Vision for Welding Industry

Submit comments and suggestions to:

America

550 N.W. LeJeune Rd. • Miami, FL 33126
305-443-9353 • 800-443-9353 • Fax 305-443-7559

Table of Contents

1

Executive Summary

Welding is a critical technique for the joining of materials in the Nation's major manufacturing industries. On the eve of the twenty-first century, the welding industry is defining its vision of the issues and opportunities that it will face in 2020.

WELDING, *the fusing of the surfaces of two workpieces to form one*, is a precise, reliable, cost-effective, and "high-tech" method for joining materials. No other technique is as widely used by manufacturers to join metals and alloys efficiently and to add value to their products. Most of the familiar objects in modern society, from buildings and bridges, to vehicles, computers, and medical devices, could not be produced without the use of welding.

WELDING goes well beyond the bounds of its simple description. Welding today is applied to a wide variety of materials and products, using such advanced technologies as lasers and plasma arcs. The future of welding holds even greater promise as methods are devised for joining dissimilar and non-metallic materials, and for creating products of innovative shapes and designs.

The WELDING INDUSTRY consists of the "users" of welding techniques as well as the companies, universities, and other organizations that provide the equipment, materials, processes and support services for welding. All branches of the industry look for improvements in their operations by 2020, and should find their interests addressed in this document.

MAJOR CHALLENGES will be overcome by the Welding Industry by the year 2020:

> *Welding will be better integrated into the production cycle*, eliminating the occasional impression . . . that it is a barrier to a smooth manufacturing process on the factory floor.
>
> *Training of welders and welding technologists* will be more comprehensive and scientific

The *welder's working environment* will become more attractive.

The residue of the *image* of welding as the "weakest link" in a fabrication will be eliminated.

New *materials development* will increasingly incorporate weldability.

This vision document is a pivotal step by the welding industry in meeting the requirements of tomorrow's manufacturing and construction industries.

<u>WELDING will be better integrated into the overall manufacturing process</u>.

As it is more completely integrated to the design and manufacturing cycles of products, welding will be accepted as crucial to improving the life-cycle costs, quality, and reliability of manufactured goods. There are a number of "drivers" that will help determine this future favorable position of welding. The use of information technology will grow to help develop a "virtual manufacturing plant," in which technologies for design, fabrication, and inspection are seamlessly integrated with welding technology where they are needed. Wise investments in capital goods and communication between the welding industry and its customers are also believed to be very effective methods for improving welding's competitiveness. Likewise, the sharing of new information about welding operations within industry will ensure progress throughout the fabrication, manufacturing, and construction industries.

<u>PEOPLE issues may be the most important</u>

Engineers employed in the welding field have been educated in a variety of disciplines, but rarely in welding.

Workers who do the actual welding have usually learned their skills on the job; only occasionally through apprenticeships or formal welder training.

Given the present-day image of welding, which does not yet reflect the recent progress made by the industry in machine processes and automation, it is not surprising that the percentage of workers who can weld and who work in the manufacturing industries is on the decline. However, as in every field, there is a crucial need for talented people, and manufacturers want to attract people to welding who will help improve their products and their productivity. Industry has set a goal of investing in educational opportunities for people interested in welding, metallurgy, and closely related disciplines. Early investments in training at all levels will generate a large return to industry.

<u>QUALITY, RELIABILITY AND SERVICEABILITY of welded joints will improve</u>

This is a practical and an image issue. The industry must learn how to ensure that welds will have "zero-defects," and establish practical methods which achieve that result.

<u>WELDING will change (in the minds of industry) from an art to a science</u>

This is another of the image issues, and a theme that will appear several times in this document. There is also the need to provide better guidance to manufacturing engineers in the application and control of welding, so more consistent results become commonplace.

MATERIALS OF THE FUTURE will be designed to be weldable

as part of the total integration of welding into the manufacturing cycle. They will also be energy efficient and environmentally benign, and "smart" materials with a computer component will help with materials processing at any point in the life cycle of the component. U.S. industry will lead in the development of other technological innovations that will expand welding's presence in the manufacturing sector.

INCREASED COMPETITION IN GLOBAL MARKETS for materials fabrication

This is already forcing U.S. companies to consider new manufacturing and distribution methods in order to attract customers worldwide. Numerous markets are emerging in developed and developing nations for the welding industry to exploit, if it is alert to societal needs and has the appropriate technologies and manpower in place. Industry will gain access to new technologies by participating in cooperative research programs with government and academia, but *the time-line between discovery and implementation must be dramatically reduced.*

In developing this vision document, more than 25 senior managers and respected experts from various segments of the welding community met on June 30 and July 1, 1998, at the National Institute of Standards and Technology in Gaithersburg, Maryland, to begin a dialog about the future of the welding industry (see Appendix A for a complete list of the attendees at the Vision Workshop, and their affiliations). They were brought together to develop a long-range business plan for their industry that would identify how it would meet the needs of manufacturers, of the marketplace, and of society in 2020. In essence, these decision makers created an ideal vision of the state of their industry in 20 years, and the strategy to reach it.

This document is the vision of the welding industry for 2020. It is also the industry's first step in carrying out its partnership with the U.S. Department of Energy's Office of Industrial Technologies to improve welding's energy efficiency, environmental performance, quality, and productivity. The next step will be to produce a technology roadmap for the industry that will spell out an agenda for developing new technologies to help accomplish the vision.

The goals of this vision document are ambitious, and there are barriers to be overcome, but the expectations are that the approach described will help the U.S. welding industry maintain a competitive worldwide position well into the next century. This vision document is the industry's answer to those challenges as it takes this important step in achieving an enhanced place for welding technology in the Industries of the Future.

Strategic Goals

--Cost/productivity/markets/applications
reduce the average cost of welding by one-third, by providing better process selection guidance, increasing the use of automation and robots, and lowering reject and repair rates; increase the use of welding by 25%

--Process technology
Enhance the use of welding in manufacturing and construction operations by integrating welding with other manufacturing and construction disciplines, at the engineering level and also at the operational level.

--Materials technology
Develop welding technology along with new materials so practical fabrication methods are available are available for all engineering applications

--Quality technology
Through the use of modeling, systematic process selection and procedure development, and NDE technologies, assure that welding can be part of a six sigma quality environment

--Education & Training
increase the knowledge base of all people employed in the welding industry, at every level, enabling them to make decisions that will result in utilization of the best welding technology for each application

--Energy & environment
reduce energy use in by 50% through such productivity improvements as decreased pre- and post-heating operations, and use of advanced, lower heat input welding processes, and avoidance of overwelding.

2

The Welding Industry

The welding industry oversees one of the most widely used technologies in materials processing.

The Scope and Impact of Welding

> **A Definition of Welding**
>
> Welding is a joining process that produces a local coalescence of materials by heating, by applying pressure, or both. In essence, the welding process fuses the surfaces of two distinct elements to form a single unit. It encompasses a broad range of joining techniques that include fusion welding, solid state welding, weldbonding, diffusion welding, brazing, and soldering.

Welding dates back to the earliest days of metalworking, and continues to be widely applied today due to its cost-effectiveness, reliability, and safety. When compared with other joining methods, such as riveting and bolting, welded structures tend to be stronger, lighter-weight, and cheaper to produce. More than 100 processes and process variants comprise the family of welding technologies, and include methods for welding metals, polymers, and ceramics, as well as emerging composite and engineered materials. These various technologies allow a great deal of flexibility in the design of components to be welded. They also encourage designing for optimal cost-effectiveness in productivity and product performance.

Welding and joining technologies pervade commercial and defense manufacturing, and are a significant source of value-added in the manufacturing process. Occurring late in the manufacturing stream, the joining process is typically the final step in assembly and plays the major role in ensuring structural performance. Additionally, the emergence of near-net-shape processes to produce sub-components has raised the importance of assembly processes as the next area for increased production efficiency. The role of welding and joining in the repair and life extension of manufactured products is even more critical since these processes are frequently used to repair structures and components that were not originally welded.

Profile and Structure of Today's Welding Industry

The welding industry incorporates the **workforce** that uses welding technologies to perform welding operations; the **welding supply industry** that provides the equipment, products, consumables, and services needed by the workforce; and the **end-users** in the larger national and international industrial sector who rely on welding and joining processes to manufacture their products.

The Welding Workforce

Assembly operations account for a significant percentage of the labor content of manufactured products. Given the dominance of welding and joining as an assembly process, a significant percentage of the U.S. manufacturing workforce is involved in the application of welding in the course of their manufacturing duties.

The *1996 Occupational Outlook Handbook* published by the U.S. Bureau of Labor Statistics indicates that over 450,000 Americans were employed as welders, cutters, and welding machine operators. Additionally, the *Handbook* lists 25 other trades (e.g., ironworkers, boilermakers, pipefitters) or occupations (e.g., precision assembly, shipfitting) where welding is either a specialized skill or an integral part of the operation. By including the workers from these professions that are directly involved in welding, the size of the welding community swells to *over 2 million workers*, or *over 10 percent of the manufacturing workforce*. These employment figures, significant both in terms of raw numbers and the impact of welding on the manufactured-goods component of the gross national product, still do not reflect welding's total influence. Other individuals work with welded products in the areas of product design, industrial and systems engineering, production engineering, and management. These individuals are not counted in the employment figures cited above. Clearly, welding is a vital element of U.S. manufacturing and critical to future U.S. competitiveness.

Changes in the manufacturing sector's workforce are likely to cause the percentage of workers involved in welding to fluctuate. According to the U.S. Bureau of Labor Statistics, manufacturing's share of total employment is expected to drop from 14 percent to 12 percent by the year 2006, with a loss of 350,000 jobs. Since manufacturing is expected to maintain its share of total output, overall manufacturing productivity must increase by a minimum of 15 percent, just to break even. From welding's perspective, *this implies a greater reliance on mechanized, automated, and robotic welding*.

The Welding Supply Industry

The bulk of welding products are purchased from "welding distributors," virtually all of whom are primarily industrial gas distributors. Most of these businesses are owned by industrial gas producers (e.g., Praxair, AGA, Air Products), or by rapidly growing distribution conglomerates (e.g., Airgas). Their primary focus is merchandising, and few have technical staff trained to help customers select the best processes for their needs or to solve their technical problems quickly. Thus, small- and medium-sized manufacturers have little or no direct access to experts and many of their welding applications are sub-optimal, with penalties to the cost and quality of their products. (Recently, some suppliers have realized that lack of technical expertise makes them look like commodity suppliers to their customers, and they are moving to improve their service.)

Machinery, filler materials, and accessories for the various welding processes are manufactured and supplied by fewer than 10 large companies whose sales exceed $100 million. Several hundred much smaller companies specialize in items like welding torches, welders' helmets, hammers, marking equipment, welding screens, special fluxes, and so forth. The value of shipments at the manufacturing level fluctuates with the volume of metals consumed in U.S. industry, and there have been pronounced upward and downward movements in these figures over the years. Recently, however, shipments have shown a substantial increase, as illustrated by data for the period 1992-1995, shown in Table 2-1.

Table 2-1. Value of Shipments of Welding-Related Industries

Product		**Value of Shipments ($ millions)**			
SIC	**Description**	**1995**	**1994**	**1993**	**1992**
35481	Arc Welding Machines	1311.9	1135.3	1051.9	886.1
35482	Arc Welding Electrodes	872.4	852.0	682.8	631.7
35483	Resistance Welding Equipment	385.9	380.3	664.7	280.6
35484	Gas Welding/Cutting Apparatus	248.7	241.0	281.7	252.8
35485	Other Welding Equipment, Accessories	394.1	345.9	211.6	242.6
35480	Other Apparatus	87.8	89.1	153.7	97.1
3548	**Total Welding Apparatus**	**3300.8**	**3042.6**	**3046.4**	**2390.9**
	Year to Year Change (%)	8.5%	-0.1%	27.4%	
	Change During Period	38.1%			

Source: U.S. Census Bureau, 1995 Annual Survey of Manufactures

These data do not include information on the following products:

Welding automation, arc and spot welding robots that make up more than half of all equipment sold . . annually, and ancillary equipment; total annual sales estimated at more than $1 billion, according to 1997 statistics of the Robotics Industry Association

Lasers, now out of the laboratory and prominent in precision cutting and welding operations; about 200 systems installed annually at an average value of $500,000 each

Microjoining, miniature versions of joining methods such as resistance, laser, friction, brazing, and others, for fabrication of electronic components, medical devices, specialized control devices, and hundreds of other new products; equipment not of high value, probably adding $75 million annually

Thus, the approximate total value of the U.S. welding-related market was $5.3 billion to $5.5 billion in 1995. It has continued to grow, creating some shortages, particularly in filler metals, resulting in the need to import some products.

The End-Users

Virtually every manufacturing industry uses a welding process at some stage of manufacturing or in the repair and maintenance of process equipment. From the soldering of PC boards to the heavy-duty welding of steel plates for shipbuilding to the repair of industrial boilers, industry relies on welding for reliable joining of materials. Among the manufacturing industries that rely on welding are the following:

- Automotive

- Heavy Equipment
- Aerospace
- Electronics, Medical Products, and Precision Instruments
- Electric Power
- Petrochemical

Although end-user manufacturers would not typically consider themselves as part of the welding industry, advanced joining technologies allow manufacturers to use the latest materials and designs to enhance their products' performance, reduce manufacturing costs, and decrease life-cycle costs. Because the established distribution system sometimes places a barrier or “filter” between the manufacturers of welding products and the end users, it is sometimes difficult for these manufacturers to learn what the users think of their products, and what their long-term needs (and opportunities) really are. The joining needs of each industry vary, of course, depending on the demands placed upon its products, and the pressures for more cost-effective productivity.

U.S. manufacturers have requirements in at least three areas: meeting the changing demands of their customers, competing with foreign manufacturers, and complying with government regulations. This means they continually concentrate on developing a new generation of improved, high-value-added products. Joining technologies that have evolved to meet new industrial needs include specific arc welding techniques for the shipbuilding, aerospace, and oil and gas industries, and advanced resistance welding that has been driven by the automotive and appliance industries.

Even as manufacturers expand their development of new products, they must continually strengthen their production economies and achieve the bottom-line performance required by shareholders. The result is a movement towards “mass customization,” where the manufacturing base is both highly flexible and highly efficient.

To achieve this flexibility and efficiency, responsibility for manufacturing components and subassemblies is being pushed to suppliers, leaving the prime manufacturers free to concentrate on marketing, sales, and final assembly. As a result, prime manufacturers and the companies in their supply chains are more closely integrated now than at any time in the history of U.S. manufacturing. The ultimate example of this may be in the automotive industry, where a single facility has been proposed to incorporate the prime’s assembly plant and several suppliers' component-manufacturing operations.

While suppliers have increasing responsibility for design, production, and “just-in-time” logistics, these smaller companies find it difficult to secure the financial and technical resources to respond to the challenge. The resources they have may be fully consumed in meeting daily production commitments and in struggling to meet the needs of their customers.

The direction of the overall manufacturing base drives innovation in welding and joining technologies. Table 2-2 shows some general trends and key needs in four industries that depend on welding technologies in the manufacturing cycle.

Situation Analysis of Today’s Industry

As market pressures require industry to regularly introduce new product lines and enhancements, the prime-supplier team is driven by a short product-development cycle. Each new product cycle brings increased performance requirements and enhancements in product quality. At the same time, there is pressure for new products to be more affordable, both in their initial production costs and in overall life-cycle costs.

Spurred by the needs of product developers, the U.S. research community has spawned new classes of design concepts and new families of structural materials. There are discrete examples of these innovations being implemented in the current mix of new products, but they have not been widely used. In many cases, manufacturing technologies have lagged behind innovations in materials and design, limiting the ability of prime manufacturers to take full advantage of these new approaches.

Table 2-2. General Trends and Key Needs in Four Manufacturing Industries

Industry	General Trends	Key Needs
Automotive	• Supply chains more responsible for design and manufacture • Increased pre-competitive cooperation on technology development • Technology implementation and management remain competitive	• Real-time sensing and adaptive control • Resistance spot welding (RSW) process control, electrode wear, and equipment design • Joining of lightweight metallics • Joining of coated high strength steels • Joining of dissimilar materials • Polymer joining • Laser processes/tailor welded blanks • Structural adhesive technology • Welding design and process management tools • Microelectronics - Process development and reliability
Heavy Equipment	• Industry typically rises and falls with the general economy, currently an optimistic outlook • Impact of recent Asian economic issues unclear • Increased dependence on suppliers and supply chains • Growth in overseas operations	• Improved fatigue performance and design rules for welded joints • Process and structural modeling • Real-time process control • Optimized robotic and mechanized welding systems • Welding of high-strength steels • Laser processing (first and second operations)
Aerospace	• Shrinking prime manufacturer base • Increased emphasis on affordability (cost as an independent variable) • Shorter product development cycles • Greater reliance on integrated manufacturing concepts • Increased product life • Aging aircraft/sustainment and repair a major issue	• Welding of new Al, Ti, and Ni alloys • Solid state joining and brazing processes • Polymer/composite joining • Design tools include residual stress and distortion control • Process modeling and control • In-process nondestructive testing
Electronics, Medical, Precision Instruments	• Fastest growing industry sector worldwide • Extremely competitive • Driven by new products and technology • Joining technology historically developed in-house; now beginning to outsource to outside developers	• Design guidelines for all levels of packaging • Coating and plating - effect on joining • Process optimization • Process/product modeling • Reliability technology: assessment and test methods • Process fundamentals - microstructure/property correlation • Laser processing
Energy and Chemical	• Power generation industry remains flat with utilities continuing to streamline operations • Upstream sector of oil and gas industry is extremely buoyant with emphasis on deep water projects • Downstream sector (refining) reasonably flat; refining divisions are consolidating and merging to improve profitability	• Deep water technology (sub-sea completions) • Welding of corrosion-resistant alloys (CRAs) • Repair technology (in-service repairs, and repairs without post-weld heat treatment (PWHT) • Improved fitness-for-service (FFS) assessment methods (corrosion, residual stresses, mismatch) • Joining of high-strength steel (HSS) (linepipe) • Inspection, reliability, and risk assessment

Source: Information developed by Edison Welding Institute and its member companies and advisory boards, 1998

Other issues presented by new products include the weldability of emerging materials that may not have been designed with welding and joining in mind, the need to improve feedback control of manufacturing processes, and the development of new approaches to processing.

Advanced computational models will play a larger role as industry develops the next generation of design tools and manufacturing technologies, including techniques for the joining of materials. Traditionally, the development of joining technologies has involved extensive testing programs, detailed characterization of materials, and demonstration of components in service. With appropriate numerical-analysis tools, it will be possible to reduce the time for design and developmental work, improving industry's productivity and shortening the time to market.

Need for Coordinated Technological Development

Clearly there is a need for continued advancement in welding and joining technologies. Historically, major innovations were driven by the needs of military-related manufacture, for example, the welding of high-performance steels to meet the requirements of warships. These innovations are now applied by a number of heavy industries. Similarly, the advancements in welding high-temperature materials in military jet engines and nuclear reactors have been applied to their commercial counterparts. While this was effective in the past, that model is hampered by a number of recent developments:

1. The Nation's shrinking military budget has reduced the number of new military systems under develop` ment, resulting in fewer platforms for innovative manufacturing technologies, including those applicable to welding.
2. Similarly, defense-related R&D is now directed on a system-by-system basis, further reducing the development of broadly applicable technologies.
3. Many companies are separating their commercial and defense businesses, divesting those that are not . core businesses. This makes it more difficult for technologies to make the transition from defense to . commercial manufacturing.
4. Commercial product cycles are contracting rapidly and defense-related R&D may not be able to match the rapid pace.

Confronted by this increasing challenge to defense-driven innovation, the government has experimented with initiatives to directly support commercial industry. These new types of programs encourage collaborations in which each company's resources are leveraged along program lines to develop more broadly applied technologies. Additionally, these government-facilitated efforts are permitted under anti-trust regulations and are therefore easier to assemble than individual joint ventures.

3

Key Drivers of Welding's Future

***When the welding community got together at its vision workshop, members identified 10 driving forces and issues that are likely to determine the future of welding over the next 20 years*.**

The Driving Forces and Issues

As the welding industry prepares to meet the future materials-processing needs of its customers, it is driven by a number of key factors that shape its business strategy. They include the following:

- Markets and Customers
- Education and the Workforce's Image
- Business Practices and Economics
- Developments in Information Technology
- Quality, Reliability, and Serviceability
- Regulation, Certification, and Standards
- Integration of Products and Processes
- Development of Materials
- Safety and Health
- New Technological Strategies

Each of these key drivers is discussed in more detail in one of the following sections. *Specific issues within each key driver that were agreed upon and rated by attendees at the Vision Workshop are identified in italics.* Appendix B contains the original “storyboard” display developed during the workshop.

Markets and Customers

The most important factor influencing the industry's future direction is the potential for *increased globalization of businesses and markets for materials fabrication*. U.S. industry will feel the effects of this increased foreign competition as its companies begin to use suppliers and gain customers from around the world. Traditional lines between customers and suppliers and domestic and foreign markets will be increasingly blurred as joining operations and business alliances from both camps are melded. Information technology will be helpful in accelerating development of the "virtual manufacturing plant" of the future that uses the best of both worlds.

The welding community recognizes also that welding technologies and skills will have to *compete more keenly with alternative processes* such as near-net-shaping, deposition processes, adhesive technologies, high-speed machining, direct fabrication (sometimes termed rapid manufacturing), and combinations of certain technologies. Designers and manufacturing engineers need to know the full potential of the available welding/joining processes so they can make the best selection of potential manufacturing methods. More science, engineering, and training must be incorporated into the welding process if it is to compete with other technologies and fulfill its potential in this country. Records of excellence have already been achieved by the automotive and aerospace industries in their application of welding techniques, and welding is expected to become the established joining method in many other manufacturing sectors. Welding is *the* established method of manufacturing for shipbuilding, power generation, structural fabrication, petroleum production and refining, construction and farm equipment, and other structural applications. In many of these industries, however, the *productivity of welding needs to be improved*. In shipbuilding, for example, this country lags behind most others.

Who will be the future customers of the welding industry? Developments in U.S. transportation industries and the *state of the Nation's aging transportation infrastructure* will be increasingly important in shaping future welding markets. This network of equipment, highways, and bridges must be replaced or extensively rehabilitated in the coming decades, although it is unknown if the Federal and state governments are willing to invest in these improvements. If governments do commit funds to upgrade the infrastructure, it will drive the demand for welding in the future. The construction industry will be heavily involved in these improvements also. Technologies are available to repair or arrest cracks and address the problems inherent in aging joints. However, a few additional technologies may need to be developed for this purpose. The same problems will be present in the infrastructure of other developed nations, while many developing countries will require large first-time investments in their infrastructures. These deficiencies are seen to be a major opportunity for the welding industry.

Another market is already emerging to serve the *needs of the aging baby boomers*. Industry will develop products to support this generation's medical requirements, creating new joining opportunities in technologies such as biocompatible implants. Industry must be alert to the country's demographics and other social conditions and be able to respond quickly to the needs of the population.

Changing requirements of the government's defense systems will also have an influence on the future of the welding industry. While a reduction in defense procurements may reduce the demand for welds in areas such as aircraft and military vehicles, the good performance and affordability of welding are causing the defense sector to explore the greater use of welding and joining techniques. In addition, as the government spends less on research in universities, fewer government-funded innovations will reach the commercial sector. It will be incumbent upon the welding industry to form partnerships to fund research and develop new technologies.

It seems likely that customer-specific fabricating will become increasingly prevalent, and together with just-in-time production strategies will drive a shift toward *small-lot manufacturing* or mass customization. There may well be an opportunity for integration of welding processes into some of the direct fabrication techniques that are under development. Industrial distribution is already evolving toward the distribution of parts in real-time. This is a revolutionary change that will affect the selection of joining processes for many applications. This requires the adoption of sensor and control technology based on sophisticated programming, to enable manufacturers to effectively monitor the integrity of products produced in this new environment. However, manufacturers will need to increasingly monitor the integrity of fabricated products as this type of manufacturing becomes commonplace.

Education and the Image of the Workforce

"People issues" are paramount to the future of the welding industry. The unfortunate public image of manufacturing as an endeavor in decline is actually pushing many talented and energetic people into other fields. In academia, students and faculty are discouraged from pursuing studies in the primary production industries and expertise in these fields is rapidly being depleted.

Industry recognizes the *critical need to attract top-quality personnel* to the welding community, from welding and manufacturing engineers to business entrepreneurs and field welders. To ensure a continuous supply of talented personnel, industry plans to pro-actively nurture the growth of educational opportunities for people choosing welding, metallurgy, and related fields as careers.

Until recently, welding itself was a skill that craft people could learn without a real understanding of the science behind it. The *scientific and engineering principles behind welding* must replace the art of welding for it to achieve its potential as a preferred state-of-the-art manufacturing process.
Another part of the solution may be more *effective apprentice programs* for welders and technicians. Welding as a vocation will take on a higher level of prestige as apprenticeship and certification programs become more rigorous. The industry will also grant welders greater recognition and status for their work. In addition, the industry must "upgrade" the existing workforce through better basic training and effective apprentice programs. Today's welders will be with the industry for a long time, and *they need to continually improve their skills and their flexibility*.

Business Practices and Economics

Another important determinant of the welding industry's future is the *drive to improve productivity*. For fabricated products to compete in the future, they must be made faster, cheaper, and better than those of competitors.

While decreased labor costs are the traditional means to enhanced productivity, the industry already recognizes it needs a larger workforce to stay competitive. Corporate consolidations have weakened the industry through *loss of welding expertise*. Such practices as *distributed manufacturing* serve to isolate welding engineers from the manufacturing processes. In addition, the trend toward private or contracted welding research could discourage sharing of results.

Strategies to improve the economics of welding include changes in the investment decisions made on behalf of welding. For example, if there is *sufficient investment* in such areas as education and capital equipment early in the process, stockholders will realize a large return on their investment and be inclined to participate. An effective *cooperative research program among government, industry, and academia*, with sharing of costs and resources, would be another example of a wise investment decision that could increase future productivity. New governmental *tax policies* could also have an influence on investment decisions by private companies.

If welding is to be accepted as a significant factor in the fabrication of metal parts, accurate models of life-cycle costs should be developed for welded joints and alternatives. By exploiting state-of-the-art information technologies, manufacturers will be able to incorporate *virtual/integrated techniques* into their manufacturing processes and take advantage of their cost-reducing features. Modeling will certainly be important to *compress the time needed between development of the design and start-up of production*. The use of simulation technology to develop the "virtual manufacturing plant" of the future has been mentioned previously and is discussed in greater detail in the following subsection, "Developments in Information Technology," and in Section 6 under "Manufacturing Integration."

Improvements in the energy efficiency and environmental compliance of the welding industry will also be positive additions to the overall productivity of the welding industry. As business practices, increased product quality and serviceability are considered so important, they have been included in a separate category for key drivers (see below).

Developments in Information Technology

Welding processes based on rigorous engineering analysis, numerical modeling, and computer-based automated manufacturing will be widely used, and will depend heavily on information technology. Similarly, information technology will be important as welding markets become more international, helping to incorporate cost-saving business practices and increase productivity both here and abroad. By *modeling the life-cycle costs* of welded products, designers can determine early if new products should be produced using welds. Computers will be used to *solve other complex problems* associated with the application of welding. The *growth of information technologies such as the Internet* is seen as an important driver that will influence the future of welding in other unexpected ways. Decision tools that support the cost-effective use of welding need to be put in the hands of product-development teams and of manufacturing engineers.

The welding industry should not have to "reinvent the wheel." There should be wide availability of established procedures. Through the use of information technology, new findings can be disseminated quickly and accurately to others in the industry. There will be no need for various segments of the industry to search extensively for information or repeat studies already carried out.

Additionally, a history of past solutions should be available in a database for easy access. The welding industry should take the lead in setting up and maintaining these knowledge-based systems so that industry's progress can be shared by all interested parties. Manufacturers who experience joint failures, for instance, can use the "lessons-learned" from these failures to improve joining strategies and system designs, and transmit this information to other companies.

Quality, Reliability, and Serviceability

Welded joints will become widely accepted as the superior design option for manufactured products between now and 2020 as their quality, reliability, and serviceability are improved above today's already high standards. The welding industry will work to remove reservations in areas where there is concern about welded joints due to limitations of materials, process, and ability to ensure quality. Welding will be associated with products that offer *performance and endurance, and that can be serviced*.

Competitive pressures will drive fabricated products toward having zero-defects and lifetime repairability. Although every product has some defects or discontinuities, the challenge is to know the level that is acceptable for desired performance of the product. Because connections are always seen as the weak links in manufactured structures, they receive special attention from designers trying to gain a competitive edge. Although the emphasis will be on producing products that are defect-free and of high quality, customers will also be guaranteed that technology will be available to make repairs necessary to restore performance and extend the life of complex, expensive products.

Industry will also incorporate information derived from any failures into the future, improved design of welded products. Manufacturers need accurate predictions of the performance of welds and weld systems. Again, simulation technology will be used to *model* these *links of the manufacturing cycle*. The capability to model and analyze welded joints will be an important development in improving their quality. While most welded products are produced to meet a high standard of quality, a movement is underway by the industry to insist on superior "*6-sigma quality*" in all its welded fabrications. The term "6-sigma" refers to a weld that is highly reliable and that is usually demanded for such critical products as aircraft and bridges. This level of quality requires that better than 99.999 percent of all welds will exceed the standards.

Another area that needs more attention for there to be progress in the industry is in *non-destructive evaluation techniques*. Simulation technologies will be called upon to predict the performance of welds and weld systems well before they are manufactured. Customers will have the capability to monitor the integrity of fabricated metal products throughout their life cycles.

As part of the product's quality, customers are insisting more and more on the *aesthetic quality of the weld* in products where the weld is visible. It is particularly difficult to ensure that the appearance of a weld of dissimilar materials such as steel and nickel alloys is cosmetically acceptable. One of the drivers of the future industry is an effort to improve the aesthetics of welds.

Regulations and Standards

New regulations and standards may be imposed by government to limit industry's energy use and *environmental impact*. Such mandated constraints will affect competitive selections among joining alternatives.

To remain a player in the rapidly changing, global, manufacturing environment of the future, the U.S. welding industry is likely to adopt a flexible system of codes and standards. The major challenge is to move to a group of universally accepted international standards, allowing manufacturers to compete in any market without needing multiple designs. It is not easy to change an industry's codes and standards, but such changes will help *increase the acceptability of new joining techniques* worldwide. There should be *centralized control of standards*, though not necessarily by government. Centralization will help simplify issues that arise regarding the certification of welded products, and *reduce industry's liability* for products that fail.

Other legal issues related to regulation of the welding industry involve the *intellectual property issues* that arise concerning the research findings funded under Cooperative Research and Development Agreements (CRADAs) or other government contractual vehicles. These need to be clearly stated in a legal document to protect the interests of those involved.

Integration of Products and Processes

Welding operations must be more completely integrated into agile manufacturing processes and process control schemes. This will, in turn, compress the time from the first day of design work to the start of production and delivery of the product. Welding will be a consideration early in the design process, whether the design is related to new materials, products, or manufacturing processes. *Communication* among all those who are part of this integration is very important to its success. It is even likely that welding and the inspection of those welds will be *integrated into one operation*.

Welding will become increasingly *automated as it is integrated into the entire manufacturing design and coordinated with improved information systems*. These computerized systems will easily link welding to the appropriate manufacturing process. Welding may be incorporated into agile manufacturing "work cells," where the *welding technology is embedded on-site in processes* where it will be needed. Monitoring and control of such links will, of course, be part of the operation. Such automation will also help relieve the short supply of trained and certified welders and eliminate the need for manual operators in some tedious, unpleasant, or potentially dangerous working situations.

Future products requiring welded joints will be composed of designed-to-be-weldable materials, such as high-strength steels that are also smart materials containing embedded computer chips to monitor the weldment's life-cycle performance. Such materials could create new opportunities for using welding as a joining technique in the coming decades.

Incorporating welding in the design process is an important component of the key driver, "Integration of Products and Processes." At present, the welding industry is "on-call" to perform welding operations when the processing stage requires it. In the future, the modeling of welding will be part of the new emphasis on integrating welding across the entire manufacturing cycle.

Development of Materials

One fundamental need in the welding arena is a *greater understanding of metallurgy* as it applies to welded materials. Welding and materials engineers will develop new materials and adapt existing materials, which are specifically designed to be welded into world-class, fabricated products. Also, as new materials are developed, the welding industry must develop new techniques to ensure their weldability.

New concepts in this area include the development of materials that will *reduce energy requirements*. Less energy will be used for both pre-heating and post-heating purposes. "*Smart" materials will have a microchip embedded within the material*, to monitor the physical characteristics of materials as they undergo the fabrication process and allow engineers to know exactly how they will perform in service.

Studies will also be needed to *develop new filler metals and to improve the purity of certain products associated with welding* (e.g., gases, filler wires). These issues are covered in more detail in Section 6, in a discussion of materials as a key competitive challenge to the future of the industry.

Safety and Health

The welding environment of the past was frequently viewed as dark, dirty, and dangerous. That perception is already changing, and will continue to change as education and training increase the awareness of workers concerning newly developed welding technologies. The factory floor of 2020 will be a very different place compared to previous manufacturing facilities. Workforce demands, government regulations, changing business practices, and increasing environmental awareness will drive the manufacturing environment to be quieter, cleaner, healthier, safer, and “friendlier” for workers.

Customers, too, will have far fewer worries about the products they purchase. In the coming decades, goods will be produced to be fail-safe and therefore *safer* to use.

New Technological Strategies

U.S. industry needs to lead technological developments that will in turn allow rapid and flexible fabrication of new products to satisfy customers' demands. To achieve this, the following strategies will be pursued:

1. Make current processes more reliable and more robust
2. Allow for greater use of process automation.
3. Develop welding technology concurrently with development of new materials
4. Develop processes and methods that facilitate joining of metals, glass, ceramics, plastics, and other materials as required, to optimize performance of the product.
5. Implement methods of integrating welding requirements and welding knowledge into total manufacturing planning and management information systems (MIS).

4

The Vision for Welding

In 2020, welding will continue to be the preferred method by which metals and other engineered materials are joined into world-class products. U.S. industry will be the world's leading source of these cost-effective, superior-performing products by virtue of its leadership in joining technology, product design, and fabrication capabilities, and a globally competitive workforce.

Interpreting the Vision Statement

The industry has summarized its goals and objectives for the year 2020 in the preceding vision statement. The statement clearly states that the United States expects to maintain its superiority in joining technologies in the future. However, industrial representatives at the vision workshop stated that the joining of materials is too narrow a definition for welding and it should instead be considered a method of assembling fabricated products.

The vision statement also suggests that welding will not be seen as an impediment to a smooth manufacturing process. Rather, welding will be integrated into product design, development and manufacturing and will be a primary contributor to the superiority of U.S. products. In a multi-disciplinary approach, the welding engineer will be teamed with the design engineer, the manufacturing engineer and customer in order to end the present isolation of welding from the manufacturing process. It is also likely that the teaming effort will help improve quality control and service for the welding industry's customers.

While new designs are expected to create near-net-shape products with fewer components, the techniques of welding will continue to be in demand by manufacturers. New materials will be more "weldable," with the constraints of welding already considered in the design of the materials. The industry noted that composites, especially metal matrix composites, are very difficult to weld, and may have to be joined using adhesives or other methods. The welding industry as a whole will progress as it gains greater understanding of these types of problems and develops new tools and capabilities to handle them.

In order to compete with other joining technologies, the quality of welding must continue to match the significant improvements being made by the competing technologies. Welded products must approach zero defects, eliminating the need for repairs and re-handling, and ensuring cost-effectiveness.

The vision also states that the welding industry of 2020 will have a world-class workforce. Although a present concern is that today's industry is not attracting as much talent as it needs to ensure its future viability, several steps can be taken to change this. A cleaner, more automated factory will ensure a healthier and safer working environment to potential workers. More educational opportunities in the science of welding will also influence people to choose welding as a career. Formal apprenticeship programs will give workers more training and recognition, and certified welders will be deserving of the title.

Globalization of welding is also part of the industry's vision for 2020. Most U.S. companies already consider themselves global, but with their focus on the United States. Nonetheless, industry sees globalization as a key driver of its future, and seeks a 25 percent greater utilization of welding worldwide.

5

Strategic Targets for 2020

In order to meet its vision by 2020, the welding industry has identified a series of strategic targets (sometimes called performance targets or goals) that should be met within this time frame. These strategic targets have been assigned to one of seven categories that are generally recognized as issues in the welding industry. The targets will correspond to research pathways that will be laid out in the future roadmap.

The objectives and the related tasks for each of the industry's seven strategic targets are summarized in Table 5-1, below.

Table 5-1. Meeting the Strategic Targets of the Welding Industry by 2020

Strategic Targets (Industry Issues)	Objectives	Related Tasks
1. Cost And Productivity	Achieve cost-effective welding operations	Conduct "up-front" design and development (modeling, process/materials databases) to achieve a greater market share; strive to compress the time and associated costs for this work by a factor of 10 in the future

(continued)

Table 5-1. Meeting the Strategic Targets of the Welding Industry by 2020

Strategic Targets (Industry Issues)	Objectives	Related Tasks
	Increase productivity and throughput 100%	Improve weld quality, reduce welding time during manufacturing, use automation to decrease labor costs, use simulation to model the welding and the manufacturing process
	Improve the welding process and product	Use multi-disciplinary teams (material suppliers, designers, welders, product users); reduce time spent on qualification of welds for a specific application; eliminate inspections, testing, and reworking as weld quality improves
II. Technologies and Processes	Enhance use of welding in manufacturing operations	Develop new technologies and processes, use simulation technology to model entire manufacturing sequence (will be important to industry's progress in 21st century)
	Conduct virtual qualification of weld designs	Evaluate welds and alternative joining techniques at design phase, improve simulation technologies
	Integrate welding within entire factory	Use systems technologies to integrate the process upstream and downstream
	Move to an "open architecture" and automation in welding technology	Make 80-90% of equipment compatible ("plug and play") by developing an industry standard
	Seek new ideas from other industries applicable to welding	Accept technologies, innovations from sensor and computer industries
III. Quality Standards	Produce extremely high-quality welds and fabrications	Improve such parameters as corrosion-resistance, strength, and fatigue-resistance; eliminate need for inspections

(continued)

Table 5-1. Meeting the Strategic Targets of the Welding Industry by 2020

Strategic Targets (Industry Issues)	Objectives	Related Tasks
	Predict accurately the structure and lifetime of fabricated products	Conduct virtual simulation of welding and manufacturing
	Reveal conditions that lead to defects and cracking	Conduct virtual simulation of welding and manufacturing
	Make welding codes and standards more flexible	Use modeling and simulation to determine how much codes can be relaxed; emphasize fitness for service.
	Open international markets to U.S. products	Set a global standard for welds in manufacturing, adopt uniform codes and certification standards, insist on quality and reliability in products wherever they are manufactured
IV. Materials Performance	Use most advanced cost-effective material appropriate for each application	Match the material with the processes and advanced consumables of the application; develop more effective methods for welding traditional materials
	Make welding the preferred choice of manufacturers when materials are joined	Increase product design community's understanding of science of metallurgy, stimulate development of product designs and of new technologies and materials for welding, adapt certain alloys as weldable materials, increase access to information on welding's attributes
	Integrate welding into an automated, intelligent system by 2020	Integrate materials, processes, sensors and controls

(continued)

Table 5-1. Meeting the Strategic Targets of the Welding Industry by 2020

Strategic Targets (Industry Issues)	Objectives	Related Tasks
	Seek higher-performance materials	Develop long-lasting, reliable, corrosion-resistant materials that do not require pre-heating; make new materials and associated consumables accessible to various applications
V. Markets and Applications	Increase global markets for welding 25% by 2020	Capture the demand for aircraft construction for Asian markets; develop technology to ensure use of welds, not rivets, in airplanes; increase welding markets in auto and defense industries.
VI. Education and Training	Attract more people to the field of welding in the workplace and in academia	Significantly increase number of faculty and students in this discipline (>50%), double number of engineering programs focused on welding, substantially increase welding-related information in the manufacturing - engineering curriculum, increase number of apprentice programs for welders, keep present workers in welding community aware of state-of-the-art technologies and processes
	Train more specialists in fields related to welding	Provide knowledge of metallurgy and welding to materials scientists, mechanical and systems engineers, architect and product designers

(continued)

Table 5-1. Meeting the Strategic Targets of the Welding Industry by 2020

Strategic Targets (Industry Issues)	Objectives	Related Tasks
VII. Energy, Environment, Health and Safety	Reduce energy use in pre- and post-heating operations by 50%	Use advanced materials and processes in welding operations
	Make welded fabrications with a concern for the environment	Use "green" techniques throughout life cycle of welded products
		Use welding in producing energy-efficient and environmentally sound advanced technologies (e.g., fuel cells); develop methods for welding in hostile environments (e.g., in deep water on oil rigs, in Artic conditions)
	Ensure a safe and healthful working environment for workers	Continue industry's concern for health and safety issues; address potential hazards such as burns, welding fumes, excess noise, electric shock, falls

6

Key Competitive Challenges

In order to meet the ambitious "Strategic Targets" set forth in the previous section, the welding community must be able to hurdle certain barriers, or "Competitive Challenges," in the following areas: Materials, Manufacturing Integration, Workforce Integrity, and Quality.

Materials

As materials are developed with increased strength, corrosion resistance, and other performance factors, welding them can become more and more difficult. Special filler metals, pre- and post-weld heat treatment, and other techniques make welding feasible in many cases, but at substantially increased cost. The challenge is to make these materials as easy to join as simple carbon steels. By 2020, industry wants 95 percent of the materials commonly used today by manufacturers to have a corresponding alloy that can be welded. Advanced computational methods will be used to engineer materials that can be welded reliably and consistently.

Research will be needed on filler metals, along with pure metallurgical research, in order to understand the behavior of materials at the atomic level. For example, solutions must be found to overcome the mechanical degradation of aluminum alloys by the welding process. With a new level of understanding of metallurgy, the entire welding industry will benefit and progress.

Part of gaining this additional knowledge will be close monitoring of the various products that feed into welding operations. These include the base metal, any filler metals, and gases. Another challenge will be to ensure welds of dissimilar materials will be cosmetically acceptable to customers, as well as high in quality. The appearance of welds will be an ongoing consideration for some manufacturers.

Advances are needed in information technology in order to have “smart materials” ready for use in 2020. With computer chips embedded into the materials, there will be significant opportunities to program and control subsequent welding operations. This new technology will be exploited by product designers, manufacturers, and welders to improve the entire manufacturing cycle.

Product Design, Development and Manufacturing Integration

The “virtual factory” is a term that will be heard frequently over the next 20 years as computer modeling and simulation tools become commonplace in welding operations. Welding will move from being an “art” to being a manufacturing science with the help of computers.

The virtual factory will occur when welding technologists go outside the traditional scope of welding to better understand, control, and automate welding processes. Modeling will help workers predict when the welding process will be robust and the conditions under which it becomes distorted.

Designers will also contribute to the virtual factory. They are accustomed to using simulation tools in designing products and processes for manufacturers. These tools also allow welds to be modeled, and these models can then be integrated into more comprehensive informational systems used in manufacturing. By integrating welding operations with product design and other manufacturing steps, the welding stage will no longer be isolated from the entire manufacturing process. The image of joining as the weakest link in any product must disappear, as it becomes an important but routine step during manufacturing.

All manufacturers look for ways to improve their productivity, to get the product “out the door” faster, cheaper, and better. Manufacturing integration will help reduce the time required from concept to production. Among the techniques foreseen are integration of design, sensing, and process control, and development of modular processing equipment to ensure compatibility of various systems.

The Workforce

The attractiveness of welding as a vocation and engineering profession must be improved. Industry believes that success or failure in meeting this challenge will be important in determining how U.S. industry competes in world markets.

A workforce that is appropriately educated at all levels will drive a technological revolution in welding for this country. The prestige and promise of welding as a career will grow as welders are certified to guarantee their capabilities, and engineers gain greater appreciation of the potential use of welding.

Multi-disciplinary teams will provide a supply of necessary talents, from designer, to engineer, to operator, to welder. Workforce integration will see customers, manufacturers, educators, and possibly the government, collaborating and developing ideas for new products and new ways of using welding techniques. The communication among these various experts will be key in removing barriers to a smooth manufacturing operation. For example, with customers more knowledgeable and aware of the welding process, there will be greater participation by customers in new product development and in exploiting the potential of welding. Engineers who are working side-by-side with welding technologists will better understand the importance of their role in manufacturing. New welding-related knowledge must be widely disseminated among all interested parties, and a better educated workforce and the team approach in manufacturing will help meet this challenge.

The number of qualified workers is not increasing at the moment, and a key challenge is to reverse this trend and provide adequate human resources to meet the needs of tomorrow's welding industry. A stable and growing workforce will be needed in the new century.

Quality

Improvements in the quality and reliability of joints will help overcome the image problem of the welded joint as the weakest link in any structure. For the industry to move ahead, it must remove the perception of manufacturers, customers, and others that welding is a barrier to a smooth manufacturing process.

Another challenge is that academia typically does not accept primary metals and the primary production industries as worthwhile academic pursuits. Faculty and students are not entering the field, and academic expertise in these disciplines will eventually be non-existent. Again, a better understanding of the quality and usefulness of welded metal products will help overcome this negative perception. Processing research, artificial intelligence and robotics, advanced materials, and other developments outside the traditional scope of welding can all be applied to making dramatic improvements in welds.

The industry also sees a challenge in its inability to quantitatively predict distortion of materials due to welding. Research is needed to clarify this issue.

As the quality and reliability of welded products improve, their safety will also increase. There must be no opportunity for welded products to have a potentially negative impact on customers.

A

Attendees List

Name	Organization
Heavy Industry Group	
Pete Angelini	Oak Ridge National Laboratory
Dennis Blunier	Caterpillar, Inc.
William King	Pratt & Whitney
Lee Kvidahl	Ingalls Shipbuilding
Bill Myers	Dresser-Rand
William Owczarski	McDermott Technologies, Inc.
Richard Seif	Lincoln Electric
Herschel Smartt	INEEL
James Snyder	Bethlehem Steel
Krishna Verma	Federal Highway Administration (DOT)
Specialty Applications Group	
Frank Armao	Aluminum Company of America
Donald Bolstad	Lockheed Martin
Stan David	Oak Ridge National Laboratory
Glen Edwards	Colorado School of Mines
Stanley Ferree	ESAB Welding & Cutting Products
Karl Graff	Edison Welding Institute
James Jellison	Sandia National Laboratory
Sylvia Nasla	Trumpf, Inc.
Larry Perkins	Air Force Research Laboratory
John Phillips	Johnson Controls
Observers	
Shirley Bollinger	American Welding Society
Michael Cieslak	Sandia National Laboratories
Frank DeLaurier	American Welding Society
Richard French	American Welding Society
Charles Sorrell	U.S. Department of Energy

B

Key Drivers

Exhibit 1, Key Drivers That Will Shape Joining Needs Through 2020, appears on the following pages.

Exhibit 1. Key Drivers That Will Shape Joining Needs Through 2020

(• = Top Priority Category, o = High Priority Driver)

Design Issues	**Product/Process Integration** ••••	**Regulation, Certification, & Standards**	**Education/ Workforce/Image** ••••••••	**New & Existing Materials Development** •	**Information Technology** ••
Weld process modeling is non-existent today ooooo	Integration of sensing, process control, materials (more communication between parties) oooooo	Certification issues oo	De-emphasis on manufacturing careers in United States ooooooooo - lack of welding engineers - loss of corporate knowledge - lack of design engineers - lack of manufacturing engineers	Development of weldable materials ooo	Growth of information technologies (the Internet) oooooooooo
Design to process capability oo	Automation - avoid 3D's (dark dangerous, dirty) - no welders ooo	Environmental regulations o	Need for talented people - industry image discourages talented people oooo	New level of understanding in metallurgy (fundamental through applied) oo	Applying latest computer techniques to solve multi-attribute problems
Welding industry is forced to wait for material - joining must be considered in design	Integration of inspection and welding in the same process oo	International standards o	Absence of adequate apprenticeship programs for welders	Filler metal developments o	Life-cycle cost models to predict welding costs up front versus other options
Ability to predict design allowables	Ability to fully simulate welding manufacturing oo	Code development - increases acceptability limitations to new/existing joining methods - centralized control of specifications	Loss of faculty in primary metal industries	Purity of products (gases, filler wires, weld and ability to monitor purity)	**Safety & Health**
Designers will need knowledge bases to support simulations	Linkage of welding throughout whole manufacturing process o	Product liability	Welding is still seen as a problem in manufacturing - not a science	Smart materials by embedment	Safety of products in terms of how they impact their customers
	Incorporate welding processes into agile manufacturing work cells - embed weld technology o	Intellectual property issues - as relates to CRADAs	Public awareness of strategic need for welding	Development of materials to reduce energy requirements - preheating and post-heating	Processes that are more friendly to factory workers (noise, heat, etc.)
	In-processing monitoring and control o				
	Computerized automation from design to fabrication				
	More efficient designs; need to design from welding stand point, not just structural				

Exhibit 1. Key Drivers That Will Shape Joining Needs Through 2020

(• = Top Priority Category, o = High Priority Driver)

Joining Technology & Processes •	**Markets & Customers** ••••••••••••••		**Quality Reliability & Serviceability**	**Business & Practices Economics** ••••
Advanced weld-repair technology oo Reproducible, proven techniques Modularize various aspects of technology Joining of advanced materials - ceramics - inter-metallics - non-traditional materials and combinations metal matrix composites Micro-joining (nano technology) Need something between bench top and full commercialization - test bed experiment, prototype Simple, easy to use embedded technology New ways of looking at existing applications (new fillers, etc.) Availability of equipment that can prohibit cracked weld Need to eliminate deformation in metal Difficulty welding in the field (difficult ambient surroundings) - hostile environments Need to understand and control distortion in welds for high quality/low costs	Globalization of business and markets ooooooo - increased foreign competition Competition with alternative processes ooooo - net shape processes - deposition processes - adhesive technology - hybrid processes - joining and alternative processes Developments in transportation industry and infrastructure oo - new infrastructure for underdeveloped countries - aging U.S. infrastructure Customer specific fabrications oo Changing government defense needs o New energy requirements (different systems and fabrication methods) o Supplier alliances o Just-in-time and customization will drive small-lot manufacturing o Customers need to monitor the integrity of fabricated products	Design for reuse Medical needs will create new joining opportunities - implants, biocompatible Current revolution in industrial distribution - real-time distribution - storage requirements for adhesives Competing technologies could result in parts consolidation Markets must respond quickly to necessities of society - industries/products will emerge to support retired baby boomers	Product performance, endurance, and lifetime (repair ability) ooo - accuracy of predictions - joints are seen as weak link in structures Movement to 6-sigma quality oo Inadequate NDE will restrict advancement oo Using lessons from failures (fatigue, seismic erosion) for improving design o Prediction of welds and weld systems performance o Robustness in weld equipment (make it right the first time) Reliability of welding systems Drive to aesthetics (quality) Cosmetics of dissimilar welds (e.g., Al to steel) Capability to model and analyze joints	Productivity pressures for improvement (faster, cheaper, better) oooo Funding availability oo Distributed manufacturing (isolates welding engineers) oo Corporate consolidations (loss of welding expertise) oo Virtual/integrated manufacturing o Move toward shorter work weeks Effective affiliation of government, industry and academia Shrinking workforce Better communications between customers and manufacturing Compressing time from day of design to start of production Labor costs Cost of capital equipment Return on assets - must see return for stockholders High enough investment early enough in process to get high return on investment Improved energy efficiency Tax policy and its effect on how companies invest