1980s and World-Wide-web businesses took off after the recession of the early 1990s.*
>
> *Beyond the recession, industry continues to face a wide range of challenges:*
> - *Global competition is fierce*
> - *Energy sources are changing*
> - *Energy and materials are getting more expensive*
> - *Environmental concerns are leading to new regulations*
> - *Our workforce is aging while technical skills are becoming more important to our competitiveness*
>
> *These business challenges mean shorter product development cycles, increased performance requirements, higher quality expectations, and a relentless drive to reduce costs.*
>
> *To compete, North American industry must innovate more quickly. The Global Manufacturing Competitiveness Index published in June 2010 gathered data from 400 senior manufacturing executives worldwide and ranked the drivers of global manufacturing competitiveness. It found the highest ranking driver to be talent-driven innovation, or the capacity to continuously innovate and simultaneously improve production efficiency. This finding flies in the face of the common perception that manufacturers are simply chasing cheap labor around the globe.*

Other regions of the world have recognized the need for continuous technical innovation and are successfully employing public/private partnerships and other collaborations to give their industries a competitive advantage.

We are here to explore collaborative approaches to advance North America's competitive position with respect to materials joining. We've gathered together a range of people with different perspectives from various organizations, including industry, government, national labs, universities, and nonprofits.

If all we accomplish is starting a dialog on better collaboration to advance competitiveness, then this conference will be a success. But we intend to go much further. We plan to create a report of the conference findings which identifies high-priority needs and potential collaboration models. We will use the report as a roadmap to engage stakeholders and develop effective collaborations that advance the competitiveness of North American industries which rely on materials joining."

The 2010 FMJNA conference did not stand in isolation, but in fact built on a strong foundation of previous examinations of the welding industry. From a historical perspective, the 1976 Henniker, New Hampshire, conference on "Welding R&D Problems and Opportunities"[(1)] set forth the need for increased welding research, and the establishment of a North American welding research center, a recommendation that ultimately led to EWI. In 1994, a follow-on Henniker conference was held to identify individual industry sector technology needs and explore collaborative research models.[(2)] The 1998 National Academy of Sciences/Department of Energy (DOE) workshop on a "Vision for the Welding Industry" identified key thrust areas of materials development, design and manufacturing integration, workforce integrity, and quality.[(3)] The 1998 work resulted in the landmark Department of Energy "Welding Technology Roadmap"[(4)] in 2000 that set forth a 20-year vision for the U.S. joining industry:

"U.S. Industry will be the world's leading source of these cost-effective, superior-performing products by virtue of its leadership in joining technology, product design, and fabrication capabilities, and a globally competitive workforce."

This vision provided a comparative basis, at the halfway mark of the 20-year period, to gauge our progress toward achieving the vision. As will become clear in this report, a dramatic increase in U.S. manufacturing and joining technology competitiveness will be required to achieve the 2020 Roadmap vision.

The 2002 AWS/EWI welding economic impact study "Welding-Related Expenditures, Investments, and Productivity Measurements"[(5)] demonstrated that welding is a critical enabling manufacturing technology that has economic impact across the entire economy. In short, leadership in product and manufacturing innovation relies in part on leadership in materials joining innovation.

In 2006 the Canadian Welding Bureau set forth "A Technology Roadmap for the Canadian Welding and Joining Industry"[6] that highlighted key issues for the welding field, including a lack of awareness of the importance of welding in manufacturing, and the critical shortages at every level of the welding workforce (e.g., engineers, technicians, welders). Needed actions that were identified included increasing awareness among executives of the strategic importance of welding, improving the image of welding as a career path, and increased investment in welding research. Many of these issues and actions will be found among the findings of this conference.

More recently, in 2008[7] and 2010[8], EWI has carried out in-depth needs assessments and focus groups to identify a range of business challenges and critical materials joining technology needs. Finally, although not available at the time of the FMJNA conference (reported in summary form at the conference, and since available) was the 2010 report by AWS and Weld-Ed on "The State of the Welding Industry,"[9] which projects emerging workforce gaps.

What emerged from these predecessor studies, surveys, and reports is the identification of a broad range of materials joining challenges that impact manufacturing competitiveness and established the need for greater collaboration to overcome these challenges. What also emerged was the clear need for vision, planning, and leadership to move the industry forward. It was recognition of this issue that drove the planning for the FMJNA conference.

In his concluding remarks, Conference Chair Chris Conrardy spoke of the need for vision, leadership, and commitment in following through on the conference recommendations.

> *"This conference has identified opportunities to advance the competitiveness of the North American materials joining industry. If we are bold enough to seize upon these opportunities, we will help secure the manufacturing future for the next generation and ensure the best days are ahead of us. Our industry has faced adversity in the past and come out on top. We can do it again if we have a common vision and the will to implement it."*

It is hoped that this report will provide the basis for continued collaboration to make the 2020 vision for the materials joining industry a reality.

Abbreviated Terms

AWS	American Welding Society
CEUs	Continuing Education Units
DOE	Department of Energy
EPRI	Electric Power Research Institute
EWI	Edison Welding Institute
FMJNA	Future of Materials Joining in North America
GDP	gross domestic product
IP	intellectual property
I/UCRC	Industry/University Cooperative Research Center
NSF	National Science Foundation
OSU	The Ohio State University
PRCI	Pipeline Research Council International
USCAR	United States Council for Automotive Research

Executive Summary

There is an urgent, growing sense that North American manufacturing is at a crossroads and that its global competitiveness is at risk, in turn endangering our global leadership, our national security, and our very standard of living.

Materials joining is an essential aspect of nearly all manufactured products. Increasing the global competitiveness of materials joining methods will help support a vibrant manufacturing sector. Innovation is vital to strengthening manufacturing competitiveness. Unfortunately, we have witnessed a relative decline in the competitiveness of the North American materials joining industry. Global competitors have pushed forward with investments in workforce and technology innovation as our industry has atrophied in comparison.

The "Future of Materials Joining in North America" (FMJNA) conference was organized to take a critical look at the current state of materials joining and to identify actions that need to be taken to contribute to a strong North American manufacturing base. Seventy invitees from industry, academia, government, trade associations, and research organizations participated in the event. Presentations by prominent representatives from industry, academia, and government agencies highlighted:

1. The criticality of manufacturing to the North American economy
2. The criticality of materials joining to North American energy and defense security
3. Evolving industry technology development needs and approaches
4. The status of welding research in the national labs
5. Academic research challenges
6. Workforce training and education trends

The conference also included a series of breakout sessions to develop a strategy to strengthen manufacturing competitiveness. The sessions targeted identification of key challenges and collaborative approaches to overcome those challenges. Breakout participants contributed hundreds of suggestions that were then consolidated, ranked, and distilled into themes.

Two "grand challenges" emerged from the discussion:

1. Increasing the level of technical innovation
2. Increasing workforce competitiveness.

Two broad opportunities to address these challenges also emerged:

1. Greater collaboration
2. Influencing government policy and funding priorities.

The two grand challenges and two broad solutions are tightly coupled and must be addressed in concert.

Thus, world-class manufacturing technologies cannot be developed and implemented without a world-class workforce; nor can effective broad collaborations be created to address the grand challenges without government and industry support. It will take a holistic approach and long-term commitment to achieve lasting manufacturing competitiveness improvements.

Conference attendees expressed a sense of urgency and the importance of acting quickly on the conference findings to keep momentum. Conference attendees also recognized that ongoing leadership from key organizations will be vital to push forward with solutions. It is recommended that the conference organizers, EWI and AWS, take the lead in engaging stakeholders to develop a strategy for addressing the technology innovation and workforce competitiveness challenges. The following specific actions are suggested to keep momentum in the near term and build alignment for structural improvements in the long term to strengthen our competitive position:

- Conduct a benchmarking study to review innovation models identified by conference attendees, and recommend a preferred innovation infrastructure to enhance the competitiveness of our manufacturing technologies
- Assess projected materials joining workforce needs, review current workforce development programs, identify gaps, and suggest areas of focus to strengthen the competitiveness and innovation capacity of our workforce
- Hold an Innovation Summit involving thought-leaders from industry, research organizations, workforce development organizations, and policy makers to validate or amend the proposed approaches, and develop a strategy to build support for implementation
- Engage policy makers to relay the findings from the conference and express the need for investment to strengthen our competitive position
- Organize follow-on FMJNA conference to review the status of the activities and determine future needs and directions

1.0 Introduction

The field of materials joining — thought of as "welding" by many — is a foundation and enabling technology that underlies nearly every manufactured product, object, system, or device in the North American economy.

From life-sustaining medical products to aerospace systems to everyday consumer products, materials joining is essential to our economy and way of life. As an integral part of manufacturing, the materials joining field is also impacted by the same conditions that impact North American manufacturing in general. Given the rapid changes in the manufacturing industry, it was deemed timely to assess the status and critical issues faced by the materials joining field, and recommend actions to be taken for its advancement.

A conference on the "Future of Materials Joining in North America" (FMJNA) organized by the American Welding Society and EWI (Edison Welding Institute) was held in Granville, Ohio, August 3 and 4, 2010. The purpose of the conference was to take a critical look at the current state of materials joining technology and to identify actions that need to be taken to contribute to a strong North American manufacturing base. The conference, with attendance by invitation, drew 70 participants.

The stage was set with the benefit of presentations by prominent representatives from industry, academia, and government agencies. Dr. Henry Cialone, EWI president, opened the conference. Dr. Cialone discussed the opportunity industries have to transform themselves following economic downturns, and that the current recession poses such an opportunity for North American manufacturing. He also warned that North American industry must innovate more quickly to compete effectively. **Other regions of the world have recognized the need for technology innovation, and are successfully employing public/private partnerships and other collaborations to give their industries a competitive advantage.** He stated that the purpose of the conference was to explore collaborative approaches to advance North America's competitive position with respect to materials joining.

The keynote speaker was former Ambassador W. R. Timken Jr. from Strategic Public Partners Group. He discussed the value of strong manufacturing to the future of North America. He described how his views on globalization and manufacturing were shaped by his experiences as former ambassador to Germany, chairman of The Timken Company, chairman of the National Association of Manufacturers and The Manufacturing Institute, member of the Council on Competitiveness, the U.S.-Japan Business Council, and many other leadership positions. Ambassador Timken stressed the importance of manufacturing to a strong national economy and the need for government policy to support manufacturing.

Dr. Bob Rivett of Emerson Electric shared his thoughts on improving the interface between industry and outside resources. As a large multinational company, Emerson Electric accesses a wide range of technical resources from across the globe to support its product development and manufacturing needs. **He compared the rapidly growing and sophisticated manufacturing technology support organizations in the emerging economies with the relatively fragmented and limited capabilities now found in North America.** He also spoke of the need for "intelligent providers" that can communicate the importance of emerging technologies to industry so that industry can invest in solutions with the greatest impact.

Dr. Suresh Babu of The Ohio State University Welding Engineering program provided a summary of materials joining technology research at the university level. Dr. Babu used the number of technical publications as a metric to identify the top researchers in North America and other parts of the world. He found that North America has many leading researchers doing important work in materials joining. He also suggested key technical areas for additional research. During the question-and-answer period, he acknowledged the difficulty in finding funding for materials joining research. Multi-university National Science Foundation Industry/University Cooperative Research Centers were discussed as one collaborative approach to jointly develop funding to support materials joining university research.

Monica Pfarr from the American Welding Society (AWS) spoke on the manufacturing employment outlook and workforce initiatives. Ms. Pfarr reviewed the results of a forthcoming study (that has since appeared[9]) on the welder employment outlook, which projects that while the overall employment will be flat, anticipated turnover will necessitate significant ongoing workforce attraction and training efforts. AWS is actively working to improve the image of welding and has expanded scholarship opportunities to encourage young people to consider welding and welding engineering as a career path.

Emily Stover DeRocco of The Manufacturing Institute discussed the new manufacturing landscape. (Ms. DeRoccco's paper has since appeared.[10]) She reminded the audience that the U.S. continues to lead the world in manufacturing output and that 60% of U.S. exports come from manufacturing. The U.S. faces tough competition from both emerging low-cost labor countries and developed countries that provide strong support to their manufacturers. Ms. DeRocco described business innovation as a strategic imperative and that **a highly skilled and educated workforce is the most critical element for innovation success.** She described a skills certification system to help manufacturers ensure the workforce has the necessary manufacturing skills.

The conference chair, Chris Conrardy of EWI, discussed previous materials joining strategic planning exercises over the past 30 years. He also presented the results of recent EWI materials joining needs assessment studies, which identified top business challenges and technology needs. Mr. Conrardy also reviewed the results of a recent survey that explored technology development collaboration opportunities and barriers. Barriers most often identified

by survey respondents included funding availability, intellectual property ownership, and competitive concerns. He described a collaboration model EWI is using for the recently founded Additive Manufacturing Consortium to overcome barriers to successful collaboration.

Courtney Hill of GE Aviation talked about the path to affordable manufacturing technology. His talk described a strategy for aggressively advancing manufacturing technology to achieve ever-increasing product performance goals. The approach involves assessing potential challenges as early as possible and engaging supply chain technology partners to overcome these challenges. He also stressed the need for collaboration to share the technology development costs and risks, and to mature technology more quickly.

Dr. Matt Johnson of Los Alamos National Laboratory spoke on the topic of industry-government collaborations. Dr. Johnson expressed concern regarding **a general decline in the advanced manufacturing capabilities available in North America, and in the manufacturing technology intellectual infrastructure.** He also spoke of the relatively low visibility of this problem and a lack of national dialog on the issue. He suggested that greater collaboration is needed to make policy makers aware of the need for technology investment at all levels to strengthen the materials joining infrastructure. Aside from the obvious importance of such investment to the overall economy, Dr. Johnson emphasized that our national security is dependent on advanced materials joining.

Dr. Jim Dowdy from NASA discussed his technology transfer efforts. Dr. Dowdy reviewed his technology investment strategy and discussed the importance of collaboration in technology development and commercialization. He used NASA's investment in friction stir welding as a recent example.

The presentations were followed by a series of breakout sessions that challenged conference participants to answer three strategic questions:

— "What key materials joining challenges and opportunities should be highest priorities to address in the next decade?"

— "What collaborative approaches would be most effective to advance North America's competitive position for materials joining?"

— "How do we overcome funding availability, IP ownership, competitive concerns, and other barriers to successful collaboration?"

Participants proposed answers to these questions and then voted on the most important suggestions. Parallel breakout sessions were conducted in which suggestions were collected, consolidated, and ranked. The results from these breakout sessions were subsequently

compiled and distilled into major themes. The relative importance of each theme was also ranked based on the number of votes the constituent suggestions received from the conference participants. The conference report committee, with members from industry, academia, government, AWS, and EWI, met on August 5, 2010, to begin drafting the conference report.

The sections that follow first provide an overview of the current state of the North American materials joining industry. Then, the identified “materials joining challenges and opportunities” are presented. Next, the suggested collaborative approaches and methods to overcome collaboration barriers are discussed. Finally, recommendations to act on the conference findings are put forth.

2.0 Materials Joining in Manufacturing

This section will provide an overview of the field of materials joining and its role within U.S. manufacturing. It will be shown that declines in materials joining R&D negatively impact manufacturing. The critical linkage between the two will be described.

2.1 The Field of Materials Joining

What has a welded, bonded, brazed, or soldered structure? While the list might be endless, some appreciation can be gained by mentioning a few, from the most advanced to the most prosaic. Thus, automobiles, hybrid battery technologies, aircraft, trucks, heavy equipment, marine craft, medical devices, communications devices, computers, satellite dishes, gas pumps, appliances, weapons, food packaging, medicine delivery systems, garden tools, farm implements, carpeting, coffee mugs, makers and packets, clothing, shoes, bicycles, motorcycles, skis (water, snow, or jet), aircraft carriers, stents, pacemakers, artificial joints, oil and biofuel refineries, toothpaste tubes, diapers, plumbing, lamps and lighting fixtures, light bulbs, bridges, monuments, caskets, beverage and food cans, fuel cells, solar energy and photovoltaics, wind towers and blades, and power generation from nuclear power plants to hearing aid batteries. Materials joining is how the products of today are made, and it is how the materials of tomorrow will be combined by the joining processes of tomorrow into the products of tomorrow.

The field of materials joining encompasses the processes of welding, soldering, brazing, adhesives bonding, and mechanical fasteners. The field has expanded into all areas of materials and is now a scientifically based discipline requiring understanding and application of an enormous range of phenomena, including physics, chemistry, surfaces, materials, mechanics, heat transfer, and electricity. It is employed in manufacturing nearly every object, product, and system known in our economy. Few things can be manufactured without materials joining technology, and it lies at the heart of every combinatorial manufacturing process.

Materials joining is also a field of increasing technical complexity, because the fundamental technology must be delivered rapidly and reproducibly. Robotics and computer-controlled welding systems deliver high concentrations of energy in the form of arcs, lasers, and electron beams. Very rapid thermodynamic, metallurgical, and chemical processes occur, and sophisticated methods of analysis are required to control stress, distortion, and fracture. New materials, or materials systems, no matter how seemingly miraculous, quickly lose their

advantage if they cannot be combined with themselves or other materials. The wonderment of the "nano-world" and the "bio-world" disappears when those materials cannot be combined (joined) with others, while sophisticated microchips have hundreds of welds and joints, the failure of any one of which can lead to a blank screen.

Touching as it does essentially all of our industrial, national, and personal lives, it is not surprising that materials joining has great impact on the national economy. Techniques as esoteric as laser welding and ultrasonic metal welding have enabled the development of fuel cells and electric and hybrid vehicles. It may be "just welding," but the technologies developed will forever change energy delivery. It is estimated that manufactured goods using welding in some stage of their fabrication represent at least 30% of the gross domestic product.[5] Add to that the impact of brazing, soldering, and adhesive bonding, and it is clear that materials joining forms a primary foundation of our economy.

Other countries are investing in these fundamental technologies that are central to all manufacturing, whereas the U.S. is not. The next section delineates the current status of this neglect. A point is being reached in manufacturing where the ability to compete is threatened and the country's defense could be put at risk.

2.2 Manufacturing and Materials Joining Research in North America

The field of materials joining does not stand in isolation, but is itself integral to, and a critical part of, the broad field of manufacturing, which produces the goods of still the world's largest economy. However, that economy is becoming one governed more by consumption rather than production. Thus, in examining the future of materials joining in North America, it is also critical to discuss the status of North American manufacturing in order to understand the overall context of materials joining issues.

Much has been written, especially in recent years, on the status of North American manufacturing. Unfortunately, the word for status is "decline." During the summer of 2010, the plight of American manufacturing became a rallying point with several critical reports appearing on the subject. This report does not presume to address what has been well dealt with elsewhere. Instead, a brief summary of the manufacturing arena and the potential impact to be affected by materials joining technology development will be emphasized.

On July 5, 2010, Commerce Secretary Gary Locker emphasized that "A vibrant manufacturing sector isn't just critical for the millions of Americans whose jobs depend on it," but that "manufacturing is absolutely central to driving the innovation that fuels the American economy."[11]

Manufacturing is the central pillar of the U.S. economy supporting 13.4 million jobs in 2008, or about 8.7% of the civilian workforce. The manufacturing sector is the major productivity driver in

the U.S. economy. In 2007, 11.7% of the U.S. total GDP was produced by the manufacturing sector. In 2008, manufactured goods were 60% of the total U.S. exports. Seventy percent of R&D in the U.S. is driven by manufacturing. Manufacturing workers in 2007 enjoyed being compensated 20% higher than nonmanufacturing workers.[12]

All Indicators used to track the health and state of the U.S. manufacturing sector are all telling the same alarming story. **We have lost or are losing our position as the world's most innovative and productive manufacturing economy and, most troubling, are that all signs are pointing to a continuing weakening trend.** Also, our foreign competition is gaining on us and approaching the critical mass necessary to develop and sustain its own innovation machine.

2.2.1 Alarming Trends

There is an unfortunate gathering of alarming trends in manufacturing that must be recognized and reversed, including:

- **Decreasing R&D Funding:** U.S. growth in R&D has averaged only about 1% per year in real terms since 2000.[13] This is of great concern considering that R&D investment drives innovation, and innovation is thought by many to be the critical strategic imperative to a healthy economy.

- **Decreasing Manufacturing Output:** Manufacturing output as a percentage of U.S. GDP has decreased. From 1996 to 2007, manufacturing's share of GDP has fallen from 15.5 to 11.7%.[12] Furthermore, manufacturing output since the last recession lags that of earlier economic recoveries – it has only grown 15%, which is half the pace averaged in recoveries of the past half century.

- **Declining Employment:** The ultimate metric of manufacturing strength, that of jobs, is the most alarming of the trends. The manufacturing employment base has declined by 4 million jobs in the past 10 years, as shown in Figure 1, and is suffering severe losses in the current economy.[12] While improved productivity accounts for some job reductions, the major impact is from factory shutdowns and the exporting of manufacturing overseas. As previously noted, manufacturing jobs generally earn higher wages than other sectors. However, job erosion in the manufacturing sector is difficult to recover and permanently scars the standard of living.

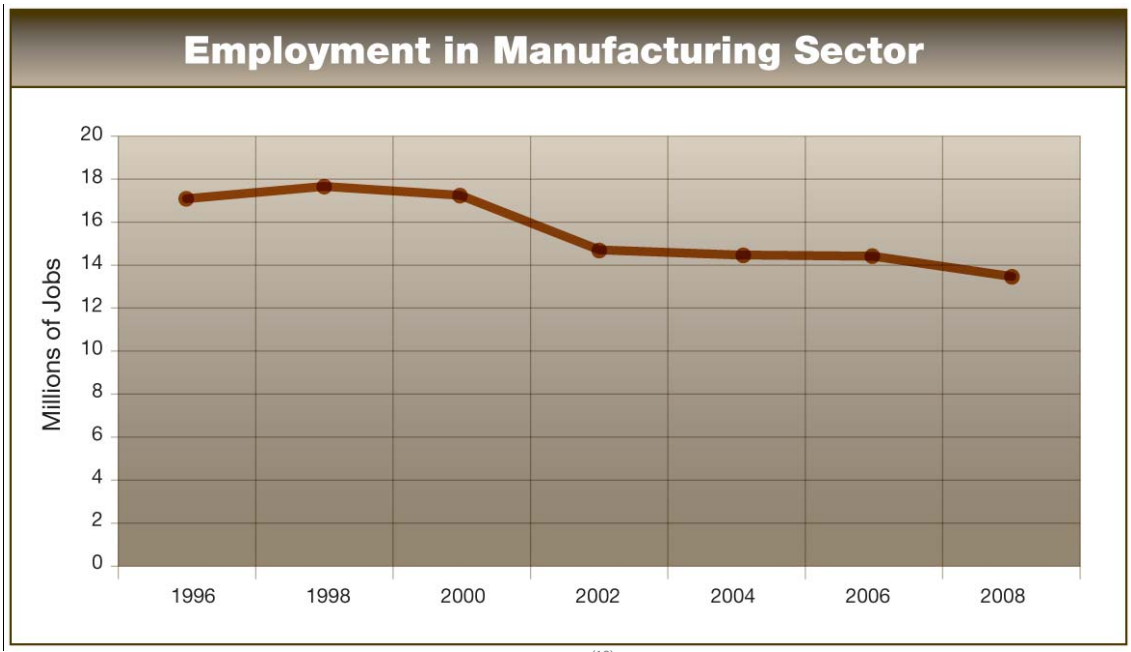

Figure 1. Declining Employment in the Manufacturing Sector[12]

- **Lack of a Trained Workforce:** There is a growing lack of trained workers with required skills for today's and tomorrow's modern work environment. One major concern is the ever-increasing number of baby boomers that will retire in the near future leaving a significant gap in the required number of trained workers needed compared to the number available.

- **Shrinking Global Market Share:** The global market share of U.S. manufactured exports has declined from 19% to 14% (2000 to 2007).[13] The U.S. share of global trade is falling in high value-added export industries such as machinery and equipment, resulting in reduced GDP share and increasing trade deficits.

- **Output is in Freefall:** Demand for manufactured products has plummeted since September 2008, resulting in less production and more excess capacity.[12] Excess capacity from the global recession builds on previous excess capacity. This is digging a hole deeper and deeper. Recovery may prove to be long and costly.

- **Rising Costs:** Healthcare, taxes, labor, tort claims, and pollution abatement are all contributing to higher costs that impact the ability to invest the needed funds to sustain our leadership position in innovation and R&D. Innovation is the single most important strategic imperative to drive manufacturing.

Why is this important? The manufacturing sector is such a strong influence on the national economy that a weak manufacturing sector will adversely and immediately affect the whole. A decreased standard of living, higher unemployment rate, reduced productivity, higher trade

deficit, reduction in investments for R&D and innovation, and an increased threat to national security are some of the effects as a result of a troubled manufacturing economy.

It is clear that the U.S. needs a manufacturing policy that focuses on and stimulates those factors that will make U.S.-based production a viable and profitable business choice. This will then naturally stimulate innovation, which will be needed to satisfy production improvement requirements.

2.2.2 Trends in Industrial Research

An important historical element of manufacturing and materials joining R&D has been the industrial research laboratory. In fact, one of the reasons the U.S. has not invested heavily in manufacturing research, and especially in materials joining technologies, is because it has not needed to do so. Over the last 100 years, progress in materials joining has benefitted heavily from contributions made in industrial research laboratories. This has included contributions from welding equipment producers (e.g., Lincoln Electric, Berkeley Davis, Taylor Winfield, etc.), primary metals producers (U.S. Steel, ALCOA), original equipment manufacturers (General Motors, Caterpillar, Boeing), and energy producers (Exxon, Shell), to name a few. **However, most of that supplier network has gone overseas, and as American manufacturing has gone overseas, R&D dollars have followed.**

The role that these facilities have played in development of new generations of welding and materials joining technologies largely parallels the trends occurring in industrial and corporate research laboratories overall. This can be tracked through the growth of North America as an industrial and technological power through conditions of the present day.

The foundations of North American technology growth find their origins in the 19th century. There was wide access to natural resources as well as large domestic markets. In addition, North America offered a wide-ranging educational system, providing talent for industrial growth. The combination of readily available resources, a stable business climate, and educated workers allowed North America to become a world leader in mass production industries by the close of the 19th century.[14]

Science and technology innovation at the time were largely derived from two sources. First were the “inventor-entrepreneurs,” which drove new business start-ups from concepts derived from larger industrial companies.[15,16,17] Such start-up firms were considered to be agile, risk takers, and served to quickly transform concepts to products for market. Second were university researchers whose work was largely focused on “basic concepts” rather than industrial application of those concepts.[17,18]

At the dawn of the 20th century, however, this landscape began to change. Growth of large companies able to invest in research laboratories, the development of anti-trust laws, and management of intellectual property portfolios all contributed to the internalization of industrial research.[16,18,19] Development of internal research laboratories provided both stable funding for development and offered growth potential for large companies with a long-term view.[16,18,19,20] This led to the formation of a wide range of corporate research capabilities that served to de-emphasize small company innovation as a primary technology driver.[15,16,19] Government investment during and following World War II served to strengthen industrial research.[15,17,20] This included both defense-related spending[16,19], as well as that for other national priorities (e.g., space exploration[14]).

The landscape for industrial research facilities began to change dramatically in the late 20th century. Growth of global markets, liberalization of trade laws, internationalization of corporate structures, and improved educational opportunities around the world all affected the industrial business climate in North America.[14,16,18,20,21] **Over the last several decades, industry has viewed its internal R&D capability with a shorter and shorter term outlook.** One result is that industrial R&D is progressively being carried out by third parties including universities, independent research laboratories, and "science-based start-ups."[16,18,19,20,22] Corporate goals are more focused on accessing technology to bring new products to market, rather than internally developing unique next-generation approaches. This behavior is demonstrated in the plot provided in Figure 2. The results here indicate that between 1984 and 2001, the fraction of industrial research and development completed by small companies (<500 employees) has nearly tripled (from roughly 7% to 20%), while that conducted by large companies (>25,000 employees) has decreased by better than one-third (60% to roughly 38%).

Industrial research in North America reflects a leveling of the playing field around the world. Worldwide growth in development capability is providing numerous resources for industrial innovation. Corporations searching to minimize costs, reduce risks, and shorten product cycles increasingly focus on accessing the best available technologies, regardless of country of origin.[20,21] Corporations then become advanced technology managers, and will form alliances with a range of providers whose capabilities are specific to the short-term product need.

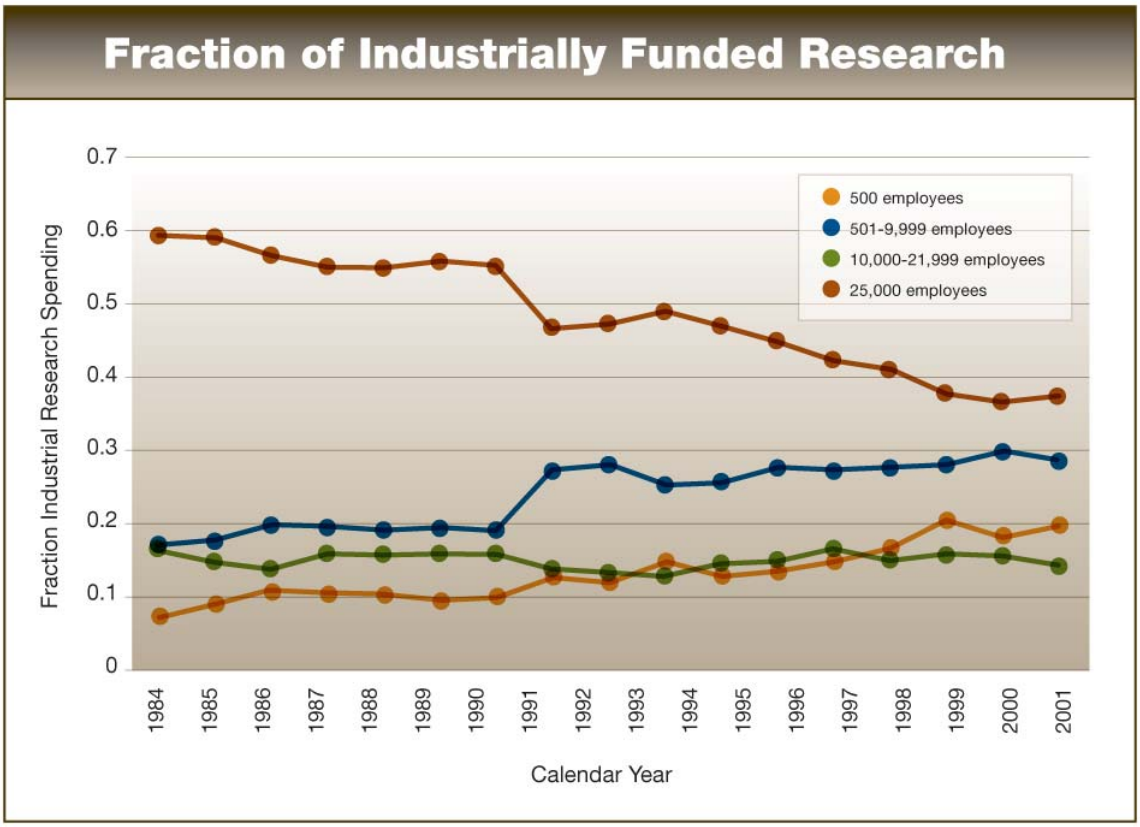

Figure 2. Fraction of Industrially Funded Research in the U.S. as a Function of Firm Size[16]

In a materials joining context, much of this is already apparent. Future developments will largely be product based (new technologies for specific applications). Further, development approaches for such technologies will include significant horizontal integration, including aspects of product development, manufacturing, and marketing. Also, technology development will increasingly take advantage of resources outside the corporate structure, including universities, independent research laboratories, other corporate laboratories, and innovation-based start-ups. Communication will be the key to the next generation of materials joining technology developments, with rapid communications of developments being essential for North American industries to succeed in the 21st century.

2.2.3 Trends in Academic Research

It is well known that materials joining adds value to products within a typical manufacturing life cycle[23] that includes raw material processing, the making of semi-finished goods (e.g., rolled sheet and bar stock), production of finished goods (e.g., automobiles, computers, medical implants), as well as to the service life (e.g., repair[24]). It is critical to the competitiveness of the U.S. manufacturing industry. The role of academia in contributing to meeting these challenges includes development of 1) workforce; and 2) science and technology of joining. This section

outlines challenges and issues facing U.S. academia that are relevant to welding and materials joining curricula.

2.2.3.1 Challenges

- **Availability of Welders and Welding Technologists:** As a part of workforce development, academia is expected to educate current and future welders, technologists, engineers, and researchers. Currently, such training is being offered across vocational institutes, community colleges, technical colleges, and higher education institutes. The first challenge is the lack of availability of welders and welding technologists. This critical need has been identified by AWS, it was discussed at length at the conference, and is an important part of the recommendations of this report.

- **Availability of Welding/Joining Engineers:** The next challenge is related to the scarcity of welding engineers and researchers. The average age of welding engineers and researchers is reported to be over 50 years in U.S. industries. As these engineers retire, there is a need to maintain a steady supply of young engineers and researchers. While the number of undergraduate students in welding engineering/technology has been relatively constant, the demand for qualified welding engineers outstrips the supply from U.S. universities (e.g., OSU, Ferris State, LeTourneau).

- **Availability of Welding/Joining Researchers:** The number of graduate-level (M.S., Ph.D.) students in this field has been declining to levels that threaten the discipline as a field of study. This is attributed to lack of funding to perform research in the areas of welding and joining. This can be discerned by comparing the number of welding publications by U.S. researchers with that of other countries, as shown in Figure 3. For example, by 2007, publications from the People's Republic of China reached parity with those from the U.S. and have continued on a sharp upward trend, while those from the U.S. have been on a precipitous decline (a recent 2010 uptick notwithstanding). Those in competing industrialized economies have been generally stable, or at most, only slightly declining.

- **Academic Programs in Adhesives Bonding**: Several universities in the U.S. are considered strong in adhesion science and adhesives bonding technology. However, no university offers an engineering degree in this technology. Adhesive bonding is central to medical products, advanced energy products (photovoltaic devices, wind energy, fuel cells), composites, and other lightweight structures for vehicles and aerospace, and for assembly of components.

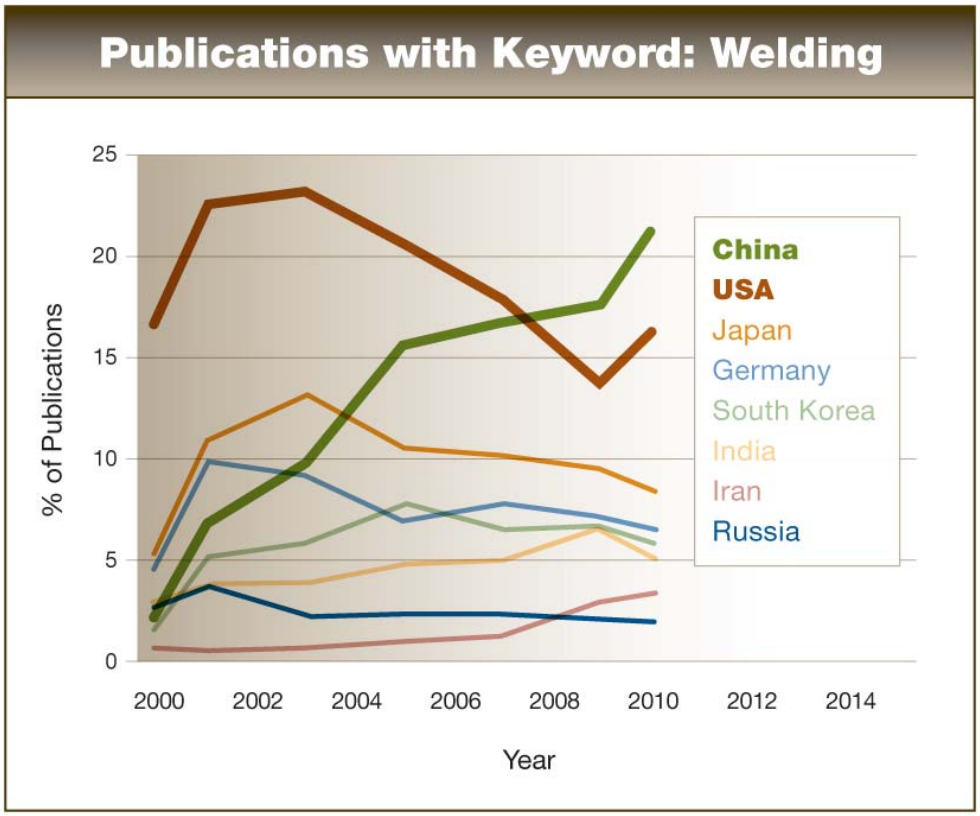

Figure 3. Number of Publications Based on Welding as a Keyword[25]

2.2.4 Value Statement for Academic R&D and Industry Needs

The productivity of the academic community is measured by the tangible demonstration of expertise in fundamental research and publication of the results in international journals. In addition, there is an increased focus on emerging science and technology subjects by governmental agencies (e.g., nano-technology[26], hybrid materials[27], additive manufacturing[28]). Despite the value of welding and joining to manufacturing competitiveness, the percentage of R&D funding in this area is limited due to limited R&D budgets. The government tends to focus on *fundamental* research.[29]

It has been assumed that industry would fund academia to perform *applied* research. This has not been prevalent in all institutions. Academic research is mostly funded by governmental agencies (80%). There has been a flight of academic researchers to emerging areas in materials and engineering, where grant money is more plentiful, to the disadvantage of research in manufacturing, including materials joining.

Representing a further divergent path over the last ten years, **industry has shifted from academic research support and has focused on incremental advances or in maintaining the status quo.** With the decline in industrial research, R&D activities within industry cannot

afford to fail and thus become evolutionary. As a result, disruptive or high-risk technologies are not pursued. Further, the engineering talent to develop those technologies is not being groomed. This is only possible within the university framework, which encourages students and professors to take risks, at least in currently popular technologies.

With this pattern of R&D investment, U.S. industry can only lose its edge on innovation in the welding and materials joining area. Meanwhile, European and Asian governments have realized the need for government-industry-academia partnerships to support *applied* research to maintain and increase their competitiveness in manufacturing.

2.2.5 Narrowing Focus in Materials Joining R&D by U.S. Academia

Not all the fault lies with sponsorship or industry vision. Academia is culpable because of the necessity for it to attract what research dollars it can. Interviews with industry sponsors have revealed that, traditionally, academic research focuses on a single topic (e.g., process, materials, modeling, nondestructive evaluation, etc.) instead of the overall problem-solving "holistic" approach relevant to industry. Investment in academic research is not perceived to produce immediate business value. Now, as in the past, integration of research results from academia has been left mostly to industry. With the decline of R&D departments inside large companies and lack of expertise within small and medium companies, this integration is never achieved in a timely fashion or at all.

For example, welding consumable and process optimizations are being done by trial and error without leveraging the computational models for microstructures and processes.[30] Similarly, structural adhesives bonding lacks overall problem-solving approaches linking design, analysis, surface science, and engineering.

2.2.6 Paradigm Shift in U.S. Industries

There is a paradigm shift in U.S. industry to focus on faster, better, and cheaper products so that it can compete with European and Asian manufacturing. Academic research, sometimes perceived as slow moving, is not considered valuable or timely. Some companies (e.g., Caterpillar) have started developing internal education to render innovative methodologies more relevant to their bottom line. Unless academic researchers provide a better education and research model to provide value to industry, they may become obsolete. Some of the research models based on academia-industry collaboration centers appear promising[31], although the number of such centers may be insufficient to have significant industrial impact. **However, evolutionary research as practiced by industry is not disruptive and the "safe" approach may not lead to disruptive technologies that truly boost competiveness.**

2.2.7 Perception of Manufacturing (or Welding)

Currently, manufacturing (and welding) research is not considered high-tech, although progress made in energy, consumer products, medical equipments, defense, and transportation depends on high-tech welding research. Very simply, the importance of manufacturing and contributory materials joining technology has to be emphasized to attract a new generation of talented students. **The pipeline of manufacturing engineering talent urgently requires replenishment.**

A strong academic community, linked with an engaged industrial community, is essential to maintaining manufacturing and materials joining technologies. Without the faculty, the research, and the students, the relevant engineering skills will disappear. With that, our ability to compete in manufacturing will disappear.

2.3 Issues Impacting Materials Joining and Manufacturing

The point has been emphasized that materials joining technology and manufacturing strength are inextricably linked – there cannot be one without the other. Other countries are investing in these fundamental technologies and are rapidly gaining in momentum. **The need to coordinate government support, industry support, and academic vitality are real and immediate.**

Why should this matter? It is because strong leadership in materials joining technology is closely tied to manufacturing leadership. There are critical needs for society that must be provided by domestic manufacturing unless we are to become dependent on overseas suppliers for critical components and systems in areas such as:

- Energy supply (in wind, solar, nuclear, battery technology, bio-derived, clean coal)
- Transportation (in automotive, air, rail) and the infrastructure to use it
- National defense (for aircraft, surface vessels, submarines, vehicular and body armor, weaponry, cyber-defense, electronics, and computer manufacturing)
- Medical devices, diagnostic devices, and medical technology
- Welding equipment (welding torches, power supplies, dispensing equipment, robotics, control software) and consumables (welding wire, adhesives, brazes, solders)
- Academic and engineering pipelines (teachers to teach and students to learn – intellectual capital)

3.0 Challenges and Opportunities for Materials Joining

At the FMJNA conference, a key question addressed by invited speakers and by participants in the break-out sessions was

"What key materials joining challenges and opportunities should be highest priorities to address in the next decade?"

This next section will review the challenges and opportunities identified by the participants.

The nominal group technique was employed to solicit answers to this question in four parallel breakout sessions. Breakout session participants contributed a total of 155 ideas. Participants ranked the ideas by voting, with 59 of the ideas receiving votes. Facilitators compiled and consolidated the ideas receiving votes into major themes. These themes were reported back to the conference participants to validate the analysis.

On review of the detailed data, it was found that two "grand challenge" opportunities emerged:

1. Increasing the level of technical innovation
2. Increasing workforce competitiveness

Two broad solutions to address these challenges also emerged:

1. Greater collaboration
2. Influencing government policy and funding priorities

Figure 4 illustrates the percentage of aggregate votes received for these challenges and opportunities.

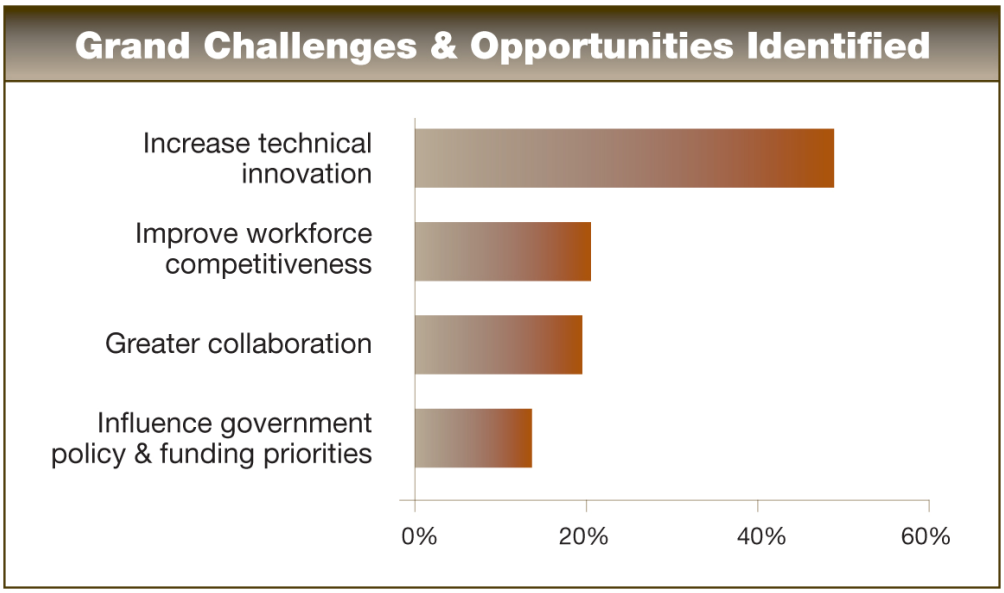

Figure 4. Grand Challenges and Opportunities Identified in the Conference and Percent of Aggregate Votes Received

Each of these areas will be described in the sections that follow. While the identified challenges and broad solutions are presented here as distinct, conference participants recognized that they are, in fact, tightly coupled. For example, world-class technical innovations cannot be implemented without a world-class workforce. Also, greater collaboration will be needed to influence government priorities and to address the technical innovation and workforce competitiveness issues.

Many participants expressed a high sense of urgency in addressing the identified challenges and opportunities. There is a sense that other nations are investing more in their manufacturing competitiveness, and that we are losing our competitive position and even our ability to support our defense needs. Section 4 describes the suggested approaches put forth in the conference.

3.1 Technical Innovation

Conference participants identified a broad range of technical challenges that should be addressed to improve the competitiveness of the materials joining industry. These were collected into the following themes:

- **Advanced Materials:** The introduction of new materials and new material combinations are driving the need for joining and repair technology advancements.

- **Advanced Processes and Automation:** Demanding applications are pushing the limits of existing manufacturing processes. There is a need for new processes or hybridized processes; improved process optimization methods; improved process controls; and more flexible automation to maximize productivity and quality.

- **Modeling and Information Technologies:** Improved numerical modeling tools are needed to allow material and process interactions to be simulated in the context of a 3D structure. Knowledge-based solutions are also needed to better capture and share materials joining knowledge so effective decisions can be made based on cost and performance.

- **Standards:** There is a need to harmonize industry codes and standards to reduce unnecessary and non-value-added variations in requirements. Standards must be adapted more quickly to accommodate changes in technology. Quantitative criteria are needed to replace qualitative workmanship standards, and acceptance criteria should be based on a fitness-for-purpose understanding. Certification systems are needed across all manufacturing levels.

- **Quality:** More accurate, reliable, and portable nondestructive evaluation technologies are needed to verify quality. Real-time process monitoring and control technologies are also needed to ensure first-time quality.

— **R&D Effectiveness:** There is a need to more effectively mature and introduce advanced manufacturing technologies. The time from basic R&D to application must be reduced, and resources must be available to bridge "valley of death" in technology commercialization. Some participants expressed the desire to reduce duplicate welding and joining centers to better focus available resources.

Figure 5 illustrates the relative importance of these areas as expressed by voting of the conference participants.

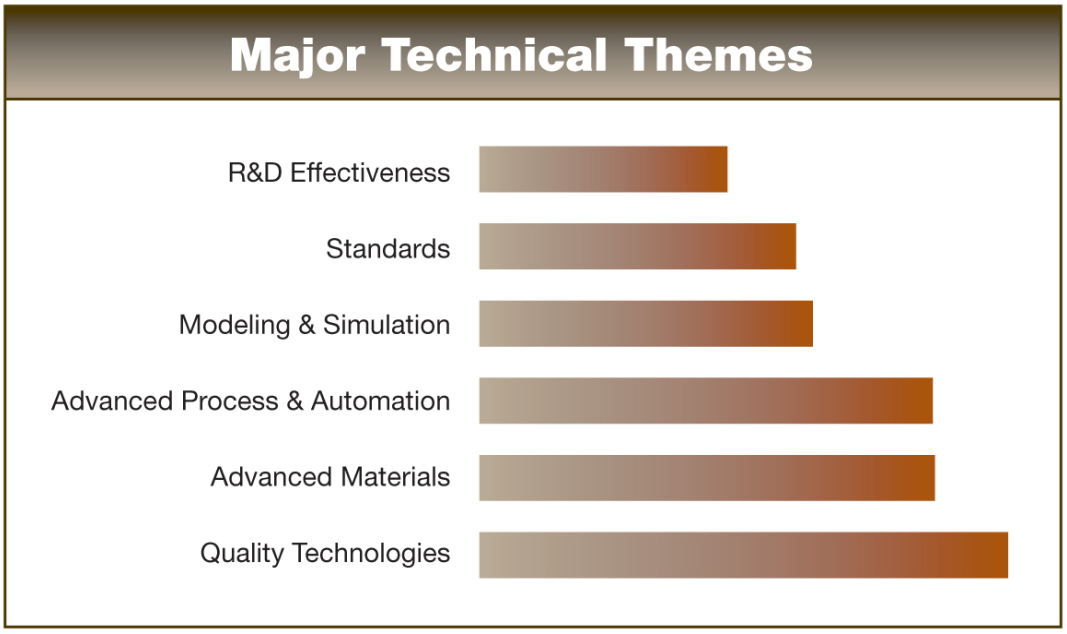

Figure 5. Major Technical Themes and Percent of Votes Received by Each

It was noted in the Preface that surveys were conducted by EWI on materials joining business challenges and technology needs[32], with results markedly consistent with findings at the FMJNA conference. For example, Table 1 shows the top 10 ranked responses to the question, "*What will be your most important materials joining related business challenges in the next five years?*" The table also shows the top four ranked responses for six different industry sectors: automotive, oil and gas, defense, aerospace, heavy manufacturing, and advanced energy.

Materials Joining Challenges: Ranked by Sector

	Automotive	Oil & Gas	Defense	Aerospace	Heavy Manu	Adv Energy
Increased use of new materials or material combinations	1	4	3	4	4	1
Qualifying new processes and procedures			2	1		
Maturing and successfully transitioning technologies from R&D to production			1	3		4
Keeping staff current on the latest materials joining processes and methods	2					3
Shortage of engineers and designers with materials joining expertise		1	4			
Increased joint performance requirements	4	2			2	
Competition from low labor-cost countries	3					
Cost to introduce new processes, procedures, or product designs				2		2
First-time quality expectations are increasing					3	
Shortage of skilled welders and other skilled trades		3			1	

Table 1. Materials Joining Challenges (Top 4 Ranked for Selected Sectors)

A recurring theme is the need to introduce new technologies to improve quality and competitiveness, and to adapt to changing product performance requirements and materials. In a broader vein, the surveys also reveal a difficulty in dealing with technology proliferation and effectively introducing advanced manufacturing technologies, as expressed by the challenges "qualifying new processes and procedures," "maturing and successfully transitioning technologies from R&D to production," and the "cost to introduce new processes, procedures, or product designs." These challenges align well with the conference theme of improving R&D effectiveness.

Another major theme emerging from the survey data is the ongoing shortage of talent with materials joining expertise. This theme is discussed in the section that follows.

3.2 Workforce Development

Many of the suggested opportunities and challenges related to strengthening the materials workforce at all levels, from skilled trades on the production floor to researchers in the laboratories. The need for improved training and education was suggested by every breakout group and received the most aggregated votes from the participants. The previously cited EWI survey (Table 1) also reflects the workforce challenges, noting the shortage of engineers, designers, and skilled tradespeople, and difficulty in keeping staff current on the latest materials joining processes and methods.

Suggested opportunities to improve the materials joining workforce included increasing awareness and recruitment of talent into materials joining related fields. Another suggestion was to expand materials joining engineering programs and tailor those programs to meet the rapidly changing needs of industry. It was also suggested that closer collaboration is needed between industry and educational programs to ensure alignment with industry needs. Another suggestion was increased interdisciplinary training (for example, to educate designers to take advantage of the latest materials joining technologies). Regional technology demonstration sites were suggested as one vehicle to improve awareness of manufacturing technologies.

The importance of retraining of the workforce for employees already in the workforce or who have lost jobs in manufacturing was emphasized.

(For example, one of the key elements of Germany's success is the continual training of employees to support new technology and innovation). Technical schools, community colleges, and universities should be engaged in workforce retraining efforts to support the changing needs of industry. This would also help our competitiveness. Other specific challenges and opportunities included

- The need to get to middle and high schools to actively promote the value and worth of manufacturing and materials joining engineering careers
- At the technical school level, promotion of the need for manufacturing support technologies such as welding, joining, and automation
- The need to emphasize the value of federal research programs (e.g., NSF's Industry/University Research Centers) that allow undergraduates to get into graduate education
- Incentivizing of industry to provide internships and to foster certifications for welding and adhesives bonding (a common practice in many countries)
- Connecting of pay grades to advanced or increasing certifications
- Development of "continuing education" virtual training with Continuing Education Units (CEUs)
- Model such efforts on an earlier successful collaboration program known as "National Excellence in Materials Joining Education and Training" while introducing distance learning and other more recent innovations
- Integrate workforce development with new training and projects such as has been done at Lehigh, Colorado School of Mines and OSU

3.3 Collaboration

Of the 155 challenges and broad solution ideas contributed in all the expert focus groups, "collaboration" was the single idea receiving the most votes.

Conference participants recognized that the scope of the issues involved, and the limits on total resources that might be mobilized for a response, would require extensive cooperation over many organizations. Thus, the concept of encouraging collaboration as a means of arriving at goals was a part of conference thinking.

The view was expressed that other regions of the world are much more effective at establishing effective collaborations for manufacturing technology innovation and workforce development. It was suggested that we leverage globalization and learn from what is working elsewhere.

To be effective, collaborations need to extend broadly to include all stakeholders. For technology innovation, an effective collaboration may involve industry, corporate R&D centers, research institutes, universities, national labs, commercialization partners, investors, and government agencies at the federal and state levels. For workforce development, the collaborations could include industry, unions, professional associations, high schools, vocational schools, community colleges, universities, industrial training programs, and relevant government agencies at the federal, state, and local levels. Conference participants expressed the need for strong leadership from a few key organizations to create collaborative structures, find motivations to collaborate, and break through historical barriers to collaboration. Some of the barriers identified included "not invented here" perspectives, difficulty in building consensus among industries, and competitive tendencies. Participants also expressed the need for government support, as described in the next section.

3.4 Influencing Government Priorities

A common suggestion was that government must play a significant support role in strengthening the competitive position of the materials joining industry. Some conference participants expressed the view that the current legislative and legal environment is antimanufacturing. There were a number of suggestions for areas where government support is needed:

- Funding for manufacturing technology innovation and maturation. A view expressed was that too much emphasis is being placed on "boutique technologies," such as nanomaterials, with little funding to transition needed manufacturing technologies.
- Funding for materials joining workforce development programs from the trade schools through to graduate schools

— National certification programs

With federal and state governments facing deficits and declining tax bases, conference participants recognized that a case must be made that targeted investment will pay off in the long run. That is, expanding the manufacturing base will create high-wage jobs that will expand the tax base. **The most-voted challenge was the need to improve public and government awareness in the importance of materials joining to the economy and national security.** It was felt that a compelling story is needed, but the diversity of products and organizations that rely on joining technology makes this difficult. One suggestion was to focus on a few critical industries, such as energy, transportation, and defense to illustrate the need for investment in technology innovation and workforce development. Another suggestion was to focus on the risk from the pending loss of corporate memory and competitive manufacturing capabilities.

Finally, a commonly expressed challenge or opportunity was following through on the FMJNA conference recommendations. Participants expressed the need for clear leadership and a message to build a coalition to move forward with solutions.

4.0 Approaches to Advancing Competitiveness

The previous section identified challenges and opportunities to advance the competitive position of the North American materials joining industry. These were distilled into two "grand challenges:"

1. Improving manufacturing technology innovation
2. Improving workforce competitiveness

This section focuses on approaches to address these challenges. Six breakout sessions were conducted to discuss and rank potential approaches to enhance the competitiveness of the materials joining industry. Two questions were posed to the groups:

- "What collaborative approaches would be most effective to advance North America's competitive position for materials joining?"

- "How do we overcome funding availability, IP ownership, competitive concerns, and other barriers to successful collaboration?"

The nominal group technique was employed with four parallel breakout groups producing over 90 ideas. Each group consolidated similar ideas before participants were asked to identify the most important concepts using distributive voting. All the data from the multiple groups was then combined and interpreted to identify major themes. The following summarizes the major themes that emerged from these exercises.

4.1 Summary of Findings

As a result of these discussions, there was general agreement around the theme that the North American economy will not prosper without a strong manufacturing sector. Further, greater collaboration involving a broad range of stakeholders was identified as the single most important opportunity to advance manufacturing competitiveness in North America. The goals for collaboration targeted three main areas:

- Improving the manufacturing technology innovation infrastructure
- Improving workforce development approaches
- Increasing public awareness and influencing government investment priorities

Effective collaborations will not be established without sustained leadership from organizations that have appropriate structures, missions, personnel, and resources. Several organizational models were suggested to provide this collaborative leadership, and a benchmarking exercise was recommended to identify the preferred model. Lack of funding was identified to be a

primary barrier to executing collaborative initiatives that address the technology innovation and workforce development challenges. Competitive pressures prevent individual industries from investing in long-term knowledge building to benefit all industry. Government thus must play a major role in underwriting these initiatives to provide the foundation for industry involvement. To influence government policy, a more compelling case must be made for the importance of materials joining to manufacturing competitiveness, economic prosperity, and national security.

Conference attendees expressed a sense of urgency and the importance of acting on the conference findings to keep momentum.

Conference attendees also recognized that ongoing leadership from key organizations is vital to push forward with collaborative solutions. The outstanding question remained regarding who would lead such a collaborative initiative. It was suggested that a task force be organized to formulate a go-forward strategy and plan.

4.2 Technology Innovation Infrastructure

Many recent studies have concluded that innovation is the primary driver of manufacturing competitiveness. The 2010 Global Manufacturing Competitiveness Index[33] gathered data from 400 senior manufacturing executives worldwide and ranked the drivers of global manufacturing competitiveness. It found the number one driver to be "talent-driven innovation," or the capacity to continuously innovate, while simultaneously improving production efficiency.

There is nothing new about the drive for manufacturing innovation, as evidenced by the strong manufacturing productivity growth in comparison to the remainder of the economy over the past 50 years. **What is *new* is the rate of change and innovation required to keep pace with global competitors.** As a Chicago Federal Reserve Bank president put it: "Globalization has sharpened competition in recent years so that survival requires ever more dedication to staying one step ahead and at the forefront of innovation…One way to boost productivity is through research and development. Manufacturing companies are investing more in R&D as a way to develop new products and improve productivity."[34] Such investments can be greatly leveraged through increased collaboration with university and government research efforts.

The increased pace of technological change is posing a challenge to the materials joining industry. A 2010 EWI industry survey posed the question: "*What will be your most important materials joining related business challenges in the next 5 years?*" Respondents identified the need to keep up with the proliferation of new materials and technologies as a major challenge. Respondents also indicated that they are looking for more effective ways to mature, qualify, and transition new technologies from R&D to production.

As described in Section 3 of this report, conference participants identified a broad range of technical challenges that should be addressed to improve the competitiveness of the materials

joining industry. These broad technological challenges and needs are beyond the capabilities of any one company or technology organization to provide an effective solution. Conference participants recognized the need for collaborative solutions to these technical challenges, and discussed various means of collaboration.

A 2010 EWI industry survey asked recipients: *"What types of collaborative development approaches would be most useful to advance the state of manufacturing technology?"* The top five most selected alternatives are shown in Figure 6 along with the percentage of respondents selecting the option. By far the most often selected alternative was to form broad groups involving industry, research organizations, universities, and government. Conference participants discussed possible collaborative structures in more detail.

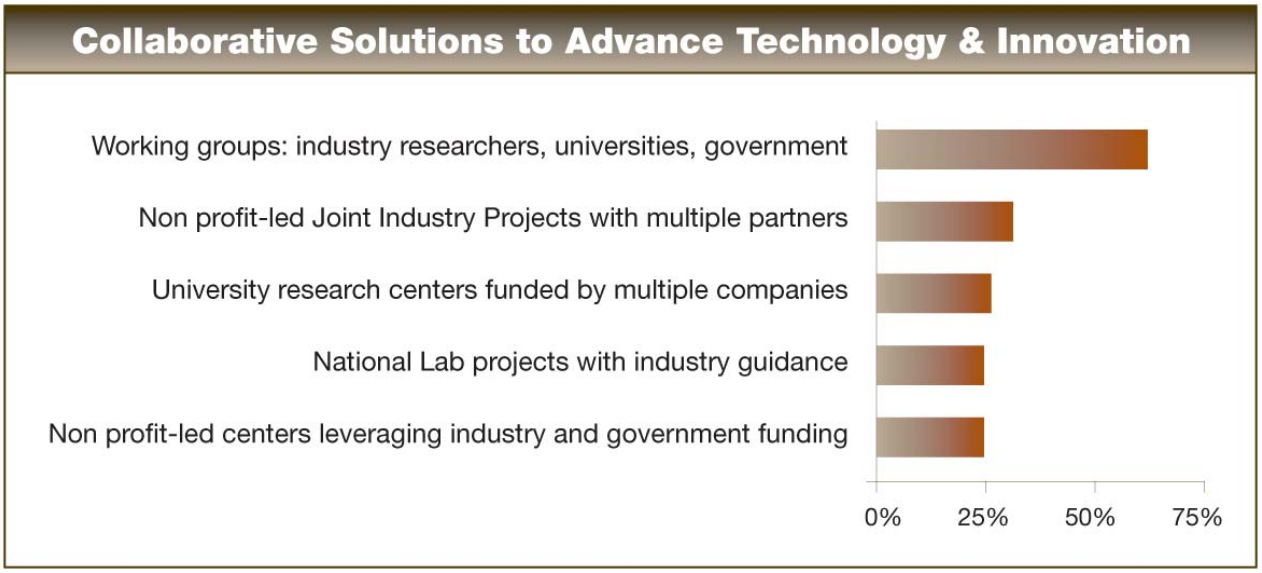

Figure 6. Most Highly Rated Collaborative Solutions to Advance Manufacturing Technology Innovation

4.2.1 Collaborative Structure

A common suggestion was that a central organization is needed to identify industry needs and to coordinate technology innovation activities to address industry needs. This was viewed as a national organization that serves as a coordinating body for the development and dissemination of advanced materials joining technology, linking industry, academia, and research organizations.

Conference attendees suggested a number of areas where this central organization should focus its efforts. For example, it was suggested that small and medium businesses often drive growth and should be a focus area. Similarly, it was suggested that more support is needed for tiered suppliers to help them grow their technical capabilities. Since small businesses and tiers suppliers are often stretched for resources, there must be a funding mechanism to help these companies access the joining innovations they need to compete and to grow. Another

suggestion was the idea that preference be given to materials joining innovations that impact national defense or energy security. Focusing on areas of national significance would justify sustained federal government investment in technology innovation. Another suggestion was for the central organization to focus on demonstrating and piloting advanced manufacturing technologies. Regional application centers would allow businesses to identify and evaluate the benefits of various technologies for their particular applications.

Conference participants discussed the most effective structures to enable collaborative technical innovation.

It was suggested that successful models for manufacturing technology innovation throughout the world be benchmarked to borrow elements that worked well elsewhere. The following organizational models were mentioned:

- **Fraunhofer:** One suggestion was to emulate the German Fraunhofer public-private partnership model. The German Fraunhofer organization includes 59 Fraunhofer Institutes located throughout Germany, with 17,000 staff of mostly scientists and engineers. They act as an intermediary between universities and industry to develop products and processes right up to commercial maturity. Of the 1.6 billion Euro annual research budget, 1.3 billion Euros is generated through contract research. About 20% of its revenue is government institutional funding that is invested to build leading capabilities.

- **Member-Based Centers:** Another suggestion was to build upon the member-based center models, such as EWI (U.S.), TWI (U.K.), and SIMTech (Singapore). These organizations use membership fees to build technical capabilities and perform contract research for both industry and government to address specific client challenges. They work with many different industry sectors, which facilitates cross-sector collaborations and leveraging of technical innovations.

- **Industry-Specific Organization:** Another suggestion was to tie industry, government, and academia into cohesive development programs through member-based industry-specific organizations, such as the Electric Power Research Institute (EPRI) and the Pipeline Research Council International (PRCI). These organizations typically receive the majority of their funding from membership fees and structure research portfolios that serve common industry needs.

- **I/UCRCs:** The National Science Foundation (NSF) has a program that allows for addressing some of the challenges mentioned above. For example, the Industry/University Cooperative Research Center (I/UCRC) allows for engagement of industry and academia. Within this research franchise framework, academia can meet their goals of exploration and fundamental knowledge generation, while the needs of industry can be satisfied. Currently, three multiuniversity NSF I/UCRC programs focus

on welding and joining research. The above model could be expanded to more industries and universities.

- **ManTech Center:** A federally funded center was suggested as another possible model. Such a center would typically be operated by another entity, and receive most of its funding from the government. Examples include the Navy Centers of Excellence, such as the Navy Metalworking Center, operated by CTC, and the Navy Joining Center, operated by EWI. One suggestion made was to extend this model to other government agencies such as the Departments of Energy, Transportation, or Commerce.

- **Regional Programs:** Regional industrial support programs or manufacturing solution centers were suggested as a way to make manufacturers aware of the latest technical advancements. The Ohio Manufacturing Institute was mentioned as an example of a program that is being pilot tested. Once a successful regional model is found, it could be replicated elsewhere.

- **Industry-Led Consortia:** Consortia pool their resources and capabilities and leverage government funding with a specific end-goal in mind. Perhaps the largest example of this is the SEMATECH initiative two decades ago that focused on improving the competitiveness of the U.S. semiconductor manufacturing industry. Recent examples are the Nuclear Fabrication Consortium, which is focused on improving manufacturing technology to strengthen the U.S. commercial nuclear supply chain and USCAR.

- **Virtual Organization:** The suggestion was made that the organization be virtual, in which technology needs could be communicated through a potential provider network. Technology needs could then be addressed by provider groups that could independently coordinate to provide the necessary solution(s). This vehicle was seen to address a range of technology challenges, including research, development, implementation, and training services. Web-based interactive systems and social media were seen as enabling tools.

- **Professional Societies:** There was also some discussion about the role of the professional societies and standards organizations in encouraging collaboration. These organizations have well-established linkage with industry, which could be leverages. Concern was expressed that these organizations may be too slow to be effective in technology innovation collaborations due to their volunteer nature.

4.2.2 Barriers to Collaboration

There are a number of obstacles that must be overcome to achieve successful collaboration for manufacturing technology innovation. A recent EWI survey asked the question, "*What are the biggest barriers to successful collaborative manufacturing technology development?*" Figure 7 indicates the top ten selected options and the percentage of the 450 respondents selecting the option.

The following are the top three responses to this question:

- Insufficient funding to execute programs
- Intellectual property ownership
- Industry competition stifles collaboration

The top three survey responses were *reiterated* by the conference participants as significant barriers to collaboration:

- **Insufficient funding to execute programs**
- **Intellectual property ownership**
- **Industry competition stifles collaboration**

Additionally, the participants identified the difficulty in reaching consensus on technology needs and priorities among diverse industry partners as another challenge. These different priorities are exacerbated by different company cultures and perspectives on manufacturing technology investment.

It was suggested that industry collaborates best when technical innovations are not related to specific applications where companies seek a competitive advantage. Therefore, the work should focus on the "precompetitive" stage of technologies where intellectual property is less of an issue. Creative ways of managing and sharing IP are also needed for the mutual benefit of industry, such as an IP warehouse managed with on-line database tools. It was felt that government funding will be needed to facilitate broad industry collaboration and investment in precompetitive technology development.

Figure 7. Top 10 Most Selected Barriers to Collaboration from a July 2010 EWI Survey and Percentage of Respondents Selecting the Option[8]

4.3 Improving Workforce Competitiveness

To compete with low labor-cost nations, North American manufacturers must be leaders in quality, productivity, agility, and product performance. This requires a workforce that is capable of technical innovation and implementing new manufacturing technologies.

Manufactures are struggling to meet their workforce needs. A 2009 survey[35] asked manufacturing companies to describe the current availability of qualified workers, and to describe anticipated changes to that availability over the next few years. Fifty-one percent reported moderate to serious shortages of skilled trades, while 36% reported moderate to serious shortages of engineers and scientists. In both cases, the vast majority also expected increased shortages ahead.

This workforce challenge was validated by a 2010 EWI survey[32] on materials joining business challenges. Respondents ranked the shortage of engineers and designers with materials joining expertise as one of the top five business challenges, and the shortage of skilled trades ranked in the top ten. For some industry sectors, these talent shortages were identified as the number one materials joining business challenge.

The need for additional skilled workers is expected to persist for many years to come. Over 150,000 new skilled welders will be needed in the U.S. over the next 10 years.[36] Many high technology manufacturing jobs will require more than a high school diploma causing employers to fall short when trying to fill these jobs. By 2018 there will be an estimated 46.8 million job

openings, 63% of which will require workers with some college education[37]. There could be three million fewer college graduates than the market demands by 2018.

Our competitive position in supplying talent continues to erode.

A report by the National Academies[38] found that there has been little progress in strengthening our public school system in the last 5 years and that many other nations have been markedly progressing, thereby affecting America's relative ability to compete effectively. Nearly 1.3 million teenagers in the U.S. drop out of high school each year. In 1,700 high schools, less than 60% of students make it to Grade 12 on time. More than one-fourth of the high school class of 2006 failed to graduate on time. The United States ranks 27th among developed nations in the proportion of college students receiving undergraduate degrees in science or engineering, 16th in college completion rate, and 20th in high school completion rate among industrialized nations. Two-thirds of the engineers who receive Ph.Ds from U.S. universities are not U.S. citizens.

Conference participants suggested a number of potential solutions to begin to address the workforce competitiveness challenge. The following is a summary of the major themes suggested and ranked most highly by the participants:

- **Talent Attraction:** Attract talent and begin education early. Get to middle schools and high schools to actively promote the value and worth of manufacturing and materials joining technology careers.

- **Secondary Education:** Integrate more manufacturing and materials joining concepts into the curricula. A recent example is the Ohio Department of Education's effort to integrate "Automated Materials Joining Technology" into high school curriculum to provide context-based learning and technical preparation for college and careers[39].

- **Skilled Trades:** Incentivize industry to provide internships and to foster certifications for materials joining trades, as is common in some other countries. For example, the Manufacturing Skills Certification System[40] and the AWS Welding Certification Programs are intended to provide skills assessments, standardized curriculum requirements, and portable credentials that validate the attainment of critical competencies required by industry.

- **Undergraduate Education:** At community college and university levels, promote the need for manufacturing technology education, including welding, joining, automation, inspection, and allied skills. Set a goal to expand welding engineering program enrollment and curricula nationwide.

- **Graduate Education:** Emphasize the value of university graduate programs, and leverage I/UCRC[41] graduate research funding mechanisms. Federal funding agencies,

such as NSF, must put more value on manufacturing technology research to address current and emerging industrial needs.

— **Continuing Education:** Methods are needed to keep the workforce current on the latest materials joining technology advances. Interdisciplinary training was also identified as a need. For example, there is a need to train designers to take best advantage of new materials and processes. Suggestions were made to revive the NEMJET[(42)] program, add distance learning, CEUs, modernize models, expand to more universities, add more skill levels, and link to certification initiatives.

Achieving these goals will take much broader collaboration between industry, state government, relevant federal agencies, local schools, community colleges, universities, and trade associations. It will also take leadership to promote, organize, and coordinate these activities. A collaboration infrastructure will also be needed to identify industry's emerging needs and to better align and integrate workforce development activities among various educational institutions to serve these needs.

4.4 Influencing Government Priorities

A consensus emerged of the importance of influencing public policy. In an era of austere budgets and the need for hard choices, government officials must be convinced that investing in manufacturing competitiveness is a national priority. Materials joining innovation must also be seen as an important pillar of manufacturing competitiveness. Conference participants expressed the need to create a sense of urgency among potential stakeholders. This will require increasing awareness among the general public and decision makers within industry and government.

There is already a growing sense that the U.S. manufacturing sector is falling behind global competitors. As a recent Milken Institute report[(43)] states, "There is no denying that the dominance of U.S. manufacturing has been steadily eroding." The recently released update to the "gathering storm" report put it this way, "In spite of the efforts of both those in government and the private sector, the outlook for America to compete for quality jobs has further deteriorated over the past 5 years." The take away is that **U.S. competitiveness continues to deteriorate rapidly and that the best hope for turning it around is through sustained investment in innovation.**

Americans intuitively understand importance of manufacturing to the prosperity of the U.S. A 2010 public opinion survey[(44)] of over 1000 people in 50 states found that over three-quarters of Americans have a strong view of the significance of manufacturing, seeing it as very important to the country's economic prosperity. A similar proportion also said they consider manufacturing very important to our standard of living, believe the U.S. needs a more strategic approach to

developing its manufacturing base, and believe the country should invest more in the manufacturing industry.

Conference participants expressed the need to create a compelling message focusing government, industry, and the general public on the criticality of materials joining technology to society. This would involve qualifying the national risk associated with not addressing materials joining technology and workforce competitiveness issues. Two areas discussed include the importance of materials joining manufacturing technology to defense and energy security. Government should view weakness in materials joining competitiveness as a threat to our economy and security.

Participants identified the need to develop specific policy recommendations.

One suggestion was to recommend a national initiative to rebuild American manufacturing through world-leading manufacturing technology innovation. This would require increased funding for materials joining R&D, education, certification, and to mature and commercialize new technologies. Suggestions were also made to institutionalize materials joining investments by establishing and office within the Department of Commerce, Energy, or Defense with a mandate to advance critical manufacturing technologies and workforce competitiveness.

Much of the discussion focused on collaboration to influence government priorities. Leadership is needed from existing organizations to push the materials joining innovation and workforce agendas within the larger manufacturing competitiveness context. It was suggested that the AWS collaborate closely with other organizations, such as the National Association of Manufacturers and U.S. Chamber of Commerce, to educate lawmakers and influence legislation.

4.5 Next Steps

Some broad steps were identified to move forward with establishing effective collaborations for technology innovation and workforce development. These steps included first assessing existing collaborative structures to build upon. Government support was seen to be necessary to develop successful collaborations, and coordinated lobbying from the interested stakeholders was suggested. Other steps mentioned included defining needs for specific market segments, assessment of precompetitive needs, and building on existing programs. Finally, it was suggested that a task force be organized to formulate a go-forward strategy and plan.

5.0 Recommendations

The FMJNA conference was organized to take a critical look at the current state of materials joining technology and to identify actions to promote a strong North American manufacturing base.

Two “grand challenges” were identified:

1. Improving our manufacturing technology innovation infrastructure
2. Improving the competitiveness of our workforce

Suggested opportunities to address these challenges fell into two broad categories:

1. Creating effective collaborations involving a range of stakeholders to tackle the technology innovation and workforce challenges
2. Influencing government policies to support these collaborative efforts

The two grand challenges and two opportunities are tightly coupled and must be addressed in concert. We cannot develop and implement world-class manufacturing technologies without a world-class workforce. We cannot create effective broad collaborations to address the grand challenges without government support. It will take a holistic approach and long-term commitment from a range of stakeholders to achieve lasting manufacturing competitiveness improvements. Figure 8 illustrates the interconnected challenges/opportunities landscape and some of the stakeholders involved.

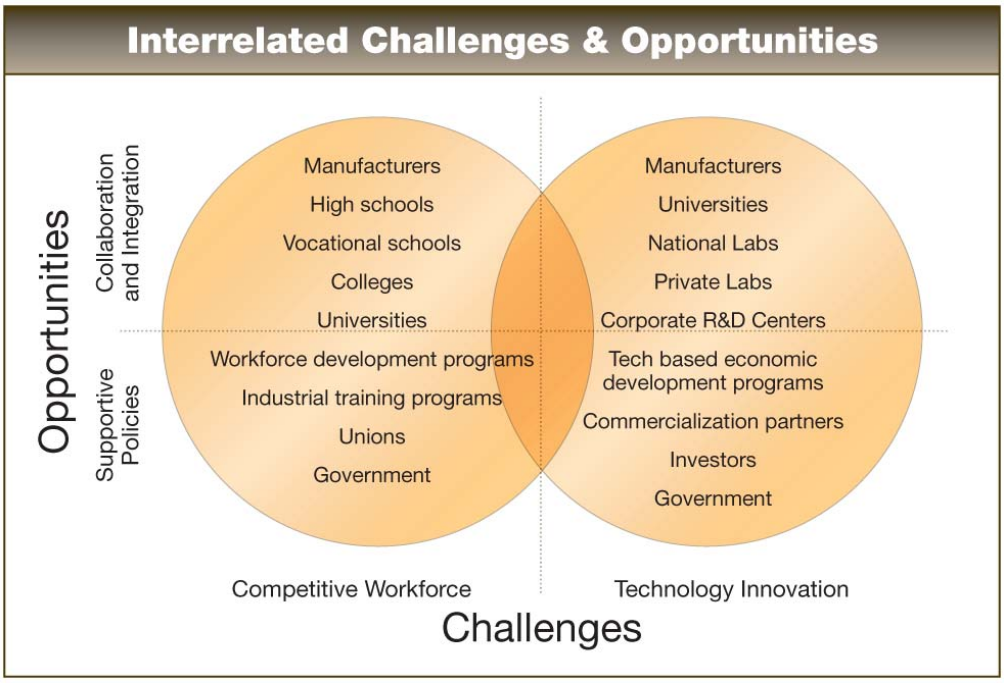

Figure 8: The Grand Challenges and Opportunities are Interrelated and Involve Many Stakeholders

Conference attendees expressed a sense of urgency and the importance of acting quickly on the conference findings to keep momentum.

Conference attendees also recognized that ongoing leadership from key organizations will be vital to push forward with solutions. It is recommended that the conference organizers, EWI and AWS, take the lead in engaging stakeholders to develop a strategy for addressing the technology innovation and workforce competitiveness challenges. The following specific actions are suggested, and the target time frame for completion:

Innovation infrastructure benchmarking study (90 days) – EWI will engage stakeholders in a review of innovation models identified by conference attendees. The study will identify elements of these models that have particular merit within the North American business, government, and economic environment. The preferred model, or a hybrid approach, will be suggested as a candidate position for discussion at the Innovation Summit.

Workforce Development Needs Analysis (90 days) – AWS will engage stakeholders to assess projected materials joining workforce needs, review current workforce development programs, and identify gaps. The review will suggest areas of focus to strengthen the competitiveness and innovation capacity of the workforce at all levels, and will be discussed at the Innovation Summit.

Innovation Summit (180 days) – EWI and AWS will host a meeting of thought leaders from industry, research organizations, and policy makers. The summit will review the findings of the EWI and AWS studies, validate or amend the proposed approaches, and develop a strategy to build support for implementation.

Policy maker engagement (270 days) – An awareness campaign will relay the findings from the conference and express the need for investment to strengthen our competitive position. Engagement will begin immediately, and will be an area of particular focus following the Innovation Summit. EWI and AWS will organize this effort, but will rely on the active participation of a range of stakeholders to influence decision makers.

Organize follow-on FMJNA conference (18 months) – A follow-on conference will be held to review the status of the activities and determine future needs and directions.

These activities are designed to keep momentum in the near term and build alignment for structural improvements in the long term to strengthen our competitive position. Success is

predicated on teamwork, commitment, and dedication from all those who are passionate about fulfilling the 20 year vision articulated in the 2000 Welding Technology Roadmap:

“U.S. Industry will be the world’s leading source of these cost-effective, superior-performing products by virtue of its leadership in joining technology, product design, and fabrication capabilities, and a globally competitive workforce.”

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