Materials Joining and Forming Technology Roadmap Prepared For the State of Ohio

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1.0 Purpose and Scope

1.1 Background

This document was prepared by EWI to fulfill the requirements of contract sub-award 60043294/RF under prime award TECH 13-105 to The Ohio State University. This effort has been carried out under EWI Project 55334GTH in support of the Ohio Manufacturing Technology Network for the development of a materials joining and forming technology roadmap. This roadmap is the output produced by convening meetings, interviewing and surveying numerous Ohio manufacturers engaged in joining and forming activities across multiple industries and gathering their input and recommendations related to joining and forming technology needs. Input was also received from other documents and sources obtained from EWI's normal business activities. Some of these sources include technology roadmaps developed by EWI as part of its on-going technology development efforts, technical inquiries from EWI member companies - particularly Ohio-based members - various technical workshops developed and hosted by EWI, and client-sponsored project work and consultation activities.

1.2 Purpose

This roadmap is intended to provide information on the current state of materials joining and forming capabilities, document gaps and needs that if addressed could meaningfully improve the competitive position of Ohio manufacturers engaged in these technologies, and discuss approaches to better align Ohio's technology development resources with manufacturer's needs to assist policymakers in developing strategies for supporting the Ohio manufacturing base and improving the health and stability of manufacturing in Ohio.

EWI is well positioned to carry out the industry canvassing activities as input to this roadmap and to assess the gaps and needs in industry to identify relevant technology development priorities in materials joining and forming. Since its founding in 1984 in Columbus, EWI has been industry focused to develop and deploy relevant materials joining technologies to benefit industry. Much of this effort has been directed towards Ohio companies as EWI was created as one of the Edison Technology Centers and has supported Ohio-based manufacturers utilizing materials joining technologies as part of its core mission.

Throughout its 30 year history, EWI has frequently surveyed its client-base to assess technology needs and carried out targeted programs to address those needs. In addition, for the past 12 years, EWI has developed internal technology roadmaps to establish priorities for pursuing technology advancements in materials joining, forming and other allied technologies (i.e. nondestructive testing/engineering, materials testing, finite element modeling and simulation, etc.). These roadmaps have attempted to address the broad needs of manufacturers in Ohio and across the nation in improving the competitive position of companies utilizing these critical manufacturing technologies.

EWI's client-base in materials joining reaches across almost every manufacturing sector of the economy from automotive and aerospace to oil and gas, ship building, defense, medical, electronics, consumer products, and the off-road construction and mining industries. By serving such a diverse client-base, EWI has been at the forefront of technology assessment, development and deployment of joining and forming solutions critical to these industries. This experience gives EWI a strong foundation on which to develop this roadmap to support Ohio manufacturers.

These capabilities and experiences provide EWI with the insight, needs assessment tools and networking connections to industry, academia and government/regulatory entities to produce this roadmap to support Ohio manufacturers.

1.3 Scope and Objectives

This roadmap provides a review of current technology and market trends with respect to materials joining and forming technologies, identifies notable gaps and needs in these technologies, and provides a course of action that may address these needs in order to improve the profitability and competitiveness of Ohio manufacturers engaged in joining and forming operations. This roadmap has considered technology and market trends over the past decade through 2014 and outlines technology needs to be addressed in the coming 5 to 7 years, extending through 2022.

1.4 Process

This roadmap was developed by EWI with information gathered from its industrial member companies, affiliated professional associations, universities and workforce development agencies, the centers and consortia organizations operated by EWI, and from information used in the development of various technology roadmaps routinely used within EWI's normal business operations to develop and manage its technology portfolio. The focus of this roadmap is on Ohio manufacturing and as such, the market assessment, gaps and needs analysis and action plan are based on information obtained from organizations within Ohio and with consideration for the industries that comprise a significant portion of the manufacturing economy in Ohio.

The data and information included in this document is the result of numerous canvassing methods to gather input from industry, professional associations, academia and various government entities. Some sources of this information gathering effort include:

- EWI Industry Advisory Board
- EWI Forming Center
- EWI Additive Manufacturing Center
- EWI member companies, particularly Ohio-based companies
- Technology focus group meetings
- Industry surveys
- EWI technology roadmaps
- Other roadmaps and relevant technical literature

A brief description of some of these sources is given below.

The EWI Industry Advisory Board (IAB) consists of approximately 25 senior technical experts at key EWI member companies who provide guidance to EWI on the development and deployment of its technology portfolio. This includes assisting EWI in identifying emerging technical needs in materials joining and manufacturing technologies, prioritizing technology development and investment initiatives, and advising EWI on industry trends. Ohio-based organizations participating on the IAB as of November 2014 include Lincoln Electric Company (Cleveland), Honda North America (Marysville), Parker Hannifin Aerospace (Mentor), Babcock & Wilcox (Barberton), The Ohio State University (Columbus), GE Aviation (Cincinnati), Worthington Industries (Columbus), Emerson (Columbus) and Crown Equipment Corporation (New Bremen).

EWI established the EWI Forming Center (EWI-FC) in collaboration with The Ohio State University's Center for Precision Forming (OSU-CPF) to serve as a nexus of applied research and thought leadership focusing on sheet metal forming and forging processes. This unique center supports automotive, aerospace and other manufacturing industries. Advanced forming and joining is one of eleven cross-cutting technologies pivotal to enabling U.S. manufacturing innovation and competitiveness. To provide collaboration and networking, *Friends of the EWI Forming Center* is a no-fee association of industry stakeholders geared toward encouraging familiarity among center participants, incubating joint project work, and understanding the needs of the market. At present more than 60 companies have become *Friends of the EWI Forming Center*.

The EWI Additive Manufacturing Consortium was created to advance additive manufacturing, an emerging sub-set of technology within the materials joining spectrum. Additive Manufacturing (AM) or "3D printing" as it is known in more general circles, is a rapidly maturing manufacturing technology that has evolved from rapid prototyping over the past 30 years. EWI established the Additive Manufacturing Consortium (AMC) in 2010 with a mission of advancing the manufacturing readiness of this emerging technology. The AMC is a national consortium of industry, government, academic and non-profit research organizations with the mission of accelerating and advancing the manufacturing readiness of metal additive manufacturing (AM) technology. At present, there are 15 members and research partners in the consortium, four of which are located in Ohio.

The canvassing of industry needs for this roadmap has consisted primarily of surveys, focus group meetings and EWI's day-to-day contract project activities and technical support of Ohio companies. Some key activities include two meetings of the EWI IAB in 2014 during which brainstorming sessions were held to identify and prioritize key needs in the materials joining technologies. Also, the EWI Forming Center convened a two-day meeting in October 2014, which included a detailed focus group session to identify key needs in the forming area. Prior to this focus group meeting, a detailed on-line technology survey was conducted to gather a broad set of data from the forming industry.

In addition, a national joining and technology roadmap is also being drafted by EWI under funding from the Advanced Manufacturing Technology Consortium Program managed by the National Institute for Science and Technology (NIST) which is requiring a series of focus group meetings and industry surveys across a broad array of manufacturing industries. This national effort has included participation from many Ohio companies and that information is added to the many sources of data gathered specifically for the Ohio roadmap effort.

The EWI membership includes 238 companies as of January 2015, 135 of which have operations in Ohio. Appendix A provides a list of EWI member companies and non-members with facilities in Ohio that are working or collaborating with EWI. EWI's normal day-to-day business activities includes engaging in numerous contract projects for clients, addressing technical inquiries from member companies seeking assistance on technical issues impacting their business, and visits to member companies to assess needs in materials joining and forming. EWI conducts more than 1200 individual projects annually for member companies covering a wide range of technical needs in materials science and metallurgy related to joining or forming, weld, soldering and brazing processes, weld inspection and engineering assessment, design support, guidance on codes and standards, and repair and extension of service life as just some examples. In addition, member companies submit more than 1000 technical inquiries each year, which are requests for technical guidance on a specific problem the member company is encountering in its operations. These inquiries are included in the annual membership fee and are offered as a key service to member companies to give them a competitive advantage. Furthermore, key EWI senior staff such as Business Development Managers, Technology Leaders and Principal Engineers routinely meet with client companies to discuss and identify key needs, conduct workshops or interviews to prioritize industry needs. These activities in combination provide a vast array of information on industry drivers and needs and provide input to EWI's strategic investment and development plans. This information is also vital to the development of this roadmap.

While some of the information gathered from these sources is national and not exclusively Ohio-based, the needs of Ohio manufacturers are closely matched with those of other states.

This roadmap has included all of these sources of data. Analysis and prioritization of gaps and needs has carefully been distilled from the Ohio-based companies and consideration given to the range of industries in Ohio utilizing materials joining and forming technologies. For example, in Ohio, prominent industries include automotive, energy, rubber and plastics, metals processing, chemical processing, appliance manufacturing, turbine power systems, food processing, aerospace, and defense. The market assessment and determination of gaps and needs has centered on these industries although all responses regardless of industry have been considered.

1.5 Stakeholders

Stakeholders include a broad swath of organizations in the Ohio economic landscape. This includes Ohio manufacturers utilizing materials joining and forming and their employees, public educators, workforce development specialists, researchers and technology developers, community colleges and universities, government leaders and policy makers, logistics and transportation companies responsible for shipping Ohio products to market, material suppliers, and energy producers supplying Ohio manufacturers to name but a few.

1.6 Desired Outcomes

The objective of this roadmap is to discern the most significant needs identified by Ohio manufacturers in materials joining and forming technologies and to discuss possible approaches to meeting those needs so that Ohio companies become more profitable and more competitive with global counterparts. Successfully meeting these goals will lead to growth in:

- Ohio's gross domestic product
- The size of Ohio's manufacturing workforce
- Average Ohio salaries and wages
- Ohio tax receipts

In turn, secondary effects from successful implementation of this roadmap should lead to improvement in public and secondary education systems and the myriad of industries that will see increased prosperity as a consequence of a more robust manufacturing economy in Ohio. This would include dining and hospitality, business and professional services, construction (roads and buildings), retail services and logistics.

2.0 Situation Analysis

The manufacturing environment across the U.S. and Ohio has undergone significant change over the past 10 years. While the health of the manufacturing economy has improved since the Great Recession of 2008-2009, there remain numerous challenges to the long-term stability of manufacturers:

- Increasing global competition for markets and talent
- Costs of materials and energy have increased
- Environmental concerns have increased regulations
- Increased liability claims for manufactured products
- Our skilled workforce is aging and the quantity and depth of technical talent needed to replace them as they retire is lacking

These business challenges must be dealt with while demands for shorter product development cycles, increased product performance and reliability requirements, and a continuing need to reduce cost of operations while increasing the value and utility of products are every day concerns.

To address these challenges, technical innovation is necessary to reinvent and repurpose our manufacturing base. The rate of technology growth and implementation in other countries is increasing at a faster pace and Ohio manufacturers must adapt and innovate more quickly as well. To do this, they will need increased collaboration with technology developers, more access to universities and workforce development specialists, and support from government policy makers to establish an environment where barriers to implementing new technologies and growing the technical talent of our workforce are reduced.

Importance of Manufacturing in the Economy

During the 50 years between the end of WWII and the late 20th century, industrial manufacturing was the cornerstone of the middle class in the U.S. and a critical foundation for the overall health of the U.S. economy. Throughout this period the U.S. generally led the world in industrial output and was recognized as the leading innovator in manufacturing technologies.

Manufacturing jobs typically provided above average incomes and contributed significantly to the overall national gross domestic product (GDP). By the 1980's manufacturing began a gradual decline in terms of the number of jobs and its contribution to GDP. That decline has continued into the 21st century and the financial standing of the middle class has suffered as a consequence.

As we entered the second decade of the 21st century, the number of manufacturing jobs in the U.S. stood at about 11 million, approximately half the number of manufacturing jobs held in 1980 as reported by the U.S. Department of Labor. In addition, the U.S. was ranked third in the world in manufacturing competitiveness compared to first in 1980 (1). Since 1990, the manufacturing trade balance in the U.S. has declined by $500 billion (2).

However, manufacturing still provides a significant contribution to the U.S. economy. In 2013 manufacturers contributed $2.08 trillion to the U.S. economy – a number which taken alone would represent the 8th largest economy in the world according to the U.S. Department of Labor. In 2010, 9 percent of all jobs in the U.S. were in manufacturing. This is down from 11.7 percent in 2007 and 15.5 percent in 1996 (3). Approximately 12 percent of GDP was directly linked to manufacturing along with 60 percent of all exports (4). U.S. workers remain the most productive in the world by almost every measure. Clearly, while the number of people employed in manufacturing has undergone a steady decline, its value to the economy cannot be overstated.

Furthermore, the importance of manufacturing to our standard of living and national defense is clear. Table 1 below highlights the responses from a survey conducted by The Manufacturing Institute in 2010.

Table 1. Survey on the importance of manufacturing

% of respondents who believe the manufacturing industry is very important to:	
U.S. National Security	79
U.S. Economic Prosperity	90
Standard of Living	90
% of respondents that strongly agree that:	
The U.S. needs a more strategic approach to manufacturing	84
The U.S. should further invest in the manufacturing industries	82
Developing a strong manufacturing base should be a national priority	80

A survey of EWI member companies in 2011 revealed that 90 percent of respondents (~350 responses) indicated that having world-class manufacturing technologies will be important or extremely important to their company's competitiveness over the next 5 years. These facts underscore the importance of reinvigorating our manufacturing economy, a goal that will require collaboration between industry, academia and government entities.

Importance of Materials Joining and Forming

Materials joining and forming are essential activities in the manufacture of a vast number of products in our economy. The production of cars, airplanes, computers, gas grills, food and beverage cans, cell phones, bridges, pipelines, electric power turbines, lawn mowers, propane tanks and televisions are but an extremely small sampling of the products that would not be possible without the use of joining and/or forming operations. It is estimated that manufactured goods using welding in some stage of their fabrication represents at least 30% of the national GDP [(5)]. Add to that the impact of brazing, soldering, and adhesive bonding, along with forming operations, and it is clear that materials joining and forming provide a primary foundation of our economy.

The field of materials joining encompasses arc fusion and solid state welding, soldering, brazing, adhesives bonding, and mechanical fasteners. The field has been expanded to join a broad range of materials from metals to ceramics, plastics and composites. Forming operations include stamping, extrusion, forging, drawing and punching operations to name just a few. These are scientifically diverse disciplines requiring understanding and application of physics, chemistry, materials, mechanics, thermodynamics and heat transfer, fluid dynamics and electricity. Few things can be manufactured without one or more forms of materials joining and/or forming technology - they are the foundation for most manufacturing processes.

Materials joining and forming activities are also increasingly technically complex as very rapid thermodynamic, metallurgical, and chemical processes result from their application. As a consequence, sophisticated methods of analysis are required to control microstructure, stress, distortion, deformation and fracture in materials. Furthermore, new materials such as ultra-high strength steel, advanced aluminum alloys, magnesium, metal-matrix composites and polymers are growing in use in automotive, aerospace, power generation and other industries to meet the increasing needs of these markets. It is clear that assisting Ohio manufacturers in developing and deploying the latest materials joining and forming technologies will be critical to their future competitiveness in the face of increasing demand for next-generation advanced materials.

Forming, stamping and related metal processing technologies are critical to Ohio's manufacturing base, none more important than the automotive industry. Automotive metal stamping is a $28B industry in the U.S. and total employment of automotive metal stamping in the US is 81,260 according to IBS World Report in Oct. 2013. Ohio is currently the second largest automotive supplier in the U.S. and holds 18.9% of the automotive stamping market, valued at $4.3B per year. About 26,000 direct employees were estimated to work in automotive stamping facilities, according to the Fabricators and Manufacturers Association (FMA), in 2011.

As an illustration of the prominence of metal forming in Ohio, Figure 1 shows the locations of major automotive stamping facilities in the state. Since the end of the Great Recession of 2008-2009, the automotive stamping business in the US has rapidly recovered and expected to sustain growth for the next five years as shown in Table 2, published by IBIS World Industry Report 2013.

![EWI We Manufacture Innovation]

Figure 1. Ohio map with major automotive stamping facilities (Source: FMA)

Table 2. Key Statistical Data for Automotive Metal Stamping in the U.S.
(Source: IBIS World Industry Report 2013)

Industry Data

	Revenue ($m)	Industry Value Added ($m)	Establish-ments	Enterprises	Employment	Exports ($m)	Imports ($m)	Wages ($m)	Domestic Demand	Light vehicle sales
2004	32,049.8	8,518.1	788	656	114,664	1,895.9	607.1	7,027.8	30,761.0	16,866,500
2005	31,435.5	8,489.3	792	656	111,168	1,844.0	615.2	6,726.7	30,206.7	16,945,000
2006	29,547.1	8,062.6	781	635	110,578	1,722.3	547.0	6,127.0	28,371.8	16,501,800
2007	32,645.2	8,215.1	758	610	100,006	1,740.4	559.1	5,717.4	31,463.9	16,089,300
2008	26,188.2	6,940.5	788	646	94,263	1,362.2	455.1	4,804.1	25,281.1	13,194,741
2009	18,996.3	5,054.7	769	632	66,944	878.9	345.8	3,451.9	18,463.2	10,402,215
2010	26,357.2	6,158.2	736	599	66,985	1,210.1	411.0	3,797.2	25,558.1	11,410,536
2011	28,480.6	7,060.1	773	628	74,353	1,189.4	464.2	4,374.2	27,755.4	12,808,784
2012	28,926.7	7,540.6	790	647	78,740	1,421.3	532.3	4,689.3	28,037.7	13,446,608
2013	29,108.6	7,840.4	808	663	81,260	1,365.8	524.4	4,842.2	28,267.2	14,509,551
2014	30,450.6	8,133.7	825	675	83,109	1,376.5	541.1	4,997.3	29,615.2	15,150,086
2015	31,028.9	8,252.0	842	688	83,737	1,345.5	547.7	5,056.0	30,231.1	15,670,835
2016	31,524.3	8,345.9	841	687	84,124	1,308.3	548.8	5,098.9	30,764.8	15,744,669
2017	32,015.3	8,430.5	852	696	84,335	1,264.0	545.3	5,133.0	31,296.6	15,800,035
2018	32,748.8	8,596.7	862	703	85,472	1,219.1	549.5	5,223.6	32,079.2	16,025,354

The automotive industry is challenged to produce vehicles with high-customer appeal, improved crash performance, reduced fuel consumption and reduced carbon dioxide (CO_2) emissions to meet the market demands and increasingly stringent government regulations. Figure 2 shows new escalating mileage standards and crash requirements established by the U.S. Government.

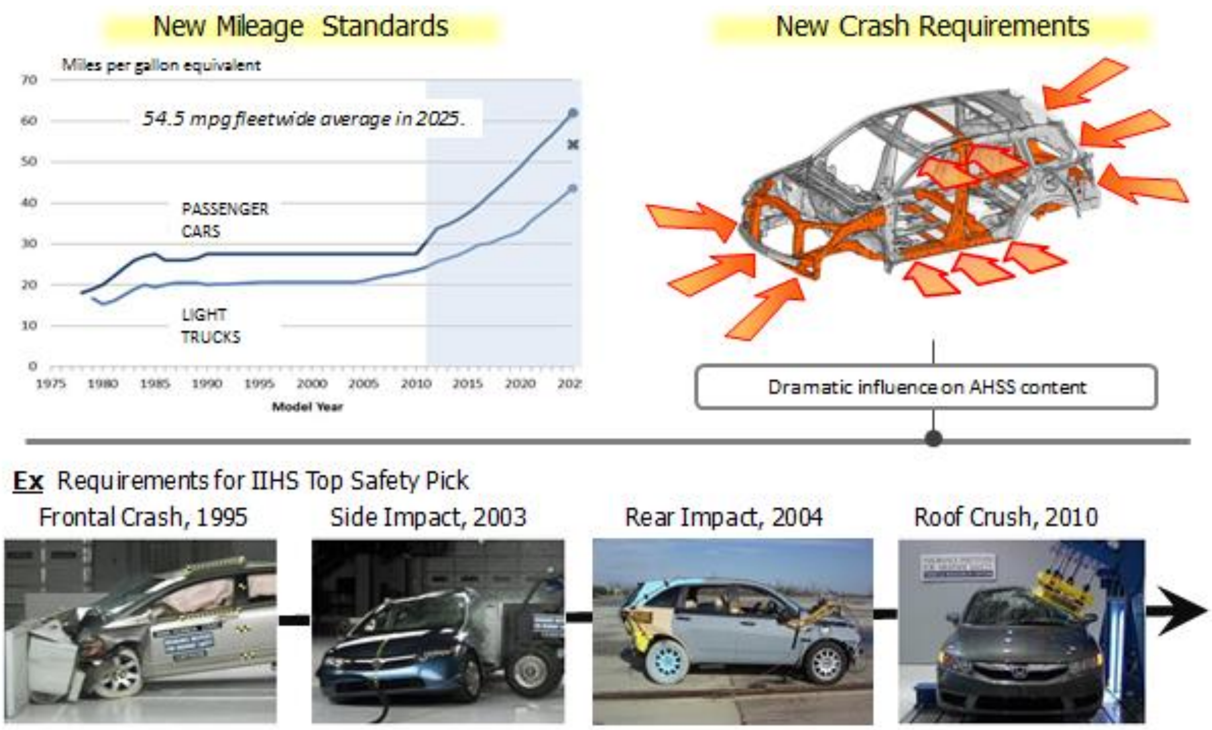

Figure 2. Increased Mileage Standards and Crash Requirements

(Courtesy: Honda R&D in EWI Forming Center Workshop held November 14, 2013)

One of the few enabling technologies to help the automotive industry meet these multiple challenges is light weighting of auto body structures. The automotive industry is increasingly adopting lighter and stronger sheet materials such as ultra-high strength steels (UHSS) and aluminum alloys to achieve these goals. These materials currently present significant technical challenges for forming and stamping operations.

Strength of Manufacturing in Ohio

Manufacturing has been a key component of Ohio's economy for more than a century. While the Great Recession of 2008-2009 resulted in a decline in Ohio manufacturing – in part due to the deep recession (or depression in the eyes of some economists) in the automotive industry – the strength of manufacturing in the state has since rebounded. According to The Ohio Manufacturers Association, approximately 17 percent of Ohio's GDP came from manufacturing in 2014. Manufacturers employed more than 660,000 Ohioans. In 2012, Ohio ranked fifth of all states in manufacturing output [(6)]. Certainly the growth in the oil and gas industries through shale production in Ohio has had a significant positive impact in recent years on the overall health of manufacturing in the state along with a strong rebound in the automotive and primary metals industries.

However, while manufacturing has rebounded and comprises a larger share of the Ohio economy compared to most states, the future robustness and sustainability of manufacturing will require investment in resources and technology innovation to meet the growing challenge from global manufacturers. Threats to Ohio manufacturing include increased material costs, difficulties in attracting skilled workers and replacing an ageing workforce, and increased product performance requirements, to name just a few. This roadmap attempts to outline some steps that can be taken to give Ohio manufacturers the tools needed to meet the growing challenges in materials joining and forming.

3.0 Gaps and Barriers Analysis

The most prominent needs identified by respondents to surveys, focus group meetings, face-to-face meetings and interviews, and other means used by EWI to canvass industry needs are centered around three primary themes:

- Workforce training and development
- Access to current state-of-the art technology
- Technology innovation

Workforce issues are relatively consistent for both materials joining and forming technologies and across different industries whereas the needs for technology innovation are specific to each technology area and, in many cases, to specific industry sectors.

A discussion of each theme follows.

<u>Workforce Training:</u>

In nearly every industry engagement related to gathering input for this roadmap, deficiencies in workforce skill or shortage of a technically qualified workforce was the highest ranked need impacting current or future productivity and competitiveness. Furthermore, this need was of equal concern for all levels of the workforce: professional, skilled trades and general laborers, and for experienced and entry-level workers. At all levels there is growing concern of the lack of sufficient numbers of potential new workers coming into the labor force to replace ageing workers who are retiring.

There are two main concerns related to workforce skill levels:

1. Replacing an ageing workforce as the baby boom generation sees increasing numbers of workers reaching the retirement threshold
2. Expanding or refreshing staff skills as the technical demands of the work environment change more rapidly

Within many companies, a majority of their skilled technical workforce is age 50 or older and an inadequate number of younger staff is in place to eventually replace these workers as they retire. This trend began to appear by 2000 but has accelerated over the past 5 to 10 years. Many companies noted that this trend became more acute in the aftermath of the Great Recession as many companies were forced to downsize staffing levels in the face of economic headwinds. Furthermore, in companies that did not reduce staffing levels, hiring of new staff was diminished due to slowing market trends even though some older workers left the workforce through retirement or for other reasons – often related to health issues. So, even in companies that had no significant staff downsizing some realized a reduction in their experienced staff and were faced with replacing them once the economy improved.

The need for replacements spans all levels from entry-level journeyman workers having only a high school education, to semi-skilled trades' jobs such as welders, electricians, hydraulic equipment maintenance technicians, etc., to professionally trained engineers and scientists having Bachelor to doctorate university degrees.

For the lower-skilled entry level jobs, many employers expressed dissatisfaction with the skills of potential employees coming out of public high schools. In particular, a lack of basic math and science skills needed to perform adequately on the job were not sufficiently developed. Examples sighted include the inability of job candidates to understand mathematical fractions and decimals to a lack of basic science knowledge needed for awareness of the fundamental characteristics of hydraulic systems as one example (i.e., an inability to link the internal pressure in a hydraulic cylinder as the driving force to its capacity to move or translate motion to the end of the hydraulic actuator). Moreover, basic reading and writing skills are often lacking to some degree making it difficult for the job candidate to adequately read and understand technical operating manuals or procedural documents without extended assistance from more experienced staff. These issues are becoming more acute as the complexity of manufacturing equipment in general continues to increase.

At the skilled trades' level, the major concern is an insufficient number of job candidates being available for hire. In general, the skills of candidates graduating from vocational or community colleges with a technical trades certificate or two-year Associates degree were considered to be good. The principal concern is an inadequate supply of such individuals to meet the current demand in the market. As a consequence, many job openings are not filled and plans to expand plant operations are delayed or postponed as the expanded workforce needed to run those operations is not available. In some cases, these issues are being addressed through overtime work from existing staff, or where possible, hiring of contract workers if they are available to fill the gap until full-time staff hires can be made.

At the professional level, manufacturers are concerned about an inadequate supply of college graduates possessing engineering or science degrees to meet current and projected future professional technical staffing needs. Interest with graduating high school seniors in pursuing university degrees in science and engineering has been on the decline for more than 15 years and many companies now feel this is approaching a critical stage in terms of an adequately sized technical workforce in the future. Some of the shortage has been addressed by hiring of foreign graduates but this is becoming insufficient to meet the total staffing needs. This issue is also discussed below from the perspective of universities and colleges.

In some cases, companies expressed a concern about graduates from four-year research universities not having a sufficient understanding of the application side of the technology and were overly theoretical requiring more on-the-job training than desired for operational aspects of the manufacturing environment. This comment was frequently heard from companies heavily involved in manufacturing operations with little to no involvement in product development or research and development activities. However, there is very broad agreement across all aspects of manufacturing that an insufficient number of students are graduating from colleges and universities with a four-year technical degree, and this has become more acute in the past five years. Expectations are that this trend will continue and potentially even worsen over the next decade. Expansion of engineering technology degree programs was cited as a need to help provide technologists that can quickly become productive in the manufacturing environment.

As noted above, concerns were expressed within numerous universities and colleges regarding the difficulty in attracting students to science and engineering programs. The number of graduating high school seniors entering colleges and universities with an intent to major in engineering or science has been declining for more than a decade. This trend appears to be particularly noticed in the engineering majors associated with traditional manufacturing such as industrial, mechanical and materials engineering. Oftentimes, entering freshman are unprepared to tackle university level mathematics and science courses without some remedial coursework. That trend has declined at the Columbus campus of The Ohio State University with the more rigorous entrance requirements now in place for freshmen students attending the main campus. However, this is not the case with freshmen starting their college career at one of the satellite OSU campuses. Other colleges and universities around the state in general continue to report declining numbers of incoming students declaring science and engineering majors and being fully prepared for these courses once on campus. If this trend worsens, it potentially could force some colleges and universities to eliminate some of these technical degree programs traditionally linked to manufacturing for financial reasons.

Since the late 1990's, the trend for entering freshman with an aptitude for math and science has been for them to enroll in computer-related or pre-medical or bio-medical programs more so than comparable students in earlier generations. In more recent years, clean renewable energy fields have become popular – a recognized manufacturing field but not of the traditional manufacturing vein. Computer information and medical careers are often portrayed as being more appealing than many of the manufacturing-based career paths.

This is a societal issue as news and entertainment outlets along with main stream society view the traditional manufacturing industries as dirty, dangerous, and in decline. The clean high technology fields related to the computer and software industries, advanced green energy and the medical field are often viewed as a better place in which to build a technical career. Historically the traditional manufacturing industries have been a battleground between employers, unions, government regulators and environmentalists, all of which have created numerous external influences on the work environment and compensation scales used in those industries. Upcoming students with the interest and aptitude to work in high technology fields more often choose to engage their talents in the newer emerging "clean field" industries starving the much larger traditional manufacturing fields of talent.

All of this, of course, correlates with a decline in students entering more conventional materials science, engineering and science disciplines. The size of the student body in these traditional technical fields of study has declined to a point that some colleges and universities are engaged in a debate on the viability of maintaining these degree programs, at least at the under graduate level. Graduate programs in these traditional technical fields typically have a heavy foreign student population and their viability is more assured due to the international demand of advanced technical degrees from U.S. institutions.

One way to enhance the skills of existing staff is for companies to provide internal training programs. Many companies do provide some internal training or mentoring programs for younger staff although this is not widespread. A recent survey of 1,913 human resource professionals by the Society for Human Resource Management and the Sloan Foundation found that 54 percent of employers have training programs designed to transfer knowledge from older to younger workers. These programs are typically mentoring or job shadowing activities as reported in a recent U.S. News and World Report online article published in January 2015 [7]. Companies that have comprehensive internal training programs claim significant benefits from them both in terms of providing a competent workforce but also in staff retention. Companies that invest in the future abilities of their staff find that their turnover rates are lower as staff see more opportunities for advancement into higher paying positions and access to more appealing job responsibilities.

The Minster Machine Company, a major international supplier of equipment and services for the material forming industry located in Minster, Ohio, has maintained an extensive training and mentorship program. This provides Minster Machine with more flexibility in staffing, greater job satisfaction from their employees, and a level of retention that is critical to this company located in the heart of Ohio's agricultural farm fields with a limited pool of local job candidates compared to competitors located in larger urban areas. The training that Minster provides to its staff is unique to their equipment and operations and thus provides a direct and near immediate return. This training is available to all levels from entry level machine operators to degreed engineers overseeing manufacturing lines. Similar initiatives across a greater number of companies could help address the growing concern of workforce skills.

Access to Current Technology:

Some companies, particularly small and medium manufacturers expressed issues related to limited access to current state-of-the-art technology. Some companies are not aware of recent technology advancements that could have a positive impact on their competitive position. In part, this may be due to limited staff to monitor technology journals, attend technical conferences or otherwise engage in activities to assess changes in the technical landscape. Many manufacturers lack the in-house expertise or cannot support the dedicated staff needed to identify, screen, optimize, and implement new technologies to improve their products and production processes.

The most common reasons for preventing access to current technology are discussed below.

Inability to fund implementation of new technology because of high cost. A common example is when new capital equipment is required to use a new technology and the financial balance sheet can't support the purchase or access to financial lines of credit is limited. As an example, for a small manufacturer using older conventional arc welding power supplies, upgrading to the newest series of computerized power supplies or adaptive real-time arc monitoring and control systems to take advantage of improved productivity and power efficiency may be cost-restrictive and often involve whole-sale change-out of other ancillary equipment such as welding torches, wire feed units, etc.

Lack of awareness of recent technology developments. Many smaller companies can't afford to have staff spend much time monitoring technical journals or attending technical conferences and workshops to maintain awareness of the latest advancements. In some cases, even if awareness is there, the technology may not be sufficiently developed for their specific manufacturing application. Larger companies may have a technology development staff to fill the gap in adapting the latest developments to their operations or may have the financial means to contract outside experts to bridge this technology gap for them. Most small and medium sized companies do little R&D and cannot easily take advantage of university based R&D. This is because universities do not typically mature technologies to the point where they can easily be implemented, and unlike many European countries, the U.S. lacks institutions to help companies develop and adopt new manufacturing technologies. A good example of an European approach to deploying the latest technology to industry is the government-supported Fraunhofer Institute in Germany, which is Europe's largest applications-oriented research organization considered by many as the most effective technology transfer model in use today.

Slow adoption of new technology in industry codes and standards. A small but notable number of companies identified this issue as one that increasingly threatens their ability to use the latest technology advancements. Many manufacturers must work to existing industry codes and standards published by technical or engineering organizations such as the American Society of Mechanical Engineers or the American Welding Society, ASTM International (formerly known as the American Society for Testing and Materials), as just three examples. Often use of these codes and standards can be a contractual requirement, particularly for equipment or infrastructure that has regulatory oversight such as for pipelines, petrochemical and refinery equipment, transportation infrastructure, etc. Maintenance and updating of these codes and standards is typically done on a volunteer basis by technical experts providing their time on an as-available basis. Their employer may or may not support these efforts by covering travel costs to attend meetings or cover time spent engaged in the standards development process. Furthermore, in recent years, the number of expert volunteers available to participate in codes and standards writing activities has diminished, in part due to the gradual retirement of the aging technical workforce.

The codifying process has typically been a slow process due to the volunteer nature of the effort along with procedural rules of standardizing bodies that adds bureaucracy that can lead to standards updates occurring once every 5 to 7 years in some cases. This gestation period for updating codes and standards is much slower than the pace of technology development in some oversea standards. There are Asian and European codes and standards that are revised more frequently, potentially putting North American manufacturers contractually restricted to U.S. based codes and standards at a disadvantage in some cases. These issues can be particularly important where technology development is occurring in a rapid manner such as in additive manufacturing (also known as 3-D printing) and in the automotive industry where use of alternative materials such as aluminum, ultra-high strength steel and magnesium alloys are increasingly used. Larger companies can sometimes develop their own internal technical specifications to address more recent advancements and flow down those requirements to suppliers and vendors. However, smaller companies often will not have the clout to force adoption of their own internal codes and specifications up or down the manufacturing food chain and moreover, may not have the luxury of a larger technical staff to continuously monitor technology advancements and revise their internal standards on a timely basis.

Inability to utilize the current state-of-the art technologies. Figure 3 below illustrates the technology development gap that can separate manufacturing companies from recent advancements in technology, often developed in universities and government labs, or in private research laboratories engaged in fundamental or basic research. Many attractive advancements are made at this basic level, defined as Technology Readiness Level 1 to 3 as shown in the figure below. The maturity of manufacturing technologies in the figure is shown using the NASA "Technology Readiness Level (TRL)" scale.

Ohio has a world class university system with significant research capabilities to work on early stage (low TRL) technologies. Universities and laboratories engaged in developing such early stage "low TRL" technology rarely have the means or experience to advance the technology to an end-user stage. However, manufacturers in the private sector will adopt low-risk (high TRL) technologies which have the potential to deliver the desired return on investment. Rarely do they invest in technology at the TRL 1-3 stage as the technology has not been sufficiently developed and matured to the stage where it can be readily used on the manufacturing floor.

Industry typically can utilize new technology once it has matured to a readiness level of 7 or 8. This is particularly true of small to medium sized companies that may not have technical staff on hand to assist in developing and implementing new advancements. Industry needs access to organizations that can take fundamental advancements and further develop and mature them to a stage where they can be commercialized and effectively deployed to users in industry. The technology gap between feasibility and implementation exists because there are so few institutions that are focused on maturing (mid-TRL) technologies to mitigate the technical risk for industrial early adopters. Bridging this development gap will greatly enhance the ability of manufactures to more quickly adopt technology that has already gone through basic or fundamental development.

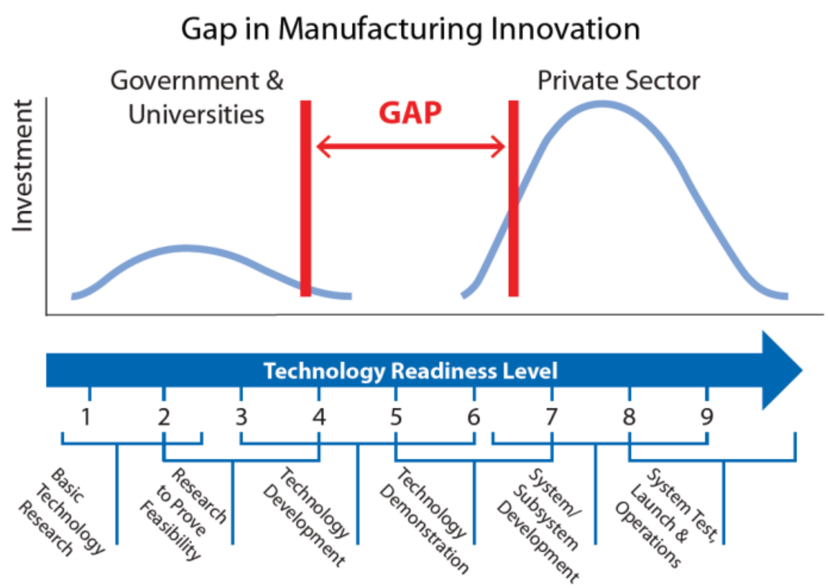

Figure 3. The realm of technology development spans from basic applied technologies at low readiness levels to factory floor deployment at readiness levels 8 or 9.
Source: NIST AMNPO presentation, Oct. 2012

Technology Innovation:

Advancement of technology is a critical element to enhancing the competitiveness of Ohio manufacturers. In 2010, EWI surveyed more than 300 companies engaged in materials joining activities to identify what should be the highest priorities in addressing the needs in materials joining technologies during the decade 2010 to 2020. Advancing technical innovation was the most common response in 2010 with slightly more than 50 percent of respondents giving this their highest priority, followed by improving workforce competitiveness, improving collaboration, and more effective government policies and funding priorities to enhance manufacturing competitiveness. Figure 4 illustrates the relative importance of these four factors. Improved collaboration goals included greater interaction between technology developers – universities, private, non-profit research centers, industry consortiums and government entities – in identifying needs and delivering or deploying new technologies to end users.

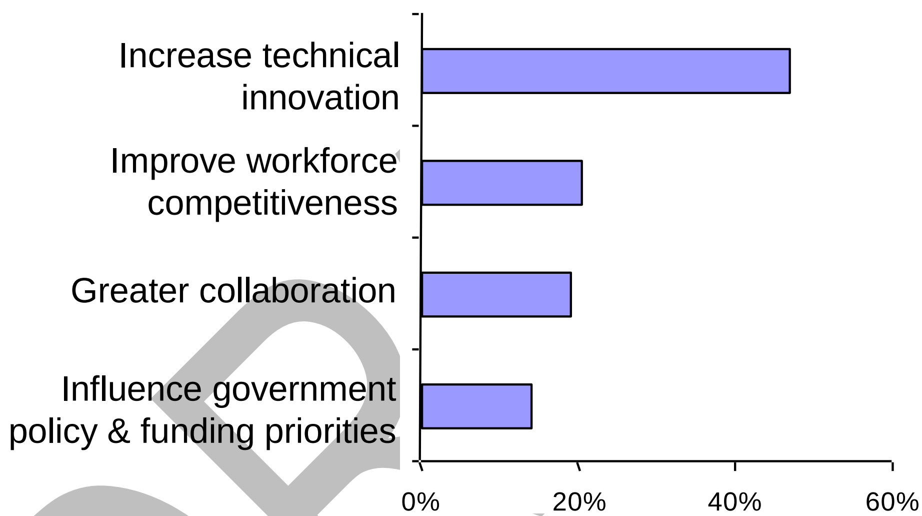

Figure 4. Response from a 2010 survey on the highest priorities to address needs in materials joining technologies

The benefits of deploying the latest innovations are equally impactful for small and large companies but barriers exist across the spectrum on the manufacturing landscape regardless of company size. Even the largest manufacturers can't afford to have world-class technical expertise in all the emerging manufacturing technology areas. Implementing new technologies is even more of a struggle for small and medium size manufacturers which don't have the luxury of large engineering and research staffs to explore and implement new technology areas.

Regardless of company size, there is a consistent number of themes that emerged from our industry canvassing activities as key innovation needs as outlined in the bullet list below. These themes frequently occur regardless of company size and scope. However, within each theme the specific needs and/or approaches to address the gap can diverge depending on the company and the industry segment.

Technology innovation needs tend to be company and/or industry specific due in part to differences in joining or forming processes employed, the material systems commonly used, complexity of their products (i.e. the range of processes employed in manufacturing, the level of sophistication required to support design and quality control, etc.) and the end use considerations of their products, which dictate the level of in-process monitoring and control, quality requirements, product performance expectations and regulations controlling the product (i.e. aircraft engines versus bicycles as one example).

The most common innovation themes uncovered by EWI include:

- **Technology Diffusion –** keeping up with new materials and process advancements; transitioning to newer technologies
- **Workforce Competency** – keeping skills current in a rapidly evolving technology environment
- **Productivity & Cost Improvements –** Managing costs in the face of global competition; reduced costs per part; automating processes for higher throughput
- **Improving Quality** – Quality and reliability demands continue to increase; improved raw material and supplier-chain quality; reduced liability claims
- **Process Development –** reduced product development cycles; get new products to market faster to beat the competition
- **Adoption of New Materials** – implementing newer advanced materials to enhance product performance, quality and in some cases improved manufacturability
- **Energy & Sustainability** – reduced energy costs, ease of recycling

One goal of this roadmap is to discuss innovation needs of significance to Ohio's manufacturing economy. The following sections outline those needs that have been identified by Ohio companies for materials joining and forming operations, with prioritization given to those needs that cut across more than one industry or that are relevant to an industry with particular presence and importance in the Ohio manufacturing base (such as the automotive industry as one example). Consequently, the needs identified here are considered more impactful and, if addressed, could produce a measurable enhancement in the competitive standing of many Ohio manufacturers. The following discussion first considers materials joining and then forming technologies.

Materials Joining Technology Innovation needs

The major innovation needs identified and prioritized by Ohio manufacturers largely revolved around two key areas: increased materials joining productivity and development or implementation of joining methods for newer advanced materials. Other areas of need include greater access to advanced engineering tools to reduce time and costs related to design efforts and improved real-time process monitoring and control methods.

Distilling these needs into a concise list results in the following (order is not prioritized):

- Joining process improvements for advanced metals (high strength steel, high strength aluminum, magnesium and mixed metal systems such as aluminum to steel)

- Improved joining methods for advanced polymers and composites and polymer-matrix-composites
- Access to modeling "plug-ins" for joining process design and performance prediction
- Advanced real-time process monitoring and control systems to improve productivity and quality, reduce re-work and repair operations

Joining of Advanced Metals: This need cuts across the automotive, metals processing, advanced energy and oil, gas and petrochemical sectors. The primary drivers for utilizing the newest advanced metals includes weight reduction (critical to automotive requirements for meeting the new CAFE standards) and higher productivity as a result of higher operating loads or smaller product "footprint" and better sustainability. In many cases, the development of these materials has surpassed the technology to effectively join them at all or to ensure adequate quality and reliability in material joints.

In some cases, such as the welding of high strength aluminum alloys, the technology is not sufficiently developed to allow manufacturers to readily use the newest joining methods and thus, less efficient joining approaches must be considered. A good example of this is the Ford Motor Company's recent adoption of 7000 series aluminum for much of the Ford F-150 pickup truck. While this alloy can be welded using arc processes, the methods are not as advanced or reliable as desired considering that this alloy requires high levels of process control to prevent cracking during or shortly after welding. The level of process monitoring and control is beyond what Ford is comfortable implementing on a large-scale basis on its manufacturing and assembly lines. As a result, the current joining approach in use includes riveting and adhesives, which can produce reliable joints but is not as economically efficient as a welding process would be. To meet this specific need, development of alternative solid-state joining methods are underway although it will likely be a few years before these processes can be widely implemented in truck body and frame manufacturing.

A similar area of need is in the joining of mixed-metals such as aluminum-to-steel, another need critical to next generation car and truck manufacturing as well as to the aircraft and energy sectors. Due to metallurgical complexities "conventional" arc welding processes are not well suited to joining some of these material systems. Certainly adhesives, brazes and mechanical fasteners can be used in many applications, although they may not be economically attractive or easily scalable for large manufacturing operations. In addition, joint strength and durability may be inferior to a welded joint. Advanced solid state joining methods are needed to allow for joints to be made without melting the metals while still providing the necessary structural performance of products. Several friction welding processes such as friction stir welding, linear friction welding and friction spot welding are being developed to address this need. Also potential resistance welding processes using a braze inter-layer for bonding are under development to improve the scalability and performance of brazed joints in larger structures. However, large-scale implementation of these methods is not available today.

There is active research in materials joining processes in the U.S., Europe and Asia related to these advanced materials and mixed-metal systems but in some cases viable joining methods easily usable on the manufacturing floor is not likely to be available for several more years. It is critical that the U.S. increase its R&D efforts in these areas to avoid falling behind. Moreover, the speed at which these developments are undertaken should increase to enable Ohio based manufacturers to access these advancements before foreign competitors.

Improved Joining Methods for Composites and Polymers: This need exists in the aerospace, defense and automotive sectors in particular. Newer advanced composites, polymers, metal-matrix composites and polymer-matrix-composites have been developed in recent years that offer:

- Use of these materials in higher temperature environments
- Improved wear resistance
- Improved impact resistance
- Higher loading conditions

These advanced materials can be used in place of metals in some situations to improve weight performance along with enhanced structural performance. An example is the development of advanced composites for armor, which can replace metals that have traditionally been used in armor applications. Methods for joining these materials primarily include welding and brazing along with adhesives. As use of these newer versions increase the operating boundaries for temperature, wear resistance, impact resistance, and ultimate strength, the reliability and durability of the joining processes must advance as well. Thus, development of braze compounds that have higher temperature limits is one example of an innovation need. In addition, improved ductility of brazed joints is needed for some applications to allow for higher loading and wear resistance. The same advancements in adhesives would allow for more direct use of these newer composites and polymers.

Along with advancement of the joining methods, improved inspection and quality control methods are desired. Joints in these materials can be difficult to inspect due to their geometry (thin bond or joint lines) and the inherent difficulty in some cases of the inspection technique to penetrate the composite or polymer to examine the joint interface. Proof testing of components following manufacture has been a common method to demonstrate product quality and integrity prior to entering service but these methods may not be as reliable for circumstances where the operating environment becomes more demanding. Examples of this include advanced jet engines that now operate at higher temperatures and pressures than previous generations of air turbines. Relying on a proof test may not be sufficient to ensure high reliability over many years of service. Furthermore, beyond initial manufacturing inspection and quality, there is a need to improve in-service inspectability of these joints after entering service. The same limitations on inspectability occur in service but improved ability to detect delamination, dis-bonding or fatigue cracking along the joint interface for in-service components is needed.

Access to modeling "plug-ins": This need cuts across most industry sectors where advanced software engineering tools can benefit the materials selection, design and joining processes. Finite element modeling and simulation of joining processes and materials response to joining operations is an established technology that has been commonly used in many failure-critical components since the 1990's. Some high-consequence examples include hydrocracker units in petrochemical plants, boiling water reactors in nuclear power plants, and assessing repair options for third-party damage to high pressure natural gas pipelines. Other common applications of advanced modeling and simulation include vehicle crash simulation to evaluate the performance of welds in vehicle crash tests, predicting weld distortion and residual stress in ship panels to improve fit-up during fabrication and predicting the microstructure in pipeline girth welds to optimize the welding process to reduce likelihood of corrosion damage in service.

While companies in high-consequence industries often will have staff in-house to carryout modeling simulation activities to support their material selection, joining process development and optimization and overall design procedures, many other companies could benefit with access to these specialized computer modeling simulation tools. The drawback to implementing these tools on a wider scale has been the need to have staff with specialist training in order to use these sophisticated software applications along with the need to maintain expensive software licenses common with many of these tools.

Considering the advancements in computing power and the price reductions in high end computers over the past decade and the advent of cloud computing, there is a desire with many companies to pursue an approach to develop and have access to “smart apps” that would allow engineers to run specialized simulations without requiring specialist knowledge. For example, a welding engineer might run a simulation to assess the effect of various welding parameters on the resulting weld or heat affected zone microstructure. This could allow identification of the optimized welding conditions to enhance performance of the end product in service, thus improving product quality and reliability. Currently, this welding engineer would need to possess some expertise in finite element mesh generation, knowledge of the thermo-mechanical models used to predict the thermal response of the materials being welded and the solidification mechanics in the weld zone, along with access to the specialized software tools. With broad band high speed internet available to wide geographic regions, the desire is for manufacturers to have internet-based user interfaces that an engineer could use to input information into a sophisticated FEA application that would run in the background on a server located in a company providing specialized computing and simulation services having the specialist staff to build the backend “engines” for carrying out the analysis.

In essence, this would behave similarly to the large number of smart phone apps that are commonly used by the public today. The manufacturing company would not need to hire and retain a simulation specialist on staff nor maintain expensive software licenses that would only be used occasionally. An engineer at the manufacturing company, very knowledgeable in welding processes in this example but not a modeling and simulation expert, would be able to upload to the online application the necessary details regarding the materials to be welded, the weld joint design configuration, and the range of welding parameters to be considered for the fabrication process. This information would be incorporated into the simulation routines to be run “in the cloud” and would automatically generate the FEA mesh, run the simulation and provide the output through the app to the welding engineer at the manufacturing company. This might be setup as a “pay to use” simulation application – based on CPU time plus administrative costs – and reduce the cost barriers for smaller companies to gain access to these high-end tools. There would be limitations to the use of some simulations depending on the complexities involved, but it may provide a means for companies to refine design and process selection sufficiently to speed up the product development cycle while enhancing quality and performance of end products.

There are many software toolsets that might be applicable to this scenario from weld design, metallurgical predictions, assessment of joining process thermal characteristics, residual stress and distortion prediction, weld stress analysis, weld and structural performance characteristics, and service life prediction to assess the likelihood of premature fatigue failure for example.

Real-time process monitoring and control: Advances in computing power, software tools, and sensors over the past decade have opened up new opportunities for monitoring many manufacturing processes in real-time and provide a means to adjust processes on-the-fly to correct deficiencies and minimize waste and re-work. Certainly in the materials joining arena there have been substantial developments along these lines with the growing use of camera and vision systems, highly specialized sensors and instrumentation systems to monitor and record numerous parameters related to the joining process, and the use of automated or robotic joining systems and computerized power supplies that can provide fine control over almost every mechanical and electrical aspect of the joining process as compared to manual welding approaches. These tools can be invaluable to pursuing a zero defect policy and drive process quality for improved lifetime performance goals. Achieving a six-sigma quality standard can be greatly enhanced with such tools.

While there is a considerable volume of off-the-shelf products currently available to develop advanced real-time process monitoring systems, knowledge of system integration and awareness of appropriate process control windows to achieve the desired goals can be a limitation with many companies. Also, advances under development in sensor design and monitoring and control systems will potentially allow greater precision and tighter process operating windows than currently available. To realize benefits, manufacturers will need greater access to companies specializing in development and integration of monitoring and control systems to tailor the operating windows that meet the goals of improved product quality and increased productivity rates. In some cases, several different specialists may be needed to fully setup and optimize a real-time process monitoring and control system. This could include instrumentation and software specialists, joining process specialists to determine the optimum process parameters, and inspection and quality specialists to measure output quality and identify process or manufacturing operations that are limiting product quality.

Forming Technology Innovation needs

The following two topic areas were identified as key needs within the Ohio stamping industry:

- Workforce development
- Technology limitations

Workforce development. Developing a skilled and experienced workforce is most the important factor for Ohio manufacturing companies to succeed in technology innovation, implementation of new ideas, and effective verification of their business value. Workforce development is not just providing employees with the right technical skills to perform “a job.” It also requires helping individuals acquire the soft skills – teamwork, problem-solving, coaching – and day-to-day business skills to succeed in more team-oriented, automated workplaces. Interestingly, there are significant gaps between high-level executives on the importance of workforce development and its implementation because of low support in terms of resources and investment. According to the Manufacturing Insights Report published by SME in 2014, only 39 percent of manufacturers admit to operating at or close to world-class manufacturing status, underscoring the potential for most organizations to improve the workforce training.

Table 3 summarizes the results of an electronic survey identifying the top areas of business operations that are most affected by the skills gap. Table 4 shows survey results on workforce skills areas that are most difficult to find within the labor force. A total of 41 US stamping companies including 10 Ohio companies took part in this survey.

Table 3. EWI's survey results on business operations impact due to the skills gap

Answer Choices	Responses	
Inability to grow the business	64.71%	22
Inability to compete with current business product line	64.71%	22
Inability to keep good workers from moving to competitors	47.06%	16
Inability to maintain good quality on current product line	61.76%	21
Inability to comply with external quality standard regulations	23.53%	8
Total Respondents: 34		

Table 4. EWI's survey result on workforce skill areas that are most difficult to find within the labor force

Answer Choices	Responses	
Material removal	11.76%	4
Fabrication	38.24%	13
Hot/Cold Forming	55.88%	19
Heat Treatment	5.88%	2
Electrical/Electronics	29.41%	10
Joining	23.53%	8
Welding	38.24%	13
Simulation skills	50.00%	17
Total Respondents: 34		

During interviews with several Ohio automotive stamping companies, the following comments on workforce development were provided by industry representatives.

- There is no apprenticeship program on forming/stamping technologies in the U.S., while a good welding talent pool exists at The Ohio State University, EWI, community colleges and within Honda's supply chain
- Most tier 1 automotive stamping companies in Ohio have an in-house welding program lead by a certified welding engineer. However, there is not much in-house training on forming because of the lack of certified forming engineers.

The primary issues hindering the implementation of forming training programs in Ohio's stamping industry are:

I. Past experience of many U.S. manufacturers sending their forming operations and related jobs to China and other cheap-labor countries and,
II. Most day-to-day production issues have been managed by tool and die shop workers without consideration for long-term development of production technology.

However, this old paradigm must be changed. Manufacturing companies have begun to on-shore more aspects of their manufacturing operations to the U.S. for various reasons. One reason is increasing competition with other foreign manufacturers in terms of labor costs as well as the ability to manage technical challenges. To thrive with global competition, Ohio manufacturers need to move much faster than in the past to adopt new product designs and implement efficient production processes to more rapidly get products to market. Therefore, the Ohio forming industry will need an expanded talent pool in the metal forming areas and identify a path to fully develop this workforce.

The findings below were found as top ranked issues on workforce development of the Ohio metal forming industry:

- Need to establish a talent pool and workforce development program in forming and joining areas.
- Need for workforce development programs and training tools/simulators for shop-floor level workers, as well as professional workers with university engineering degrees.
- Need to improve the image and reputation of manufacturing within the K-12 public school systems, college students, parents and boards of education. Establish focused curriculums emphasizing technical skills needed in manufacturing - "STEMM (Manufacturing)"

1.1 Technology limitations

The increasing use of new lightweight materials presents significant technical and financial challenges for Ohio stamping companies. New forming technologies are often required to process these advanced materials due to their properties being vastly different from more conventional materials. Existing materials formability test standards are inadequate for these new and less familiar materials such as Ultra-high-strength steel (UHSS) and high-strength aluminum alloys (HSAA). This lack of formability data has significant business impact with increased scrap rates, higher production downtime, and increased production engineering costs to adjust forming processes for these newer incoming materials.

Recent survey results from EWI member companies illustrates some of the major challenges in developing new products as summarized in Table 5.

Table 5. Major challenges in developing new products

Answer Choices	Responses	
New emerging or less experienced materials	**54.05%**	20
Increased requirements of the product quality	**48.65%**	18
Insufficient subject-matter expertise	**48.65%**	18
Insufficient capability of suppliers	**37.84%**	14
Insufficient information of the state-of-the-art sheet forming technologies	**43.24%**	16
Cost associated with low-volume prototyping	**43.24%**	16
Total Respondents: 37		

Limitations with existing material and friction models hinder the ability to reliably predict manufacturing and product performance for many forming and metal processing operations. Many of these operations are quite complex requiring multiple processes that must be carefully combined in a controlled manner and sequence to produce the desired end result.

These critical technical complexities also greatly affect business operations in many different ways as summarized in Table 6 on the following page.

Reliable formability test data and prediction capability will help Ohio manufacturers to (a) form advanced lightweight materials in more cost effective ways by reducing material scrap rates; (b) reduce production downtime associated with part failures which occur more frequently with many of these advanced materials; and, (c) shorten the product development cycle, reducing the costs to develop and deploy products to the marketplace.

Table 6. Most critical technical issues impacting business operations

Answer Choices	Responses	
Inconsistent material quality	35.14%	13
Insufficient information of the material formability	54.05%	20
Insufficient expertise in forming process design	48.65%	18
Insufficient expertise in tool and die design	32.43%	12
Die wear and associated preventive & corrective maintenances	24.32%	9
Lack or minimum use of prediction capability	32.43%	12
Lack of real-time sensing data (i.e. temperatures, tonnage and scraps)	18.92%	7
Downtime of the production due to the aged equipment or many trouble shooting issues	32.43%	12
Total Respondents: 37		

The following were identified as the top ranked issues related to forming technology within the Ohio metal stamping industry:

- Better methods for compensating for variations in material properties, press set-up and lubricants by adopting advanced technology
- Improved test methods to determine material formability and quantifying friction in forming operations
- Increased knowledge of the forming characteristics of AHSS and Al alloys
- Innovative forming technologies to improve forming quality and efficiency for existing metal forming equipment
- Need for industry collaboration to share design standards & virtual analysis tools/data and establish common best practice methods

4.0 Action Plan

The gaps and needs outlined in this roadmap have little tangible value without a plan to address these needs. Several initiatives should be considered as outlined below to assist in minimizing the barriers that currently impede the competitive position of many manufacturers in Ohio. Successfully addressing the gaps and needs will require a coordinated effort between government, industry, and academia at all levels. In addition, input from manufacturing extension partnerships (MEP's), private research organizations and industry or professional associations will be useful. An outline of possible actions that can address the most critical needs is discussed below.

Workforce Development. Effectively addressing workforce development needs will require very broad collaboration across all stakeholders of this roadmap. The need extends down to the middle school levels in our public education system all the way through graduate university degree programs. The public educational system, vocational/technical and community colleges and four-year universities across the state all have a role to play here along with government support.

To increase the available future technical workforce needed by manufacturers, more middle and high school students must become interested and proficient in math and science subjects. The public education system should consider expanding the number of classes in the STEM area and employ more creative methods to entice young students to try these classes. Engaging students and exposing them to technology at an early age should increase the number of students interested in taking STEM classes by the time they reach middle school or early high school grades. Public school teachers should encourage students that show interest and aptitude for technology subjects by ensuring they are engaged in the classroom and potentially linking students to local manufacturers for special events or tutoring. Teachers should also reach out to the parents of such students to help them further promote the interests of the student and give them opportunities to increase their learning potential. If possible, public school systems should consider establishing "technology camps" during the summer months that could provide specialized teaching and exposure to STEM subjects for 1 or 2 weeks between school years and to potentially have visits to local manufacturing and technology firms to allow students to have some exposure to the development and application of technology. These programs could be customized and expanded beyond what might be possible during the normal school year as a smaller number of students would likely participate. Funding mechanisms to support these "technology summer camps" would need to be identified.

Private industry can play a meaningful role here by having technical staff participate in science day events at schools, possibly take part in occasional "show and tell" activities in the classroom to demonstrate the exciting world of technology to these young impressionable students. In addition, companies can engage with their local school systems to arrange occasional tours of their facilities during the school day to give middle and high school students up close first-hand exposure to some of the more exciting elements of their operations.

Community college and four year universities should work to ensure their educational approaches are aligned with the needs of manufacturers. For example, one criticism of manufacturers of some four year universities is that graduates lack practical technical knowledge that allows recent graduates to quickly become productive on the job. They may be too theoretical and not have had adequate exposure to more practical applications of technology. This forces employers to engage in lengthy internal training programs once a new graduate is employed. Ensuring that engineering and science graduates have some exposure to basic industrial technology coursework could assist this transition from classroom to the manufacturing floor. One means to accomplish this might be to expand the availability of internships for under graduate students to ensure they have a few months of practical work experience prior to earning their degree. Some universities have rigorous internship programs but many do not. In addition, this could be a useful source of additional funds for students paying their way through university. Expansion of programs providing engineering technology degrees focused on technology application should be considered to provide more bachelor degreed students tailored to step onto the manufacturing floor and be productive right away compared to students graduating from the more theoretical engineering programs found in research universities. In short, closer collaboration between post high school educators and manufacturers is needed to ensure the educational needs of employers are more effectively addressed by colleges and universities.

Access to Existing Technology. There have been many technology advancements over the past few years that remain at the early exploratory stage without the maturation and development to allow end-users in industry to readily employ them. This "gap" is a fundamental aspect of the means by which technology advancements are often funded in the U.S. Most basic R&D is carried out at universities, government labs and private laboratories. Much of these efforts take the technology to a Technology Readiness Level (TRL) of 3 or 4 and then further development ceases. Most universities, government and private labs do not engage in development of new advancements beyond the basic applied levels – this is the realm of university research. Thus, many new technical capabilities do not sufficiently develop to the point of practical application in manufacturing as there are few institutions focused on this "mid-stream" technology development. This may be due to the fact that significant effort may be required in many cases to mature the technology sufficiently to an end-use state and those tasked with these efforts can have difficulty in realizing a financial profit if they are not the end-user. This can be compounded by the cost associated with securing patents and finding appropriate commercialization partners.

Efforts should be made to link private technology developers and laboratories to universities and government labs to establish a "hand-off" of early stage technology to organizations that can continue development and identify channels for deploying the technology to industry. Ohio developed several Edison Technology Centers in the 1980's in part to fill this void in maturation of technology for the benefit of industry. At the time, the Edison program propelled Ohio to a leadership position among states in developing and deploying innovative technology to Ohio manufacturers. EWI is one of those centers. While this model had some successes, most of these Edison centers never became self-sufficient, largely because they did not develop adequate ties to industry and thus were not able to create a sustainable revenue stream funded by private commercial companies. One critical element needed in such centers to develop self-sufficiency is to have a technical staff that has strong connections to industry and understands the technical needs of key commercial clients. These kinds of technology centers must be industry-focused to be successful long term.

Ohio should examine the successes and failures of the Edison Centers and consider re-inventing this model. Other states are following a similar approach by either already developing centers of innovation or considering plans. Examples include New York with their Buffalo Billion program, which includes a technology center recently established with the help of EWI to focus on advanced automation and materials technologies to aid industry in western New York. Rhode Island, Colorado and Mississippi are following a similar path to establishing technology manufacturing centers of excellence. Ohio should re-purpose it's now defunct Edison Program to re-establish centers of manufacturing innovation around the state focused on advancing and deploying early stage technologies that have relevance to Ohio's manufacturing base. As EWI has proven, with the proper business model and leadership, these centers can become self-sufficient and not rely on state or federal government funding to survive and prosper.

Another gap identified as limiting access to the latest technology by Ohio manufacturers is the slow pace at which critical industry codes and standards are updated. Development of industry codes and standards is generally done on a volunteer basis by staff at universities, laboratories and industrial companies engaged in developing and using the technology addressed by the standard. This process has been inherently slow but as the pace of technology development and the need for new advancements to remain competitive accelerates, the effect of this slow pace is now identified as a key gap by some companies. Furthermore, over the past 10 to 15 years, the number of staff available to support development of codes and standards has declined along with the general decline in the senior technical workforce throughout the economy. Thus, many codes and standards do not adequately reflect current technology, which can limit the competiveness of companies contractually obligated to manufacture products to a given outdated standard. These standards are often published by non-profit engineering or industry associations such as the American Society of Mechanical Engineers and the American Welding Society.

As an example, there have been useful advancements in fracture mechanics technology to more accurately predict the conditions that will likely cause failure of critical infrastructure such as bridges, pipelines and oil storage tanks. Advanced software tools have been created to utilize some of this new and improved technology but in some cases, use of these advancements can be limited because some key industry codes and standards documenting the approved procedures for designing and building such structures have not been updated in a timely manner to document and give guidance for its use. Implementation of these advancements in the codes and standards would not only enhance public safety in this instance, but would improve some aspects of designing, building and maintaining these structures and reduce cost and effort.

One suggestion to entice more organizations to give priority to supporting codes and standards development was to provide tax breaks to organizations for costs associated with activities to support updating and maintenance of these documents. This could include staff time and travel expenses involved in attending committee meetings. In some respects, updating these codes and standards with the latest technology and best practices is related to research and development efforts since the outcome of R&D is often transformed into practice to be used by industry at large through codes and standards. Industry clearly has a stake in using the latest information in their codes and standards and more companies must encourage their staff to engage in this important activity. Standardizing bodies should also seek other methods for gaining to input from industry staff and reducing time and costs in maintaining these important documents. Broader use of web-based tools (i.e. webinars and similar collaboration technology) to reduce the travel demands of standards committee members to attend meetings would be beneficial to having greater participation. Funding within these standardizing organizations for implementing these communication tools is needed.

Access to Technology Innovation.

The long-term competitive position of every manufacturer large and small is dependent to some extent on technology innovation. Many of the key drivers that identify specific technology innovation needs have been discussed in this roadmap. A key barrier to pushing the latest technology into industry is the “development gap” – sometimes referred to as the technology development valley of death. Many advancements are made at university, government and private research laboratories where basic research is carried out. This research is performed to prove out the basic technology but rarely does it fully develop and mature the technology to a stage where a manufacturer can readily implement it in everyday operations. Universities and government labs do not have the objective or the means to fully develop and commercialize technology. Some research centers and labs, such as EWI, have been created to help fill this void but more extensive efforts and resources will be needed to carry out the technology development and commercialization required to substantially increase the pace at which new innovations are introduced on the manufacturing floor.

The federal government has realized this gap in recent years and has created five manufacturing innovation centers around the country over the past two years under the National Network for Manufacturing Innovation (NNMI) program. One of these centers focused on additive manufacturing or 3-D printing in Youngstown, Ohio. The NNMI centers are tasked with developing and advancing a specific technology "domain" to enhance U.S. manufacturing competitiveness in key industry sectors. Current centers include:

- America Makes – additive manufacturing center located in Youngstown, OH
- Lightweight Innovations for Tomorrow (LIFT) – Detroit, MI
- Digital Manufacturing and Design Innovation Institute – Chicago, IL
- Institute for Advanced Composites Manufacturing Innovation – Knoxville, TN
- Next Generation Power Electronics Manufacturing Innovation Institute – Raleigh, NC

These centers are funded through a government-private industry shared cost model where private industry matches federal funds to establish and operate each institute. The institutes must become self-sufficient within a period of years by establishing collaborative relationships with private industry through developing and deploying pre-competitive technology.

For Ohio manufacturers, a corollary approach should be considered to establish centers of manufacturing innovation comprised of discrete facilities located around the state to support existing industry clusters. Thus, this roadmap proposes the creation of a network of "*Ohio Centers for Manufacturing Innovation*" that would support industrial innovation and create sustained differentiating competitive advantages for Ohio manufacturers. These centers would initially be established with funding support from the State of Ohio but they would become self-sufficient within 5 years.

The structure of these centers should leverage the experience of EWI that emerged from the Ohio Edison Program of the 1980's and has since evolved into a uniquely sustainable, world-class center of excellence which both develops and commercializes leading-edge manufacturing technologies. However, the structure should go beyond the current EWI model to include a greater emphasis on training and business processes necessary to take advantage of new technologies. The proposed approach also moves beyond past state and federal approaches:

- Unlike the current Edison Center model, the Ohio Centers for Manufacturing Innovation would have "best-in-class" technical capabilities and would not rely on continued government subsidies to sustain themselves.

- Unlike the Ohio Third Frontier program which funds discrete technology projects, the Ohio Centers for Manufacturing Innovation would persist over time and continue to grow their technical capabilities, creating a permanent capability that Ohio manufacturers can access to create differentiating competitive advantages.

- Unlike the new "National Network for Manufacturing Innovation" federal initiative the Ohio Centers for Manufacturing Innovation would focus on serving the needs of individual clients by helping them introduce technologies that create competitive advantages, rather than collaborative research in early-stage technologies using federally subsidized funding.

The Ohio Centers for Manufacturing Innovation would provide a range of professional services focused on helping manufacturers innovate their products and production processes. These could include technology demonstrations, business assessments, customized development projects, technology commercialization activities, new technology training, implementation support, and shop-floor troubleshooting. Most of the work the centers would perform will be confidential and proprietary to individual clients who funded the work. Professional program management will ensure services are delivered on time and to customer expectations. To make small to medium size manufacturers (SME) and technology start-ups aware of emerging technology opportunities, the centers will become expert at disseminating information through workshops, social media, and other vehicles. The centers will also collaborate with universities and community colleges to introduce students to new technologies and to provide experiential learning opportunities. In doing so, the centers will help to create a pipeline of talent which will support successful technology implementation.

To make the greatest impact for Ohio manufacturers, the Ohio Centers for Manufacturing Innovation must coordinate with other organizations.

Workforce: Recognizing that successful adoption of new technologies requires a workforce that is trained, the Ohio Centers for Manufacturing Innovation will work with the Governor's Office of Workforce Transformation to inform and augment existing workforce education and training programs in the state to position Ohioans for the jobs of tomorrow. For example, the Ohio Centers for Manufacturing Innovation can help community colleges identify emerging manufacturing technologies so they can develop appropriate curricula for the jobs of tomorrow. To fill gaps in existing curricula, the centers will provide industry training (short courses targeting specific technologies) to upskill the existing workforce to fill gaps in existing education and training programs. The centers will also provide internship programs to provide experiential learning opportunities using the center's equipment for students from community colleges, university, and industry.

University Research: The state universities in Ohio have faculty and equipment in broad fields of science and engineering. The Ohio Centers for Manufacturing Innovation will connect manufacturers to these resources by linkage to university-industry liaison offices, such as Ohio State's "Ohio Manufacturing Institute" or University of Dayton Research Institute (UDRI) which makes the technical resources of the university easily accessible to industry.

Manufacturing Extension Partnership (MEP): The federal government has established MEP centers around the country which provide government subsidized services to help manufacturers adopt commonly accepted business practices for efficient manufacturing operations. Ohio has established six regional centers to deliver these services. By focusing on technical innovation, the Ohio Centers for Manufacturing Innovation activities would be very different from, and complementary to, the MEP.

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EWI
We Manufacture Innovation

Appendix A

EWI Client Companies with Ohio Operations

Company	Location(s)
Advanced Elastomer Systems, L.P.	Akron
AEP Transmission Group	Gahanna
Aeroquip Group, Division of Eaton	Van Wert
Airam Press Company	Covington
Air Liquide America Corp.	Lebanon
AK Steel Corporation	Middletown
Amanda Manufacturing (Bent Bolt)	Logan
AmTech	Cinncinnati
AO Smith Electrical Products Co.	Tipp City
Applied Optimization	Dayton
Arcair Co., The	Lancaster
ArtiFlex Manufacturing LLC	Wooster
Atlantic Inertial Systems	Heath
Autolite	Fostoria
Babcock & Wilcox	Alliance, Barberton
BAE Systems Land and Armaments L.P.	Fairfield
Banner Metal	Columbus
Batavia Transmissions, LLC	Batavia
Battelle Memorial Institute	Columbus
Boeing Company (The)	Kenton, Fairborn
BP Husky LLC	Oregon
BP p.l.c.	Lima, Cleveland
Brighton Tru-Edge	Cincinnati
Capital Die, Tool & Machine	Columbus
Center for Automotive Research (CAR)	Columbus
Chevron Phillips Chemical Company LP	Marietta
Chrysler Group LLC	Twinsburg, Perrysburg, Toledo
Clark-Reliance Corporation	Strongsville, Cleveland
Coldwater Machine Company LLC	Coldwater
Concurrent Technologies Corp. (CTC)	Fairborn
Copeland Corporation	Sidney
Craig Walters Associates	Powell
Crown Equipment Corporation	New Bremen
Curtiss-Wright Corporation	Cincinnati
Dana Technology Center	Maumee, Toledo

Dayton Progress	Dayton
Delphi Electric Systems	Warren, Vandalia
Diamond Power International, Inc.	Lancaster
Dow Chemical Company	Findlay, Hebron
Eaton Corporation	Cleveland
Ellis & Watts International	Batavia
Emerson	Columbus, Sidney, Cincinnati, Mansfield
Enerfab Corp.	Cincinnati
Engineered Wire Products Inc.	Upper Sandusky
Erico, NSMT North America	Solon
ESAB Welding & Cutting Products	Ashtabula
Eveready Battery Co.	Westlake
Fabrisonic LLC	Columbus
First Solar, Development Engineering	Perrysburg
Ford Motor Company	Sharonville, Lorain, Maumee
Fronius USA LLC	Broadview Heights
Fusite	Cincinnati
GE Appliances	Bucyrus
GE Aviation	Cincinnati
GE Consumer & Industrial	East Cleveland
GE Energy & Industrial Services, Inc.	Newcomerstown
GE Healthcare	Warrensville Heights
GE Lighting	Ravenna, Circleville, Dover, East Cleveland
General Dynamics, Land Systems Div.	Lima
General Motors Corporation	Cincinnati, Parma, Warren, Dayton
General Tool Co.	Cincinnati
Gerstenslager Company	Wooster
Goodrich SIS De-Icing, Uniontown	Uniontown
Greatbatch, Inc.	Cleveland
Grote Company	Columbus
Guild International, Inc.	Bedford
Gullco International Inc.	Cleveland
Harper International	Lancaster
HC Starck Fabricated Products Group	Euclid
Hendrickson, Commercial Vehicle Systems	Canton
Henny Penny Corp.	Eaton
Herrmann Ultrasonics	Cincinnati
Hobart Brothers Co.	Troy

Hobart Corp., PMI Food Equipment Group	Troy
Hobart Institute Of Welding Technology	Troy
Honda North America Engineering Center	Marysville, Anna, East Liberty
Johnson Controls, Inc.	Holland, St. Marys, Oberlin
Joy Global, Surface Mining	Cleveland
Komar Industries Inc.	Groveport
KTH Parts Industries, Inc.	St. Paris
L-3 Fuzing & Ordnance Systems	Cincinnati
Lear Corporation	Zanesville, Huron
Liebert Corporation	Columbus, Delaware
Lincoln Electric Co.	Cleveland
Liverpool Coil Processing, Inc.	Valley City
Lockheed Martin Corporation	Akron, Fairborn
M. K. Morse Co.	Canton
Magna Machine	Cincinnati
Marathon Oil Company	Findlay
Marathon Petroleum LLC	Findlay
Marathon Pipeline Co.	Findlay
Metal Improvement Co, LLC	Columbus
Miller Electric Mfg. Co.	Troy
Minster Machine Company	Minster
Miyachi	Powell
Miyachi Unitek Corporation	Marysville
Momentive Performance Materials	Strongsville
Morris Technologies, Inc.	Cincinnati
Motoman Robotics Div. of Yaskawa America	Miamisburg
Mound Manufacturing Center, Inc.	Miamisburg
NASA Glenn Research Center	Cleveland
NeuroRescue	Columbus
Nirvana Energy Systems	Cleveland
Northern Manufacturing Co.	Gibsonburg, Oak Harbor
Northrop Grumman Corporation	Fairborn
Nova Machine Products	Middleburg Heights
Ohio Bridge Corporation	Cambridge
Ohio Welded Blank Division of Shiloh Indus.	Valley City
Parker Hannifin Aerospace Fluid Systems Division	Elyria
Parker Hannifin Aerospace Gas Turbine Fuel Systems	Andover, Columbus, Mentor

Parker Hannifin Fluid Connectors Hose Products	Wickliffe
Parker Hannifin Fluid Connectors Hose Products	Cleveland
Pax Machine Works, Inc.	Celina
Peerless Food Equipment	Sidney
Praxair, Inc.	Akron, Columbus, Findlay, Lebanon
Process Equipment Co.	Tipp City
Rhenium Alloys, Inc. (RAI)	Elyria, North Ridgeville
Ridge Tool Co.	Elyria,
Rosemount Analytical	Columbus, Orrville
RTI Energy Systems	Niles
RTI International Metals	Niles
Salient Systems, Inc.	Dublin
Schneider Electric	Oxford
Select-Arc, Inc.	Fort Loramie
Shiloh Industries, Inc.	Valley City
Siemens USA, Energy & Automation Division	Bellefontaine, Norwood
Sierra Lobo, Inc.	Milan
Superb Industries	Sugarcreek
Swagelok Company	Solon, Willoughby
Taylor-Winfield Technologies, Inc.	Brookfield, Warren, Youngstown
Tenneco Automotive	Milan, Napoleon
The Adhesive and Sealant Council Inc. (ASC)	Cincinnati, Dublin
The Harris Products Group	Mason
The Pipe Line Development Company (PLIDCO)	Cleveland
Thermal Arc	Troy
Therm-O-Disc	Mansfield
ThyssenKrupp Bilstein of America	Hamilton
Timken Co., Technology Center	Canton
ToolTex, Inc.	Grove City
Trentec, Inc.	Cincinnati
UCI-FRAM Group	Fostoria, Perrysburg
Unison Industries, Inc.	Dayton
United States Enrichment Corporation	Piketon
US Bridge	Cambridge
US Endoscopy	Mentor
V&P Hydraulic Products LLC	Lewis Center
Velocys, Inc.	Plain City
Veyance Technologies, Conveyor Belt Products	Fairlawn, Marysville
Voestalpine Bohler Welding USA, Inc.	Fairview Park

Wayne Trail Technologies, Inc.	Fort Loramie
Wellington Manufacturing	Wellington
Westerman Companies	Bremen
Worthington Cylinders	Columbus
Worthington Industries, Inc.	Columbus
Worthington Steel	Columbus
Xomox Division of Emerson Electric	Cincinnati