Roadmap for Accelerating Production of Large Structures and Systems (RAPLSS)

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Preface

Who Should Read This Report?

This report contains useful technical, high-level market, and economic information related to the fields of large structure and system fabrication within the U.S. manufacturing base. Individuals across academic, industrial, and government sectors who are engaged in the development, use, or management of the relevant technical disciplines and those engaged in establishing public policy will find this report useful. This report will also benefit individuals who seek meaningful context and need to understand the interplay between technology and business forces in manufacturing. Furthermore, success in addressing the gaps and needs discussed herein will require the collaboration of this wide array of stakeholders.

This report does not provide deep technical descriptions or analyses of the current state of the art in large structure and system fabrication. Instead, the report outlines the technical needs and technology development priorities in general terms. Readers can understand the current and desired future states for these critical manufacturing technologies. Readers should also appreciate the necessary actions needed to secure and maintain a global leadership position in manufacturing innovation. Technical and non-technical readers alike will gain useful insight from this report.

Acknowledgements

Funding

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Steering Committee

The authors acknowledge and thank the experts who participated on the project steering committee that supported the EWI team with their valuable time, guidance, and insight. They participated in and helped initiate many of the industry canvassing efforts. The findings and recommendations in this report have a foundation based on the insightful input of the steering committee whose contributions cannot be overstated.

Table 1. Members of the Steering Committee

Company	Point of Contact
Banker Steel	Kris Krone
Insyte Consulting	Ben Rand
America Makes	Brandon Ribic
EPRI	Dave Gandy
ATI	Mark Smitherman
SFSA	Raymond Monroe
BP International Ltd.	Charlie Ribardo
Komatsu	Ryan Cross
Caterpillar	Don Stickel
Arcelor Mittal	Murali Manohar
Cloos	Doug Zoller
Visioneering	Ray Kauffmann
Army ERDC	Larry Lynch
ORNL	Lonnie Love
AWS	Peter Portela
AWS	Mario Diaz
GE Power	Attila Szabo
IPG	Dmitri Novikov
Haynes International Inc.	Brett Tossey
Evraz North America	Muhammad Arafin

Industrial Contributions

This roadmap was not possible without the voluntary contributions and input from hundreds of technical and managerial professionals from industry who participated in one or more focus group meetings or responded to surveys. Their efforts in identifying needs in industry and the technical gaps that impede competitiveness were crucial to the final prioritization of roadmap objectives presented in this document. In all, 101 companies participated in the industry canvassing activities carried out over a two-year period. These participants are employed across all of the major industrial sectors of the U.S. economy and span the geographical reach of the country. Their collective view represents the consensus perspective on what technical priorities will most improve U.S. capacity for rapid construction of large structures and systems. The authors are grateful and indebted to those individuals who invested their time to support this roadmap initiative and who shared their insightful views on the state of manufacturing in the United States.

Disclaimer

The conclusions and recommendations in this document represent a collective view and do not necessarily represent the specific views of any individual member of the steering committee or individuals who participated in focus group sessions or industry surveys or of their employers or affiliated organizations.

Executive Summary

Motivation for This Roadmap

Large structure production combines supply chains, component manufacturing, sub-assembly fabrication, and large structure fabrication and erection processes. Typically, dedicated facilities are needed that are tailored to each large structure industry. For this report, the large structure and systems industries include the following industry segments and were grouped based on shared fabrication technologies:

- Offshore Wind / Maritime (port facilities, transportation and erection vessels) / Shipbuilding
- Hydrogen / Carbon Capture and Utilization and Storage (CCUS) / Petro-chemical / Refining
- Nuclear energy
- Primary Metals (i.e., large plate, beams, pipe, castings, forgings)
- Mega Building / Bridges
- Rail and Mass Transportation

America's ability to manufacture large structures affordably has diminished in recent decades. There is a true lack of production capacity for materials such as large plates, beams, pipes, castings and forgings, and dedicated state-of-the-art sub-assembly facilities to meet competitive market conditions. Most importantly, there is a shortage of trained, highly skilled workers. Large structure and systems industries support the nation's energy, transportation, and supply chain needs. Consequently, this roadmap initiative is focused on accelerating production of large structures and systems. The roadmap is specifically focused on improving the affordability and the schedule of the Build Back Better legislation investments of 2022 to create and grow manufacturing jobs in clean transportation infrastructure, clean water infrastructure, clean power infrastructure, remediation of legacy pollution, and resilience to the changing climate.

Based on industry research, these emerging American industries need Large Structure Production 4.0 technologies to be competitive and establish world-leading capabilities. Like Industry 4.0, Large Structure Production 4.0 (Figure 1) is about seamless connection between the digital and real world with a focus on developing, manufacturing, fabricating, and sustaining large structures and systems. It includes the integration of advanced materials and processes, robotics, internet of things (IoT), data science, artificial intelligence (AI), ubiquitous sensing, 5G, digital twin and simulation, and 3D printing/additive manufacturing (AM) but with a focus on the development of large-scale additive manufacturing, intelligent forming and joining processes, fieldable thermal and cold spray coating processes, advanced and remote robotics, in-situ intelligent inspection systems, and new training programs to prepare workers to use such technologies. Large structure manufacturers also need healthy supply chains including castings, forgings, and critical raw materials. The most common theme in every large structure industry segment engagement is the demand for highly skilled workers.

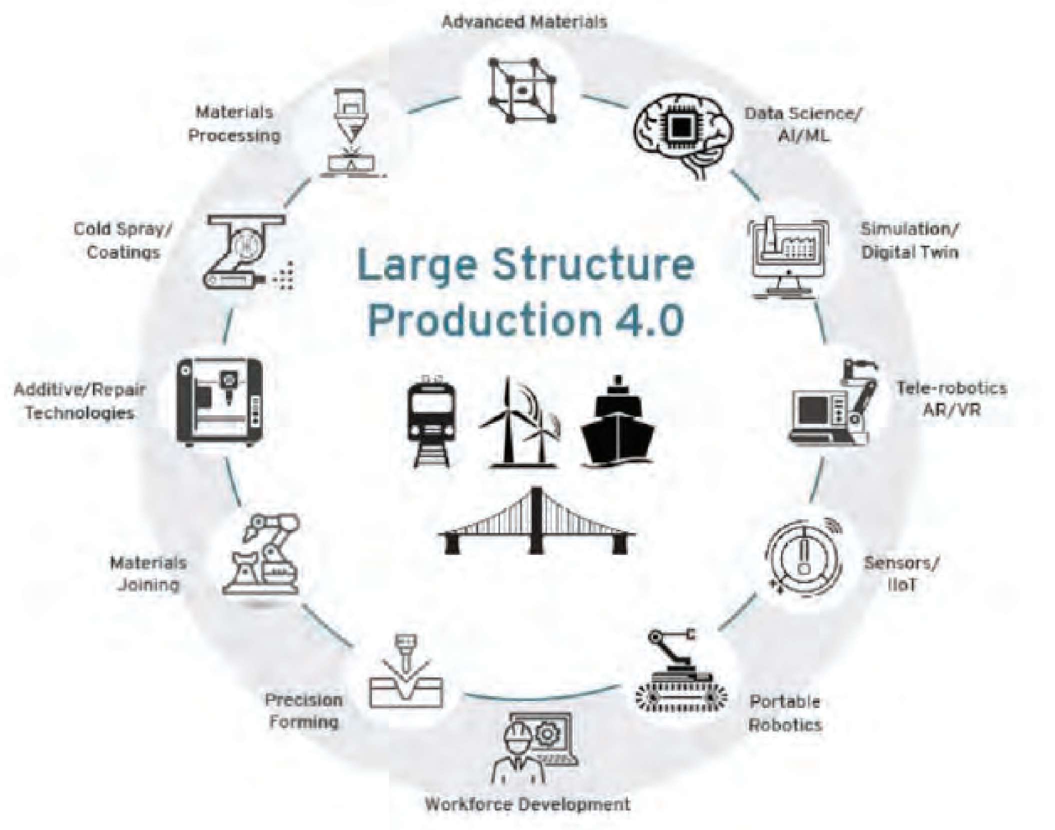

Figure 1. Large Structure Production 4.0 Technology Integrates Significant Industry 4.0 Technologies

Other regions of the world have recognized the importance of large-structure production technologies and are investing in research and development. The United States risks falling behind in the development of Large Structure Production 4.0 solutions for producing clean transportation infrastructure, clean water infrastructure, and clean power infrastructure. Workers in these industries need interdisciplinary skills in these technologies to ensure American competitiveness.

Process

EWI and The Ohio State University (OSU) Materials Science & Engineering (MSE) department have teamed up to lead this roadmap development. Both EWI and OSU are actively leading national industry consortia that need support with transformational business plans to lead production of better bridges, electric vehicle infrastructure, wind towers, next-generation nuclear plants, clean mechanical and chemical facilities, hydrogen pipelines and systems, advanced freight and high-speed passenger rail, subsea structures, shipbuilding, heavy manufacturing, and other large-scale structures and systems. For example, EWI has been a leader in shipbuilding technology since its founding in 1985. This industry needs tailored automation solutions such as tele-welding, which combines remote robotics with IoT technology to enable haptic control of remote robotic welding to accommodate welder labor shortages. Remote robotics and tele-welding are especially needed for dangerous fabrication conditions like inside ship double-hull inner bottoms or on elevated wind towers. The offshore wind industry faces even greater challenges to set up coastal production facilities and install these large structures. Large structure production requires unique solutions for advanced materials including castings and forgings, large-scale additive manufacturing, large section forming, joining and welding large components, thermal and cold spraying surface coatings, fabricating final structures, and sustaining these structures. Large Structure Production 4.0 allows the manufacturing and production of these structures in a more flexible, energy-efficient, resource-saving, industry-specific, and lower-cost manner.

This project developed the first comprehensive U.S. Roadmap for Accelerating Production of Large Structures and Systems (RAPLSS). The roadmap project was structured to meet the NIST Advanced Manufacturing Technology Roadmap objectives by:

- Creating a consortium of the leading U.S. materials, additive manufacturing, forming, joining, cold spray, automation and robotics organizations to engage industry, academia, and other stakeholders
- Identifying and ranking the current large structure production challenges of these emerging U.S. manufacturing industries
- Prioritizing research and development (R&D) topics that will create differentiating competitive advantages and produce substantive national impacts.

By leveraging existing funding sources, Manufacturing USA institutes and regional economic development structures can leverage the roadmap priorities here and develop and implement solutions across businesses of all sizes.

A steering committee was established to guide the roadmap development. This committee enlisted participation from a wide range of stakeholders. It interpreted the collected data and helped disseminate the roadmap results. The stakeholders have an ongoing commitment to encourage the development of solutions. The steering committee had representatives from industry and the leading materials manufacturing and fabrication organizations and included technology industry leaders for advanced materials (Ray Monroe, Steel Founders Society of America, and Brett Tossey, Haynes International); additive manufacturing (Brandon Ribic, America Makes); materials joining (Peter Portela and Mario Diaz, American Welding Society); large structure welding robotics (Doug Zoller, Cloos Robotics); and laser material processing (Dmitri Novikov, IPG). The steering committee also included large structure industry leaders for advanced energy and chemical (David Gandy, Energy Power Research Institute); Attila Szabo, GE Power; Lonnie Love, Oak Ridge National Lab (ORNL); Charlie Ribardo, BP International);

marine transportation and shipbuilding (Mark Smitherman, ATI – National Shipbuilding Research Program); and large fabrication construction equipment (Don Stickel, Caterpillar, and Ryan Cross, Komatsu) to name a few.

A broad range of industry representatives and researchers were engaged to identify critical needs, which were successively refined and focused down to more detailed concepts with an analysis of proposed solutions. Data collection involved a state-of-the-art review of global technology trends and hosting a series of expert focus group exercises, conducting surveys and interviews, soliciting requests for technology development ideas and analysis of potential solutions, and concluding a national conference/workshop. The resultant roadmap presented here identifies technology priorities and aligns U.S. stakeholders from industry, academia, professional societies, nonprofit research centers, technology providers, and regional economic development authorities around a common vision to develop innovative technology solutions to the nation's most important large structure production challenges.

LSS Challenges by Industry

U.S. offshore wind (OW) is the best example of an industry aligned with the large structure focus of RAPLSS. Offshore wind depends on the fabrication of monopiles, jackets, towers, and floating platforms. Hundreds are needed within the next few years and thousands within a decade. There are many opportunities in the areas of automation, sensors, high-rate welding, and fast and accurate nondestructive evaluation (NDE). Due to a U.S. law called the Jones Act, the OW industry will need dozens, if not hundreds, of new ships, and this is causing a resurgence in the U.S. shipbuilding industry. Shipbuilding can use many Industry 4.0 technologies including simulation and modeling, sensors, smart machines, and automation. In 2023, the OW industry experienced economic problems. Projects were canceled, but new leases have been announced. OW needs cost reductions, and heavy fabrication is an opportunity for RAPLSS because it accounts for ~35% of wind farm capital costs. Currently, the need for large structures in the U.S. OW industry exceeds the capacity. U.S. projects are sourcing millions of tonnes of structures from Europe. U.S. industry is failing to capture the available large structure opportunities, and increased funding/facilitation to reverse this trend is needed. As noted above related to OW, the growth of staff and capabilities for the shipbuilding and ship operating industries in the United States is needed.

The hydrogen industry for energy is still developing, but like the oil and gas energy industry, it needs long-distance networks and many individual pressure containers built to standards and specifications. Many of the large systems and structures approaches from the oil and gas industry transfer along with contracting approaches and multiple stakeholders. CCUS will also need a piping network. Both hydrogen and CCUS will need connection standards to the affected equipment whether upstream (an electrolyzer or a cement factory) or downstream (an industrial hydrogen fuel user or a storage well). Two specific ideas for improving fluid energy system construction include using sensors and AI to improve efficiency when welding pipelines, pipes, pipe fittings, and vessel connection flanges.

Of the nuclear industry documents reviewed, most are focused on advanced reactors (ARs) which operate at high temperatures and involve unique corrosive fluids. These severe conditions motivate the need for new reactor materials and joining methods. Due to the time-dependent degradation mechanisms within reactors, AR developments can use material performance models capable of virtual test acceleration (time-dependent digital twins). Another need is to develop in-situ monitoring technologies (sensors) that provide feedback on material health. Problems can be identified in time for remediation. The nuclear industry will consider large-scale demonstrations to vet new technology and to align stakeholders. These demonstrations, however, can be prohibitive from the standpoint of time and cost. A potential compromise is to scale down the scope of demonstrations or to rely on simulative technologies. Some stakeholders may balk at these approaches. Demonstrations are a primary challenge for AR developments. Several nuclear-related documents and the castings and forgings industry (C&F) have identified large-format hot isostatic pressing (HIP) and the powder metallurgy option (PM-HIP) in particular as very useful for advanced manufacturing.

Castings and forgings (C&F) are used by all RAPLSS-type industries that fabricate large structures and systems. In recent decades, the C&F industry has experienced many plant closures. The top challenges for the C&F industry were identified as inadequate workforce and capital investment in technology, equipment, and automation. The main focus of the C&F documents reviewed was this industry's interaction with the Department of Defense (DOD). Detailed examples were given with the conclusion being that the "DOD is a difficult customer to serve."

The more general primary metals industry is less dependent upon one source of revenue than just indicated for C&F, but it is quite dependent upon enormous amounts of capital with long time horizons to payback.

Mega building and bridges (MBB) have moved down the path of the rail industry toward modular segmented pieces that can be put together reliably to make the structures and systems. From an Industry 4.0 perspective, the industry can use both situational awareness for the jobsite and improved local automation to allow specialized segments to be made with automation in a remote factor.

The main rail and mass transportation industry topics of interest aligned to RAPLSS are location situation awareness, inspection technologies, digital simulation, management of big data, and cybersecurity. Inspection technologies include ultrasonics, eddy current, non-contact vibration analysis, rail surface imaging, and flaw characterization. A rail industry workshop on alternative fuels identified diesel-battery hybrid technology as promising in the near term and hydrogen as the priority for the long term. Although liquified natural gas (LNG) has been studied and deemed successful as a rail fuel, hydrogen is believed to be a better choice.

General supply industries were the most numerous among survey participants. This shows the large number of interested parties related to large structure and system production.

For large projects, oil and gas (O&G) companies hire engineering, procurement, and construction (EPC) companies. They also hire specialized construction companies and may hire independent inspection companies. Imitating this in other industries may be both desirable and difficult since the immediate profit potential and payback through the project life are less assured in other LSS industries.

There are shortages of welders, machinists, and inspectors in the United States. These skilled positions are needed to prepare metal components, join them together, and then ensure their quality. Virtual and augmented reality offers the potential to attract and train these types of positions more quickly. Virtual welder training, for example, is now widely used at technical schools to prepare and recruit individuals into welding and to help develop motor skills for process control. Another high potential technology is tele-manufacturing. Here, vision sensors are combined with process monitoring and haptic controls to enable operator-supervised controlled welding, cutting, and inspection using portable robotics. Tele-manufacturing will be combined with augmented reality in the future to support in-situ precision fabrication remotely using portable robotics. These technologies help fill critical needs but require ongoing investments to develop the technology for production to large structure and systems.

Roadmap Priorities by Industry Segments

<u>Offshore Wind / Maritime (port facilities, transportation, and erection vessels) / Shipbuilding</u>

- Workforce readiness is a critical item holding back the industry's production capability.
- Supply chain readiness is also critical and includes:
    - Heavy fabrication capacity/facilities
    - Offshore installation and support vessels
    - Domestic shipyard capacity
    - Shipyard supply chain inputs – plate, welding systems, hardware
- Heavy steel plate industrial base

<u>Hydrogen / Carbon Capture and Utilization and Storage (CCUS) / Petro-chemical / Refining</u>

- Many of the capabilities for building large systems are in place.
- Incentives for permits to counter localities' objections to routing or locating infrastructure.

- New standards are needed to determine what to build for hydrogen production and CCUS.
- Connections to new pieces of physical plant
    - Electrolyzers
    - Pyrolysis
    - CCUS units at concrete manufacturers
- Automation of NDE and fit-up for pipe girth welds are opportunities.
- Prediction tools for life assessment.

Nuclear energy

- Advanced materials as a capability limitation in energy systems
    - Integrated materials computational engineering ecosystem to accelerate new material design, qualification, and implementation
- Optimization for module fabrication versus expense of site work
- Incentives for SMR (small modular reactors) demand to drive affordability
    - Provide clean base load versus other green alternatives
- Mega Hot Isostatic Pressing (Mega-HIP) for complex reactor head production in lieu of forgings and welding complex assemblies
- High productivity electron beam narrow groove vessel joining capabilities
- Regulatory approval for in-process and in-situ monitoring from NDE after production

Primary Metals (large plate, beams, pipe, castings, forgings)

- New standards as casting suppliers are using outdated standards
    - Example: government purchasers particularly are still using requirements for film radiography.
- Incentives to invest in large capital expenditure (CAPEX) capabilities
    - Large forging and casting facilities near point of need
- What is large in tonnage?
    - Nuclear: tens of tons (high-ton plate and forgings sections, low volume)
    - Wind Structures: high-volume, thick, wide, and long plate thick sections. Also, thick forged rings and high-volume plate welding assembly
    - Shipbuilding: high-volume, high-strength steel plate and beams, nonferrous castings for ship systems, marine-grade aluminum alloys)

Mega Building / Bridges

- Modular approaches, providing pieces that can be shipped to the job site
- Planning software that accommodates site limits

Rail and Mass Transportation

- Flexible personnel – need to be at many locations for limited time-periods, which is difficult when the workforce is limited
- Automated inspection is an opportunity area
- Hydrogen is a future fuel opportunity for rail

Summary of Existing Gaps and Crosscutting Technology Solutions

The most common topic across all industry sectors was workforce challenges. There is a shortage of workers for technical positions and in the skilled trades. The biggest need is for workers in industrial settings and for the training of these workers. Industries like maritime and advanced materials — especially castings and forging sub-segments — noted limited capability to hire even for non-skilled positions. In 2023, an issue aggravating employment is competition as construction segments were strong across the U.S. and overall un-employment was low. Skilled construction workers can quickly find good employment and may not be attracted to LSS industries positions. Many entry-level workers do not understand there are major opportunities for those who enter the LLS industries. Capable entry-level workers and professionals will find near-term advancement opportunities to replace a range of manager and senior-level workers who are retiring. Compared to other industries such as automotive and information technology that no longer show rapid promotion and employment growth and are more cyclic, large structure industries offer a range of work-based learning models and apprenticeships (iron workers, boilermakers, pipefitters, etc.) that build skills quickly. In conjunction with retirement, employers also complained about “brain-drain” as senior-level employees retire too fast for succession planning and replacement training.

Public perception is that manufacturing jobs are dark, dirty, dangerous, and dying (called the 4Ds). The first three of these Ds are true for many facilities that build large structures or their components. This is especially true for advanced material mills and foundries that need cutters and grinders to post-process raw materials and castings. One approach for recruiting is to find individuals from communities that are less likely to recoil from the 3Ds, such as farming and rural communities, and to determine how to recruit/train them. One tactic to improve recruiting is to embrace automation, which changes the skilled workers’ conditions to clean, cool, and high-tech. Virtual and augmented reality offers the potential to attract and train these types of positions faster. As an example, virtual welder training is now widely used at technical schools to prepare and recruit individuals into welding and helps develop motor skills for process control. Another high potential technology is tele-manufacturing (Figure 2). Here, vision sensors are combined with process monitoring and haptic controls to enable operator-supervised controlled welding, cutting, and inspection using portable robotics. Tele-manufacturing will be combined with augmented reality in the future to support in-situ precision fabrication remotely using portable robotics. These technologies help fill critical needs and require ongoing investments to change the image of and technology for production to large structure and systems.

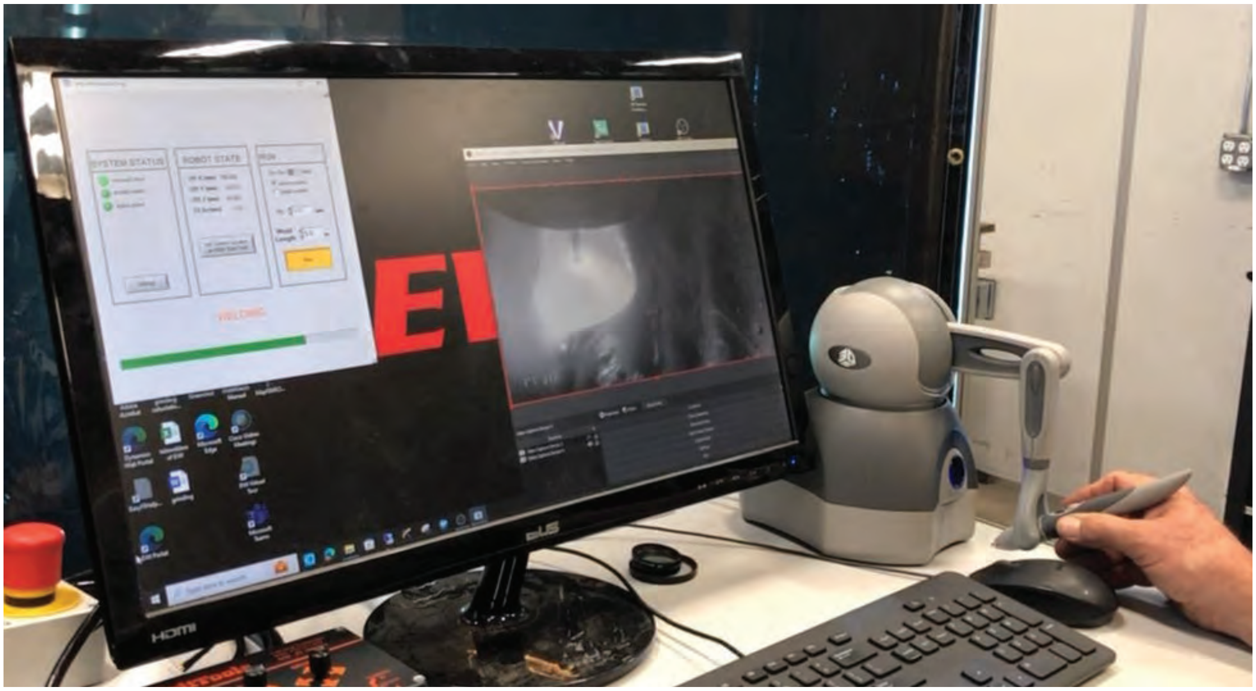

Figure 2. Tele-manufacturing Technologies that can Impact LLS Production

Understanding technologies useful for LSS means noting the size/scale of large structure operations where annual production can range from a few units to a few hundred units. LSS companies will have less need for the internet of things and edge computing in the construction phase but have a greater need during plant operation and sustainment for structure and system health monitoring. In the fabrication and construction phase, there is a greater need for smart machines, sensors, digital twins, and simulation modeling including 3D visualization tools to make sure the configuration of LSS components are right the first time. A rule cited when talking to LSS fabricators is what costs X dollars in the shop for traditional manufacturing processes, is probably 5X dollars in the yard where subassemblies are configured and outfitted, and approaches 9X+ dollars in the erection environment where workers must safely work on scaffolding, off booms, and suspended cables to fabricate tall, large structures. The ability to build structures using the concept of “neat” construction, which is a shipbuilding term, offers huge cost reductions during the erection phase. Neat construction assumes that the manufacturing through the erection process is modeled to account for all major variations (like weld shrinkage and/or material structure growth via sun-heating thermal expansion) is accounted for, so piece-by-piece material cutting and erection, also called stick-building, is minimized.

Smart sensors that improve the dimensional accuracy of sub-component manufacturing and assembly fabrication are important Industry 4.0 technologies for large structures. They can improve welding fit-up, identify sub-components needing rework or rejection, provide warnings to the operator, and notify upstream processes (cutting, machining) that are causing the problem.

For fabrication of LSS, multi-process digital manufacturing systems are needed that maximize the use of automation while minimize programming costs for a wide range of metalworking processes including machining, forming, welding, spray coatings, and NDE to name a few. Robotic computer-aided manufacturing (CAM) tools allow rapid computer-aided design (CAD) to path programming for high mix low volume production of large structures and systems. An emerging need is informatics that can drive digital manufacturing workflows between digital manufacturing processes.

Directed energy deposition (DED) processes are digitally controlled deposition processes (arc, laser, and electron beam welding-based) that can be used for welding, cladding, additive manufacturing, and repairing LLS components. Here commercial automated or robotic welding systems are converted into DED by developing a digital twin of the machine and a material deposition model for a range of structural features. DED CAM software tools for welding-based deposition processes are growing rapidly and bring unique large-format capabilities for augmenting gaps in casting and forging supply chains. Thermal spray and cold spray DED technology is emerging and offers precise and affordable control of expensive corrosion, thermal barrier, and/or wear-resistant surfaces. In addition, cold spray DED processes are being developed for structural repairs of advanced materials with minimal side effects, such as residual stresses and heat-affected zones to the structure that limit the use of welding-based repairs on heat sensitive components.

Convergent manufacturing is a new digital manufacturing term that is synonymous with intelligent multi-process digital manufacturing systems. It creates a platform for extending the digital thread, minimizing programming costs, and ensuring first-time quality for high mix LSS fabrications. For example, a convergent manufacturing technology could be used for automated inspection and repair of in-service LSS components. A multi-process robotic system could be used to inspect, identify unacceptable flaws, remove flaw for repair welding, repair component using DED, finish grind weld repair area, and then perform final NDE to certify integrity for service. To perform convergent manufacturing workflows, digital twins are needed for each machine and process, and informatics are needed to drive the multi-process data workflow.

Many industries are developing models and digital applications so they can automate the most difficult welding challenges in module building and leave the more standard welding to field erection. This is similar to the role that the use of interchangeable parts in the nineteenth century played in increasing and simplifying industrial production of complicated devices.

Depending on the LSS segment, use of digital manufacturing models and CAM tools are further advanced in some areas than in others.

Cybersecurity is vital for industrial operations because of the ubiquitous use of computerized control and data/information storage. Many manufacturing companies are small and medium-sized (SMMs) businesses that may not have the resources to maintain the latest in cybersecurity technology. The Presidential Executive Order 14028 and additional activity at NIST pertain to cybersecurity.[(1), (2), (3)] Both the roadmaps reviewed and interviews conducted brought up the need for government help in cybersecurity.

Collaboration is a 4.0 principle that can improve industry resilience, but the RAPLSS community must address the challenge of competitors that are reluctant to interact for fears of exposing proprietary data, information, and intellectual property. LSS industries are not led by original equipment manufacturers (OEMs), such as in automotive or aerospace industries, so no one company has vertical control of the specific design-manufacturing-supply chain. Those who are reluctant to collaborate may be right to avoid loss of market share. Standards and specifications may be the best format for communications to define the requirements for new materials and processes and to avoid exposure of form and function of their particular industry structure and system capabilities. New standards and specifications are needed to expedite fabrication for large structures and systems for the energy segments (hydrogen, wind, CCUS, nuclear) in particular.

The chicken-and-egg problem is a common scenario. It happens when a business might attract orders by investing in new technology, but the cost is too high without the orders being placed first. Customers are interested in placing orders, but only if the new technology is in place. When large structures are involved, the cost can be tens, if not hundreds, of millions of dollars. A useful role for the RAPLSS effort is to identify improvements or solutions to these challenges, which can be implemented for the most important cases.

The mature LSS industries (buildings, bridges, and transportation) have a more mature and standard logistic and infrastructure capability with individual and mobile on-location fabrication activities. The offshore wind, hydrogen, and advanced nuclear reactor segments need to move in this direction. This leaves opportunities for fabrication of more complicated configurations to be standardized in factory settings and for on-site fabrication to use more standardized support services, such as for fit-up and NDE. There are many opportunities in the areas of automation, sensors, high-rate welding, and fast and accurate NDE.

Abbreviated Terms

AES	Advanced Energy Systems
AHHS	advanced high strength steels
AI	artificial intelligence
AM	additive manufacturing
AM3	advanced manufacturing methods and materials
AMMT	advanced materials and manufacturing technologies
AMTech	Advanced Manufacturing Technology Consortia
ANLWR	advanced non-light water reactor
AOD	argon oxygen decarburization
API	American Petroleum Institute
AR	advanced reactor
ATGM	autonomous track geometry measurement
AWS	American Welding Society
BNSF	Burlington Northern Santa Fe
C&F	castings and forgings
CAD	computer-aided design
CAM	computer-aided manufacturing
CAPEX	capital expenditures
CCS	carbon capture and storage
CCUS	carbon capture and utilization and storage
CMC	ceramic-matrix composite
CNG	compressed natural gas
CTE	career and technical education
CUI	controlled unclassified information
DED	directed energy deposition
DLA	Defense Logistics Agency
DLC	diode laser cladding
DOD	Department of Defense
DOT	Department of Transportation
DTIC	Defense Technical Information Center
EBW	electron beam welding

Abbreviated Terms
(continued)

ECA	engineering critical assessment
EPC	engineering, procurement, and construction
EPRI	Energy Power Research Institute
ET	eddy-current testing
EV	electric vehicle
FFP	fitness for purpose
FRA	Federal Rail Administration
GHG	greenhouse gas
GOCO	government-owned, contractor-operated
HIP	hot isostatic pressing
HTGR	high-temperature gas-cooled reactors
HY	high-yield
IOT	internet of things
IRA	Inflation Reduction Act
ITAR	international traffic in arms regulation
LCOE	levelized cost of energy
LNG	liquefied natural gas
LRF	lead-cooled fast reactors
LSS	large structure and system
LWR	light water reactors
MBB	mega building and bridges
ML	machine learning
MMC	metal-matrix composites
MP	monopile
MRL	manufacturing readiness level
MSE	Materials Science and Engineering
MSR	molten salt reactors
NDE	nondestructive examination
NIST	National Institute of Standards and Technology
NSRP	National Shipbuilding Research Program
NTSB	National Transportation Safety Board

Abbreviated Terms
(continued)

O&G	oil and gas
ODS	oxygen dispersion strengthened
OEM	original equipment manufacturer
ORNL	Oak Ridge National Laboratory
OSU	The Ohio State University
OW	offshore wind
PB-AM	powder bed additive manufacturing
PCM	polymer-matrix composites
PM-HIP	powder metallurgy-hot isostatic pressing
PRCI	Pipeline Research Council International
PTC	positive train control
QNDT	quantitative nondestructive testing
RAPLSS	Roadmap for Accelerating Production of Large Structures and Systems
RD&T	research, development, and technology
SBIR	Small Business Innovation Research
SFR	sodium-cooled fast reactors
SFSA	Steel Founders Society of America
SME	small and medium enterprises
SMM	small and medium-sized businesses
SMR	small modular reactor
SPI	Steel Performance Initiative
SRM	safety risk model
STEM	science, technology, engineering, and mathematics
STTR	Small Business Technology Transfer
TRL	technology readiness level
TTC	Transportation Technology Center
UT	ultrasonic testing

1.0 Introduction

This project developed the first comprehensive U.S. Roadmap for Production of Large Structures and Systems (RAPLSS). This roadmap met the NIST Advanced Manufacturing USA Technology Roadmap objectives by:

- Creating a consortium of the leading U.S. materials, additive manufacturing, joining, forming, cold spray, automation, and robotics organizations to engage industry, academia, and other stakeholders.
- Identifying and ranking the current large structure production challenges of these new U.S. infrastructure production industries.
- Identifying Industry 4.0 technology challenges that need to be solved to create Large Structure Production 4.0 industry capabilities to accelerate production and advance the manufacturing workforce.
- Prioritizing research and development topics that will create differentiating competitive advantages and produce substantive national impacts.
- Leveraging existing funding sources, Manufacturing USA institutes, and regional economic development structures to begin to develop and implement solutions across businesses.

2.0 Scope

Large structure production combines supply chains, component manufacturing, sub-assembly fabrication, and large structure fabrication and erection processes. Typically, dedicated facilities are needed that are tailored to each large structure industry. For this report, the large structure and systems (LSS) industries include the following industry segments and were grouped based on shared fabrication technologies:

- Offshore Wind / Maritime (port facilities, transportation and erection vessels) / Shipbuilding
- Hydrogen / Carbon Capture and Utilization and Storage (CCUS) / Petro-chemical / Refining
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- Primary Metals (large plate, beams, pipe, castings, forgings)
- Mega Building / Bridges
- Rail and Mass Transportation

America's ability to manufacture large structure affordably has diminished in recent decades. There is a significant lack of production capacity for materials such as large plate, beams, pipe, castings and forgings, dedicated state-of-the-art sub-assembly facilities to meet competitive market conditions, and, most importantly, a trained highly skilled workforce. Large structure and systems industries support the nation's energy, transportation, and supply chain needs. Consequently, this roadmap initiative is focused on accelerating the production of large structures and systems. The roadmap is specifically focused on improving affordability and the schedule of the Build Back Better legislation of 2022 plan investments to create and grow manufacturing jobs in clean transportation infrastructure, clean water infrastructure, clean power infrastructure, remediation of legacy pollution, and resilience to the changing climate.

The Build Back Better Plan makes transformational and historic investments in clean transportation infrastructure, clean water infrastructure, universal broadband infrastructure, clean power infrastructure, remediation of legacy pollution, and resilience to the changing climate. Large structures and systems that need production innovation include:

- Modernizing and expanding transit and rail networks across the country
- Repairing and rebuilding roads and bridges
- National network of electric vehicle (EV) chargers
- Replacement of the nation's lead service lines and pipes to deliver clean drinking water
- Upgraded power infrastructure to facilitate the expansion of renewable energy, such as offshore wind, hydrogen pipelines, and next-generation nuclear power.

These and the other large structure production industries (shipbuilding, heavy manufacturing, chemical and mechanical processing facilities, etc.) are facing labor and talent shortages and need automated and intelligent processes to support production.

Based on industry research, these emerging American industries need Large Structure Production 4.0 technologies to be competitive and establish world-leading capabilities. Like Industry 4.0, Large Structure Production 4.0 (Figure 1) is about seamless connection between the digital and real world with a focus on developing, manufacturing, fabricating, and sustaining large structures and systems. It includes the integration of advanced materials and processes, robotics, internet of things (IoT), data science, artificial intelligence (AI) ubiquitous sensing, 5G, digital twin and simulation, and 3D printing/additive manufacturing (AM) to accelerate production of large structures. Large Structure Production 4.0 focuses on development of large-scale additive manufacturing, intelligent forming and joining processes, advanced thermal and cold spray of surfaces, advanced and remote robotics, in-situ intelligent inspection systems, and new training programs (to name a few) to prepare workers to use such technologies.

Other regions of the world have recognized the importance of large structure production technologies and are investing in research and development. For example, the United States is the sixth-most expensive country in the world for building rapid-rail transit infrastructure, and research by the New York Federal Reserve Bank and Brown University reveals that the cost to construct a "lane mile interstate increased five-fold" between 1990 and 2008.

The United States risks falling behind in the development of Large Structure Production 4.0 solutions for producing clean transportation infrastructure, clean water infrastructure, and clean power infrastructure. There is a great need for the U.S. Roadmap for Accelerating Production of Large Structures and Systems (RAPLSS) that identifies challenges, not solutions, and the time frame in which these challenges need to be addressed to ensure American prosperity and competitiveness.

3.0 Roadmaps

This section provides reviews of sixteen hydrogen energy systems roadmap publications that support one or more LSS industry segment. These documents were collected from various internet searches and industry sources. For the current report, the subsections below have been organized by industry sector (e.g., rail, nuclear) or technology type (e.g., welding, casting), and the document reviews are grouped accordingly.

The reviews were conducted to identify opportunity areas and industry for large structure and system (LSS) needs. The sixteen documents were grouped into six categories: (1) the rail industry, (2) castings and forgings, (3) manufacturing/welding/joining/forming, (4) offshore wind energy, (5) the nuclear industry, (6) hydrogen energy systems.

Each document review contains three sections as follows:

1. **Summary**: This section explains the subject matter and who conducted the work. Notable topics, observations, results, and conclusions are included.
2. **Topics within RAPLSS Scope**: This section identifies the primary topics within the scope of the RAPLSS Roadmap.
3. **Document Overview**: This section provides a more detailed description compared to the Summary, although it is still brief. Many of the documents reviewed comprise dozens (sometimes 100+) pages, whereas each review ranges from about one to five pages.

Some reviews contain additional sub-sections in the Document Overview as warranted by the subject matter.

3.1 The Rail Industry

3.1.1 Federal Rail Administration Research, Development, and Technology Strategic Plan, 2020-2024 [4]

Summary

Reference 4 is a 31-page report explaining the U.S. Federal Rail Administration’s (FRAs) strategy for establishing research, development, and technology (RD&T) initiatives for the rail industry. The FRA’s mission is, “… to ensure the safe movement of people and goods by rail through research and the development of innovative technologies and solutions.” Whereas one might think that the FRA would be interested in the economics of rail or railcar manufacture/fabrication/installation etc., such topics are not present in this report. This is consistent with the approximately 150 projects covered in Reference 5. The primary motivation of FRA's strategy is safety. Manufacturing is only of interest as it relates to integrity and reliability as sub-issues of safety.

Reference 4 (like Reference 5) distinguishes five categories for organization:

1. Human Factors
2. Train Control and Communications
3. Track
4. Rolling Stock
5. Railroad Systems Issues

It is stated that RD&T projects fall into two general categories: (1) projects where the new technology is led by, or has been conceived by, the FRA, thus the FRA takes the initial risk of proving a concept, and (2) projects incorporating new technologies emerging from private industry that then need the proper vetting with the FRA.

Topics within RAPLSS Scope

Topics in this report aligned with RAPLSS include inspection technologies, digital simulation, management of big data, and cybersecurity. It was noted in Reference 5 that a number (~10) of FRA projects relate to inspection technologies like ultrasonic testing (UT), eddy-current testing (ET), non-contact vibration analysis, rail surface imaging and flaw characterization. In the Appendix of Reference 4, research priorities are organized according to the first four categories listed above. Of the eleven priorities for the Track and Rolling Stock categories, five include inspection technologies. It appears this topic resonates with the safety focus of FRA because detection of defects is important to the safe operation of railways.

As is the case with many other industries, FRA understands the potential for simulation technologies to improve the rail industry. It is expensive to study railroad phenomena using physical experiments; therefore, the concept of digital simulation is attractive.

Because the railway systems in the United States are extensive, the volume of data collected through such efforts as in-situ monitoring of rail degradation or of inspection of rails, wheels, tank cars, etc., is tremendous. Managing and analyzing this data involves the challenges of storage and cybersecurity. FRA recognizes the risks associated with a nefarious cyber-attack to disable or damage rail operations.

One item in Reference 4 that might be of interest as an example (not as a collaboration), is the description of the FRA's Transportation Technology Center (TTC) in Pueblo, Colorado. It consists of a 52-square-mile tract of land and offers more than 50 miles of test track. ENSCO currently manages it. This facility enables railroads and system suppliers to test products before they enter revenue service. For other industries within the LSS sphere (nuclear, alternative energies like hydrogen or wind, etc.), a persistent hurdle in the commercialization of new technology is that of full-scale testing. Test facilities like the TTC can bridge the gap and need to be developed for the other LLS industries.

Document Overview

Rather than providing much discussion on technical topics, Reference 4 stays consistent with the term “strategy” in the title. The philosophy, organization, motivations, and even performance measurement methods used in selecting and managing the R&DT initiatives are explained. While improving safety is the principal goal for FRA’s programs, support is also given to other DOT goals. Specifically, the following DOT goals are given:

- SAFETY: Reduce transportation-related fatalities and serious injuries across the transportation system.
- INFRASTRUCTURE: Invest in infrastructure to ensure safety, mobility, and accessibility and to stimulate economic growth, productivity, and competitiveness for American workers and businesses.
- INNOVATION: Lead in the development and deployment of innovative practices and technologies that improve the safety and performance of the Nation’s transportation system.
- ACCOUNTABILITY: Serve the Nation with reduced regulatory burden and greater efficiency, effectiveness, and accountability.

In Section 2.2 of Reference 4, important industry trends are mentioned. It states that there is continued growth in freight traffic, trains are getting longer, and axle loads are increasing. Also, it is expected that passenger trains will run more frequently and operate at higher speeds. These trends bring engineering challenges to the design of rail cars, the materials used for construction, the reliability of manufacturing methods, and the technology used to accomplish these engineering tasks.

To emphasize the importance of the safety goal, Table 2 provides a summary of accident and incident data for 2015 to 2019. Trespassing along railroad rights-of-way is the leading cause of fatalities, and this motivates FRA programs to monitor, collect, and analyze data that help measure risk. Technologies such as smart camera systems and drone technology are useful. RD&T programs have developed a safety risk model (SRM) that analyzes risk by combining the likelihood of accidents with the consequences when they occur.

Table 2. Accident and Incident Data, 2015-2019

Accident/Incident Category	Fatalities	Accidents or Incidents	Accidents or Incidents/Million Train Miles
Trespass	505	950	1.38
Grade Crossing Incidents	261	2,093	3.00
Human Factors Accidents		699	1.01
Track-Caused Accidents		504	0.73
Miscellaneous – excluding Grade Crossings	8	308	0.44
Equipment-Caused Accidents		257	0.37
Signal-Caused Accidents		45	0.06

Reference 4 explains how it prioritizes research ideas for project selection according to the following criteria:

- Strategic Alignment – If successful, by how much would the project reduce safety risk? Are there any expected benefits to other strategic goals?
- Project Stage – How far is the project along the life cycle from basic research to technology transfer?
- Timeliness – Does the project help a current rulemaking, concern a recent major accident, or address a National Transportation Safety Board (NTSB) recommendation?
- Risks to Success – Can costs be controlled? Is there industry support for the project?

RD&T staff, Office of Railroad Safety staff, and FRA senior leadership determine the criteria weightings and score the projects.

It was mentioned above that the TTC is a valuable test facility that is regularly used for RD&T work. Reference 4 also mentions the following future plans for the TTC. There are likely parallels in the LSS world.

- Enhancing FRA's capability to independently evaluate railroad equipment and infrastructure integrity
- Developing testbeds to evaluate new track defect detection technologies
- Expanding the positive train control (PTC) testbed to enable the testing and evaluation of new intelligent transportation technologies
- Continuing to develop a training facility for FRA and Transportation Security Administration inspectors.

Associated with the DOT innovation goal, Reference 4 mentions strategies associated with emerging technologies. Augmented reality and virtual reality engineering that creates 3D modeling tools and visualization devices are mentioned as useful to train conductors and drivers. For LSS, the same concept may be true for machinists and welders who are in high demand and whose training becomes a primary hurdle to developing a sufficient workforce.

As an example of successful technology deployment through public-private partnership, Reference 4 explains the Autonomous Track Geometry Measurement System (ATGMS). This was an FRA collaboration with industry and university partners. The project evolved over 15 years and led to the prototyping, testing, and eventual deployment of unmanned rail vehicles that record track quality. To date, 15 systems have been delivered and another 15 are on order. These vehicles have helped railroads find and repair track defects before derailments occur.

One topic receiving little attention in the FRA initiatives and the projects mentioned in Reference 5 is the use of compressed gas i.e., liquefied natural gas (LNG), as a locomotive fuel. An interesting contrast can be made to the Australian rail report, Reference 6. Within the past 20 years, the LNG industry has become widespread globally because natural gas in liquefied form is a very dense energy product. Economies-of-scale have made LNG economics viable as LNG plant technology has matured and LNG ship transport has become commonplace. Additionally, carbon emissions from natural gas are roughly half that for coal, making LNG useful for emissions reduction.

In 2023, the United States became the world's leading LNG exporting country surpassing Qatar and Australia, who had historically held the top two spots. The country's rise in LNG is particularly notable considering the U.S. opened its first export terminal in 2016. Even though the United States can produce enough LNG for any applications it might envision, the use of LNG by the U.S. does not appear to be in ascendance. A worthy consideration for energy efficiency and emissions reductions would be to use LNG as a railroad fuel. This topic is essentially absent from the FRA and DOT initiatives.(4), (5), (7) The Australian rail industry, on the other hand, is pursuing the use of LNG for locomotives.(6) The reasons for the U.S.'s position on this topic will be addressed in the reviews of References 6 and 7. Suffice it to say that the FRA appears to support a more aggressive push for a 100% clean fuel — hydrogen.

3.1.2 Federal Rail Administration Office of Research, Development, and Technology: Current Research Projects, Dec. 10, 2021(5)

Summary

Reference 5 is a 157-page report prepared by the Federal Rail Administration (FRA), an agency within the Department of Transportation (DOT). This report provides roughly 150 single-page summaries of rail-related R&D projects funded by the FRA (each funded project comprises one page). The FRA has organized projects according to four categories:

1. Track
2. Rolling Stock
3. Train Control and Communications

4. Human Factors

The percentage breakdown of projects for these four categories is 43%, 35%, 17%, and 5%, respectively. The project budgets range from about $20,000 to $6 million with typical projects garnering $200,000 to $500,000. The contractors include private technology companies (like ENSCO), government rail-centric organizations and test sites (e.g., the Volpe Center), rail companies (Amtrak, Norfolk Southern), and universities (e.g., The University of Illinois). The overwhelming drivers that motivate the R&D topics are safety and reliability. These R&D projects pay almost no attention to the manufacturing of large structures. An argument can be made that there is attention paid to “systems,” considering that the rather large network of rail systems in the U.S. are complex and require modern technology to run smoothly. A summary of the projects is given in Appendix A.

Topics within RAPLSS Scope

Reference 5 contains some topics related to wheel and rail integrity, and this has a cursory connection to manufacturing these components, but there is no direct emphasis on fabrication of wheels, rails, or rail cars (nether freight nor passenger).

The most notable area of alignment between Reference 5 and RAPLSS is inspection technologies. There are a number (~10) of projects on nondestructive evaluation (NDE) technologies including UT, eddy current testing, non-contact vibration analysis, rail surface imaging and flaw characterization. There are a few projects on the testing of tank car materials and fracture in tank car steels.

Other areas of alignment with RAPLSS include managing and utilizing large data sets. For example, it appears that when rail NDE is attempted in-situ on a moving train, the size of the data file is enormous. Therefore, data storage, transfer, and analysis are a challenge.

Document Overview

A detailed overview discussion for Reference 5 is unnecessary beyond the information already provided because each R&D project description was limited to a single slide with limited detail. The manufacturing or fabrication of rail cars was notably absent from the FRA projects. Considering the volume of cars necessary for the rail industry in the U.S., this seems unusual. It is anticipated that the manufacture of wheels, substructure support (frames and suspension), and freight carrying containers whether open, closed, or pressurized, would have potential common ground with LSS production. It is likely that rail car manufacturing incorporates a large amount of machining, welding automation, manufacturing sensors, internet of things, machine learning, NDE, and steel.

There are two rail-related documents[6], [8] that provide an interesting contrast to the two FRA documents.[4] [5] References 6 and 8 concern rail industry technology in South Korea and

Australia, respectively. While References 6 and 8 do not have the same purpose as References 4 and 5 there are still comparisons to make. The controlling government authorities in South Korea and Australia address the topics of manufacturing and construction of rails and railcars. See separate reviews of References 6 and 8 for details. Again, it may be useful to inquire if FRA handles these topics elsewhere or if they are handled by private industry and are not sponsored by DOT.

3.1.3 Proceedings of FRA Workshop on Environmentally Sustainable Energy Technologies Powering Future of Rail, Federal Railroad Administration, Feb. 2022 (Workshop dates: Sept. 14-15, 2021) (7)

Summary

Reference 7 is a 63-page report on the outcome of an FRA workshop on sustainable energy technologies for use in powering railroads (e.g., locomotives, power cars). The workshop was held over two days, had around 25 panelists, and approximately 150 registrants. The motivation for this effort is primarily to reduce emissions. Discussion topics included experiences and challenges regarding alternative fuels, advanced propulsive technology research, and technology implementation. The alternatives considered were biodiesel, compressed natural gas (CNG), liquified natural gas (LNG), hydrogen fuel cells, and lithium-ion batteries.

North America (primarily the United States, Canada, and Mexico) has the largest single integrated rail system in the world. It took 25 years to convert this system from steam to diesel, and this was at a time when the network was much smaller. Therefore, a primary hurdle now for alternative fuels is deployment of infrastructure. Locomotives, for example, are designed to run for 30-50 years. At this point, the changeout technology would need to be robust and dependable well into the future.

Despite the abundance of natural gas in the U.S., the conclusion of this workshop is that CNG and LNG do not offer a good opportunity as a future fuel. Pilot programs have been conducted using natural gas. Single-fueled and dual-fuel locomotives were built/tested with millions of miles traveled. Safety was satisfactorily addressed. These pilots were deemed a success. However, the prevailing workshop sentiment was that considering the infrastructure necessary (fuel storage, refueling stations, rail cars with pressurized gas containers, etc.), and that natural gas is still a fossil fuel with carbon emissions and must be replaced eventually, it makes more sense to prioritize hybrid technologies in the near term (diesel-battery) and hydrogen in the long term. This was qualified by saying the hydrogen production must come from a clean source like electrolysis. The desire to move to a 100%-emission-free technology as soon as possible is the primary driver leading to the support of hydrogen. One approach to minimize the challenging transition period was suggested – biodiesel. This fuel is seen as an easy near-to-midterm option because it is essentially “plug-and-play” with existing diesel engines.

The United States' particular rail layout (compared to Europe) with significant long-haul needs is seen as a good match with an infrastructure changeout to hydrogen. The long-haul needs, freight versus passenger, and urban versus rural contrasts between Europe and the U.S. were discussed at some length. Also, Europe appears to be better suited to battery and electric options because there is an existing culture of short-run passenger lines and because many areas already use an electrified rail system. These factors do not exist in the United States; therefore, if any changeout is considered, the experts at this workshop favor a full changeout to hydrogen.

The long lead time for using hydrogen for rail was recognized. It was stated that hydrogen technology now is roughly where batteries were 5-10 years ago. All the same challenges that exist for natural gas also exist for hydrogen, but it is also recognized that hydrogen comes with the additional challenges of being damaging to some metals, difficult to handle, and highly combustible. Because of this, one workshop expert was quoted as saying that hazards with hydrogen are "exponentially higher than those with LNG."

Topics within RAPLSS Scope

The topic from Reference 7 that most clearly resonates with RAPLSS is hydrogen. Manufacturing topics like machining, welding, forging, NDE, materials technology, smart machines, Industry 4.0, etc. were not covered at this workshop. It was clear from Reference 7, however, that the rail industry will be pursuing the use of hydrogen as a fuel and will be interested in technologies and infrastructure related hydrogen creation, transport, storage, and handling. This means an interest in hydrogen producing systems, pipelines, storage tanks, and rail cars that carry hydrogen. Because North America's rail system is extensive, the amount of hardware needed to enable hydrogen as a railroad fuel will create many opportunities for LSS production.

Document Overview

The workshop's purpose was to

- Discuss energy-efficient and alternative fuels, status of research on fuels, impediments to alt fuel use.
- Promote safe, economical, and effective rail tech for using clean fuels; reduce climate-harming emissions; minimize the effects on railroad workers; and promote environmental justice.
- Develop actionable items for cooperative and non-duplicative technology research and project initiatives with international governmental counterparts and the rail industry.

The individual session topics were

1. Alternative Fuels for Railroad Applications
2. Logistics of Fuel-Handling, Tankage, Fueling, Safety, Infrastructure, Network Integration, and Rail Labor Organizations Concerns

3. Alternative Clean Fuels Technologies in Heavy-duty Transportation Sectors
4. Status of Specific Technologies for Rail Applications
5. Lessons Learned from Pilot Projects
6. Environmental Regulations, Environmental Justice and Related Issues.

The panels (sessions around which the workshop was designed) provided broad overviews of domestic and international approaches to alternative fuels, citing various degrees of success. Highlights included:

- Biodiesel and renewable diesel are intermediate steps in reducing emissions. Biodiesel in RR operations has been approved in limited applications. However, biodiesel is not carbon-free.
- Liquid or compressed natural gas (CNG) fuels have shown promise, especially with the construction and demonstration of a robust tender. While these fuels are viable and reduce greenhouse gasses (GHGs) compared to diesel, the cost of infrastructure required and interference with existing operations may be difficult to overcome.
- Batteries for rail applications have advanced beyond traditional lead-acid to lithium-ion chemistries due to a precipitous drop in cost and increased energy storage density.
- Battery electric technology has been embraced in Europe, with several hybrid trains in operation, such as the Coradia iLint, which is powered by a combination of battery and hydrogen fuel cell technology.
- Batteries are an attractive, emissions-reducing option for implementation on regional passenger routes. Instituting enhanced safety standards, addressing concerns of and developing appropriate technology and emergency response to potential fires caused by short-circuits in high energy density batteries will be essential before expanding the use of high-wattage batteries in rail services.
- A decade after a successful Burlington Northern Santa Fe Railway (BNSF) demonstration of a hydrogen fuel cell switch engine, this technology has advanced and is being pursued by passenger rail operators in the United States and Europe. There are safety concerns with hydrogen fuel cell propulsion such as fuel flammability and gas accumulation. Smaller prototype operations of these energy technologies will help improve the technology since fuel cells are considered very applicable to long-distance routes.

The following topics and research areas were identified as challenges to implementing alternative fuels and energy sources on a larger scale:

- Widespread installation of refueling and recharging infrastructure to support new fuels
- Upfront capital cost for upgrading existing technology
- Establishing regulatory guidelines with greater flexibility for technology in the demonstration phase
- Scaling up small demonstration projects to test feasibility at a commercial level.

At the time of the workshop, only one hydrogen train project had been demonstrated under real-world conditions: the Coradia-iLint trainset operating in Germany. This train uses a hydrogen fuel cell, and it is made by the French company, Alstom. This train design was tested in Canada in 2023, and a German railway company ordered 27 trains at a cost of $530 million. A news report in 2023 stated that "manufacturing delays and technical faults" were hindering the delivery of these units, indicative of the challenges faced by new technology during commercial scaleup.(9)

As is covered in the summary report for Reference 6, Australia has an abundance of natural gas (No. 3 in the world behind the U.S. and Qatar) and has active R&D programs to use LNG for rail power. The rail-related documents provide an interesting comparison that demonstrates how different regions of the world can come to different conclusions about how to de-carbonize the rail industry.(4), (5), (6), (7), (8)

3.1.4 Rail BIM 2030 Roadmap, 2018(8)

Summary

Reference 8 is a 31-page report outlining a roadmap to incorporate Building Information Modeling (BIM) into South Korean rail construction and management projects out to 2030. The authorship and publication authority are not clearly stated in Reference 8; however, within a list of contributors (p. 30) there are numerous individuals from Yonsei University, the Korea Rail Research Institute, and the Korea Rail Network Authority. BIM is described as a method for planning, executing, and managing construction projects based on "high-quality information, including three-dimensional information, to minimize business risks." A connection to the 4th Industrial Age is also mentioned indicating that BIM utilizes aspects of Industry 4.0.

The Rail BIM roadmap is split into five levels. In the early levels, the project participants learn how to convert from traditional planning and construction methods to BIM principles. A primary emphasis is to replace conventional 2D images with 3D models, which enables a more complete interpretation of the physical aspects of the project. The exact methods of 3D modeling are not given in this document, but certain techniques are alluded to – computer modeling, virtual reality viewing, and on-site witnessing. Even plans, budgets, etc. are digitized and communicated according to advanced models. As much as BIM is a technological approach, its success requires that the governing philosophy be embraced by all participants. A cultural transformation must occur to move away from traditional methods.

As a result of the philosophical nature of BIM, Reference 8 reads more like a description of the deployment sequence of a business model rather than delivery of an engineering technology.

Topics within RAPLSS Scope

There is limited content in Reference 8 that aligns with RAPLSS. The exceptions are (a) an emphasis on 3D visualization, and (b) robotics and automation in on-site construction. 3D visualization is at the core of BIM, and it is expected that any BIM-based projects will be using

3D models from the planning stages to construction and on through to management of the asset. Once models are created, they are modified as necessary with time, and then kept within the project asset once in operation. The BIM approach advocates for modular manufacturing in an offsite facility, then automated/robotic construction at the job site. No significant details are given about the technologies that would enable these concepts.

Document Overview

Because so little of this document is relevant to RAPLSS, a detailed document review will not be given. Figure 3 is included as an indication of a few of the concepts discussed in Reference 8. Additional discussion by a primary author about the Rail BIM Roadmap can be found in Reference 10.

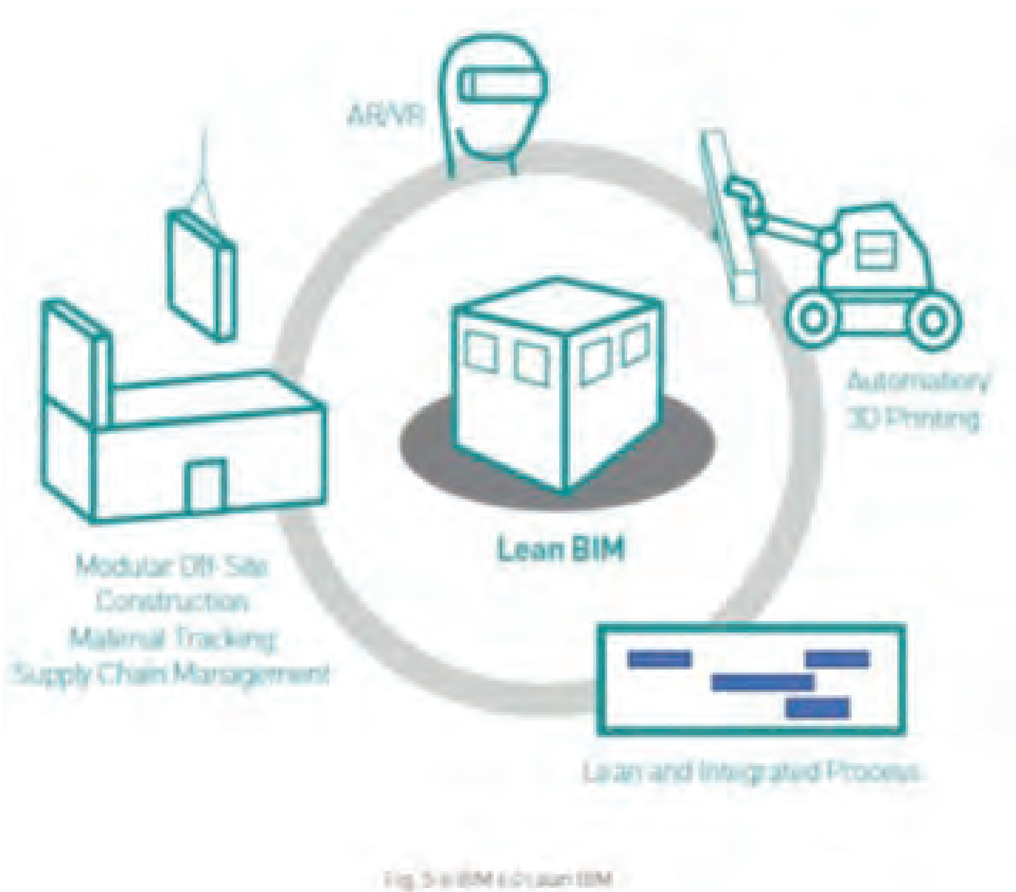


Figure 3. Rail BIM 2030 Roadmap, Yonsei Univ., Korea Rail Network Authority, Korea Railroad Research Institute, Aug. 17, 2018 (8)

3.1.5 On Track to 2040: Preparing the Australian Rail Supply Industry for Challenges and Growth, The Australian National Univ. (ANU Edge), 2012[6]

Summary

Reference 6 is an 88-page report outlining a roadmap to 2040 that addresses key challenges for the Australian rail industry. The report was enabled by engaging stakeholders from industry, the government, and academia. The engagement included 210 representatives from 110 organizations. The document itself makes no mention of the publication date, but an internet search indicates that it was published in 2012, therefore, this document is over a decade old. Nevertheless, the outlook was to 2040, so there should still be topics to consider.

Reference 6 gives a view of the industry's technology and manufacturing capabilities and of the development opportunities these present. A main point in this report is that the Australian rail industry is (a) a vital part of the economy, particularly the manufacturing sector, and (b) in recent times (surmised to be the 90s and early 2000s) feeling the effects of a liberal trade policies and the emergence of low-cost competitors in Asia that have contributed to a downturn in Australian rail manufacturing. This report suggests a roadmap to reverse this trend.

The recommended actions of this report were separated into two broad categories: strategic and technological. The strategic topics included governance, regulation, standardization, funding, collaboration, etc. The technological topics included three sub-topics: materials and manufacturing, monitoring and management, and power and propulsion. Within the materials and manufacturing subject, six opportunities were identified:

- Advanced design
- Low-cost manufacturing systems
- High performance materials for heavy haul
- Advanced manufacturing
- Advanced materials for lightweighting
- Simulation for materials and manufacturing

For power and propulsion, two of the six topics were emissions reduction and gaseous fuels.

Topics within RAPLSS Scope

Because Reference 6 relates to the Australian rail industry, no direct connection to RAPLSS makes sense. However, it is useful that Reference 6 indicates public-private interaction and technology facilitation in areas aligned with RAPLSS. This provides insight considering the U.S.-related documents do not indicate connections to such areas.[4], [5], [7] Because the rail industry in the U.S. is quite large (larger than Australia), it can be surmised that the U.S. rail industry has similar manufacturing needs as Australia.

Document Overview

Figure 4 was presented as a backdrop to the use of rail in Australia. Rail use has emerged as a more cost-effective means of freight transport than other options. This is particularly the case for the mining industry. Australia's natural resources are in demand throughout the world, and the mining industry requires heavy haul transport of mining products. This has created a need for the engineering of rail cars capable of handling heavier loads. Engineering design technology (simulation), strong materials, and advanced manufacturing methods all play a role in servicing this need.

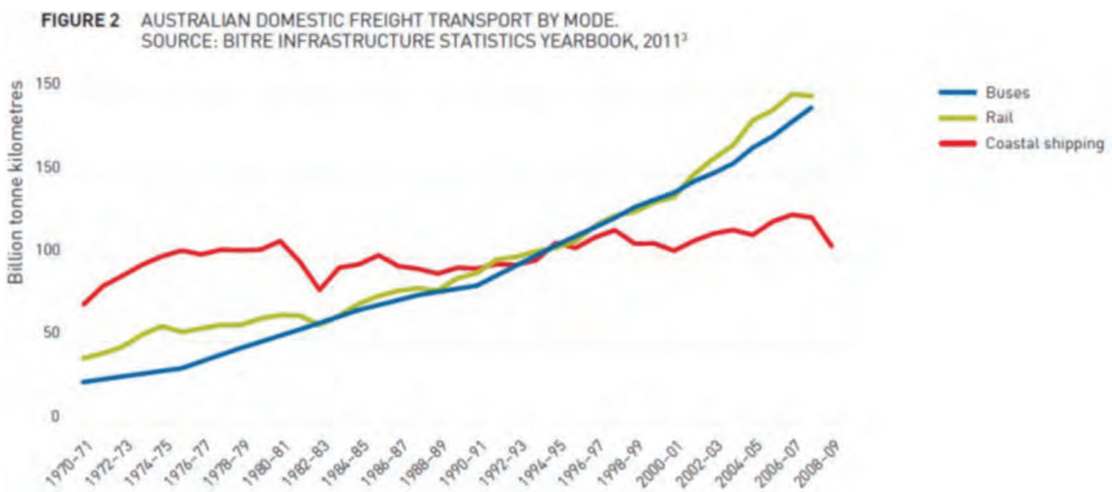


Figure 4. Australian Domestic Freight as a Function of Time[6]

Even though the strategic plans in Reference 6 include the topic of emissions reduction and new propulsion technologies, the degree to which these topics are included is much more limited than for the U.S.-based documents.[4], [5], [7] For example, Reference 6 includes three mentions of the term "hydrogen," whereas the U.S.-based Reference 7 includes 137 uses. To be fair, Reference 7 covers a workshop dedicated to sustainable technologies while Reference 6 covers a broader range of topics. Reference 6 also was created in 2012 while References 4, 5, and 7 date from 2020 to 2022.

Reference 6 includes ample discussion of the hypothetical question, "What is a roadmap?" The road mapping approach that was chosen involves a description of the complex interconnections in the industry over time. By engaging a broad range of stakeholders, they construct "layer-by-layer, a picture of the industry" and how it relates to the broader community that it serves. In this analysis, they also consider trends and drivers from social, political, and economic considerations. By understanding all these factors, potential solutions to problems are identified from which opportunities are proposed.

In the portion of this report where the actual roadmaps are shown, the bulk is dedicated to the technological sub-topics materials and manufacturing, monitoring and management, and power and propulsion. Each of these three areas is further broken down (as detailed above for materials and manufacturing) into about six more sub-topics and then each of these 18 topics has a dedicated roadmap. As an example, the roadmap for heavy haul materials is shown in Figure 5. Each roadmap includes sections on technology and on enabling subjects like research, governance, funding, collaboration, etc. The map below shows (as a partial example) the three subjects – finite element analysis, track inspection, and maintenance practices – combining to provide an axle design with a 45-tonne capacity goal. This axle design then moves on to simulation and verification of the design. Within this flowchart, gaps are listed in order of the recommended timing to address each gap. The flowchart continues beyond gap analysis to prototyping then to commercialization. Connections between the technical and enabler tasks are shown to suggest appropriate timing so that some items, gap solutions, prototyping, etc. do not get out-of-time with allied enablers that are not technical challenges but are important to overall success, nonetheless.

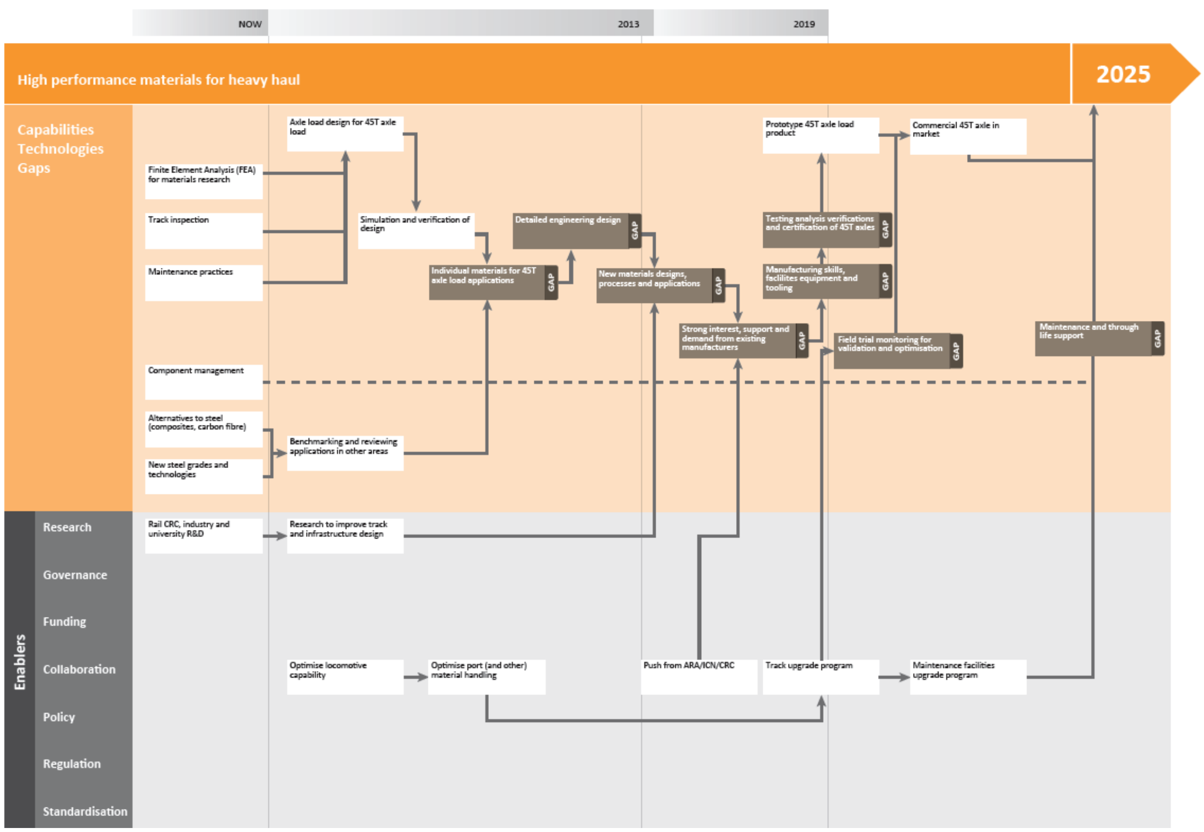


Figure 5. Australian Rail Roadmap Examples for Heavy Haul[6]

In the section of Reference 6 on gaseous fuels, a clear plan is given to pursue using LNG as an alternative fuel. “Natural gas is cheap and abundant in Australia,” the report states, “and some supply infrastructure currently exists (though some infrastructure limitations still need to be addressed). As a solution unique to the Australian environment, it has the multiplicative effect of stimulating local industry … Much of the required technology for rail applications already exists and the move to gaseous fuels will lower the industry's carbon footprint and reduce fuel cost. Concern over the impending energy security issues around oil-based fuels accelerates the drive for alternatives. Building on abundant gas reserves, new technologies will be developed that could be sold, along with the gaseous fuel itself, to the global rail market." Reference 6 states that within its grading system to prioritize potential efforts, using gaseous fuels held the highest "natural advantage" score. Gaseous fuels such as LNG received a unique roadmap in Reference 6. It is interesting that Australia, ranked No. 3 in LNG exports behind the U.S. and Qatar, decided to pursue this alternative fuel, while the FRA report reaches the opposite position even though the United States has more gas and a rail system (long haul transport) that is ideal for infrastructure changeout to gaseous fuels.[7] Because Reference 6 was written in 2012, the latest views by Australia on gaseous fuel use for rail is not known.

To locate more recent information on Australian rail initiatives, an internet search led to Reference 11 *National Rail Procurement and Manufacturing Strategy*, by Australia's Office of National Rail Industry Coordination. This document was not reviewed in detail, but it may be a good reference for a more recent reporting of Australian rail support for manufacturing. The program reported by Reference 11 identified a six-pillared strategy as shown in Figure 6.

Figure 6. Australian Rail Procurement and Manufacturing Strategy[11]

3.2 Castings and Forgings

3.2.1 Castings and Forgings. Monthly Commentary, Steel Founders' Society of America, Raymond Monroe, Nov. 16, 2021[12]

Summary
Reference 12 is a 26-page commentary on the state of the steel castings and forgings (C&F) industry in the U.S. It originally appeared as a monthly contribution on the website of the Steel Founders' Society of America (SFSA). This document is different from the other reports in this review. The other reports resulted from consortia, collaborations, and projects conducted by teams. Reference 12 is by a single author, Raymond Monroe, who is a career expert from the steel industry with a primary background in C&F. He serves as the executive vice president of SFSA. While some of Reference 12 appears generic to the entire steel C&F industry, the majority is associated with defense applications.

According to Reference 12, the top two challenges faced by the steel C&F industry are the lack of (a) skill in trades for workforce, and (b) capital investment in technology, equipment, and automation. The workforce challenge is described as "not short term or solvable with immigration" (which has historically worked). It is stated that SFSA is working with DOD partners to develop "artisan-like robots" that can handle a broader range of tasks/products without individual fixturing and programming. This is deemed critical for limited production of advanced components. Regarding capital investment, Reference 12 mentions often that the C&F industry will have difficulty meeting demand over the next decade and will find it difficult to invest in new or upgraded technology unless reliable business opportunities arise. It is suggested that public policy solutions that allow this industry to prosper and invest (automation, modernization, and innovation) are fundamental to the future of the United States.

Reference 12 makes a case that U.S. public policy has neglected capital-intensive industries like steel C&F, and this has led to a reduction in capability. The article explains that factors such as the cold war, industrial overcapacity (1970s), lack of demand for steel products (1980s and 1990s), lack of investment, trade policy, etc. through the end of the 20th Century caused the closings of steel foundries and forge shops. A cultural and economic shift away from manufacturing and into financial markets exacerbated the problem. Trade policies that enabled globalization were particularly impactful.

It was envisioned that trade with China would motivate democratic reforms, but to a large degree this did not occur. Multinational corporations pressured U.S. suppliers to engage in Chinese joint ventures. China gained access to proprietary knowledge and a market compelled by cheaper products. Since 1998, when the U.S. steel casting industry had a capacity of about 2 million tons, plant closings of 700,000 tons have occurred (a reduction of 35%). More than 14 plants with sales to the military closed (70,000 tons). This loss of capacity has caused difficulty for the defense industry (and others) to source the needed products at a reasonable price. It has also become problematic to obtain advanced products like higher strength and/or tougher steels. These challenges, in addition to China's regional aggressiveness (presumably towards Taiwan and Japan), have caused the DOD to re-evaluate the United States' industrial capability.

Reference 12 mentions new initiatives underway to improve the situation. The SFSA has taken a lead role in initiating a program supported by Congress and hosted by the Defense Logistics Agency (DLA) called the SPI – The Steel Performance Initiative.[13] This effort includes connections to academia to create and transition the most advanced steel technology to DOD systems. Other noteworthy efforts include the American Metalcasting Consortium (AMC) and the Forging Defense Manufacturing Consortium (FDMC). Additionally, the Forging Industry Association (FIA) has a foundation, the Forging Industry Educational and Research Foundation (FIERF) that funds forging research at universities as well as scholarships and employment opportunities for students.

In Reference 12's description of efforts underway or concepts being considered to improve C&F for defense applications, an overarching point is made: "DOD is a difficult customer to serve." It states that DOD has had decades of willing suppliers who could support the administrative burdens, qualification requirements, payment terms, and product requirements as a part of their ongoing business. This, however, is no longer the case. Reference 12 states that the DOD expects companies to bear too much expense to become a new supplier, or to supply a component not provided previously. The article discusses examples of stringent requirements with no room for adjustments. Once the requisite work is complete (which can take over a year and cost "*… on the order of a million dollars*"), the article notes, there is no guarantee that orders will occur.

According to Reference 12, the average steel foundry has 61 employees, and 47 are in production roles. This leaves 14 people to handle all other business, like the burden of DOD regulations. Often qualifications must include a cybersecurity system, and for small businesses, this can be a deal breaker. The International Traffic in Arms Regulation (ITAR) regulations are another liability with challenging requirements. Reference 12 states that the legal liability of supplying DOD products exceeds the risk in any other commercial transaction and that the DOD does not provide usable forecasts of demand that would enable a business decision to manage investment risk.

Topics within RAPLSS Scope

As with many other documents in this review, Reference 12 states that finding an adequate workforce is one of the top challenges for the steel C&F industry. Only a few potential solutions are mentioned. The broader use of robots is viewed as a multi-faceted solution. First, it attracts the next generation entering the workforce, as automation has become more commonplace, and more individuals are entering the workforce either familiar with or skilled at coding. Second, it addresses the needs of industry today, which enables the workplace not to replace humans with robots, but to grow the capabilities and skills of employees to work alongside robots. This is viewed as an enablement to increase overall employee efficacy. Reference 12 states that the workforce challenge is well summarized in a report, Demographic Drought, Bridging the Gap in our Labor Force.[14] This is a thorough document that helps understand workforce challenges, although the focus is not for technical work or skilled trades.

The subject of steel C&F is useful to LSS in a way that is analogous to welding and NDE. C&F are mostly components included in large structures or systems just as welding and NDE also facilitate a final product. Reference 12 identifies steel C&F as critical to the defense industry, and this joins a substantial list of industries that also use C&F. Offshore wind has identified large steel C&F as critical components and has expressed doubts that these items can be adequately sourced in the United States.[15] The rail industry (wheels, axles, rails), the nuclear industry (reactor components, piping and valves), and the oil and gas industry (valve bodies, mooring connections) may have a similar view of the C&F industry in the U.S.

Reference 12 explains that because of the small business nature of C&F companies, cybersecurity (particularly as required by DOD) can be a challenge. These companies do not typically have the workforce to address this dynamic field. This same sentiment is noted in References 16 and 17, where reference is made to small and medium-sized manufacturers (SMMs) that can be particularly vulnerable to cyber-attacks because SMMs may be understaffed and lack the latest cybersecurity technology. The context was associated with the large amounts of data stored in the cloud or on local servers that are related to smart manufacturing operations (one of the pillars of Industry 4.0).

From several internet searches related to Reference 12, including readings from the SFSA website, the topic of “collaboration” was mentioned. Raymond Monroe has been quoted as saying that one cultural barrier to improving the C&F industry is a willingness to collaborate. Many industries are made up of competitive companies that, by their nature, protect proprietary knowledge. This is an attribute of successful companies that have skills and products desired by industry. On the other hand, Industry 4.0 information, stresses the importance of collaboration, and companies are encouraged to work together.

Working with a competitor inevitably means providing that competitor with intelligence. The challenge is how to develop ideas for collaboration, including explanations why the concept makes sense, which will be supported and lead to a win-win scenario. Collaboration ideas are difficult considering private industry’s reluctance to risk intel leaks and fund external work that some managers may consider a boondoggle. The intel leak concern often can be alleviated if the company appoints as the collaboration representative a senior employee who is savvy with public discourse. The collaboration proposal needs to be well organized and reasonably thorough, including descriptions of potential projects that are of keen interest to prospective companies.

One problem identified by Reference 12 is the lack of investment by the C&F industry. C&F businesses are not willing to invest in new technology or upgraded equipment until orders are received, but the incorporation of the most cost-effective technology would potentially enable orders. Reference 12 suggests that public policy changes might help this dilemma, but no details are given. Loans, tax incentives, grants, etc. are options. The use of lobbyists or other government experts may provide ideas for alternative approaches.

"On the Issues," an online publication from the Forging Industry Association, offers a complementary, industry voice. The January 2024 issue reports that improved trade policy could enable a level playing field to support U.S. global competitiveness. Many of the U.S. challenges in this industry can be solved if given the opportunity to compete fairly on a global basis.(18) See also Appendix B

Furthermore, in a testimony before the Office of U.S. Trade Representative on behalf of the forging industry, Angela Gibian, deputy chief executive of the Forging Industry Association, suggested that, "The U.S. needs to update its antiquated system of trade laws to adapt to today's global strategy of evading tariff actions through tactics including transshipment and transnational subsidies" to enable fair global competition for its industry.(19) See Appendix C for the complete testimony.

In view of technology needs, Reference 12 states that the U.S. "… needs a large HIP vessel if we expect to have the highest quality large steel components." Hot isostatic pressing (HIP) technology is well covered in Reference 20, which was aimed at advanced energy systems. HIP technology offers LSS opportunities for cross-industry collaborations.

Document Overview

Reference 12 consists of three parts: (1) a few introductory sentences with 14 recommendations (in other words the conclusions are given straight away), (2) seven pages accounting the state of the industry including significant historical context, and (3) 17 pages of questions and answers (six questions). The Q&A appears to be an orchestrated exchange with prearranged questions. This format works well and has the feel of an expert responding to poignant inquiry. It provides an opportunity to provide nuanced detail on a number of challenges facing the casting and forging industry.

Reference 12 includes many pages of background information regarding how the C&F industry has arrived in its current situation. Figure 7 is one example (Reference 12 shows numerous graphs). This graph shows that the United States has managed to maintain an upward output trend, despite the closing of so many steel-related businesses since the 1990s. Reference 12 explains that this trend has been enabled by the use of advanced technologies like robotics and automation. Reference 12 discusses whether this trend can continue. With some technology mitigations already in place and workforce limitations anticipated to worsen, a case can be made that significant efforts (government initiatives and funding) must be initiated in the near future, otherwise the U.S. output will decline, and key industries will suffer.

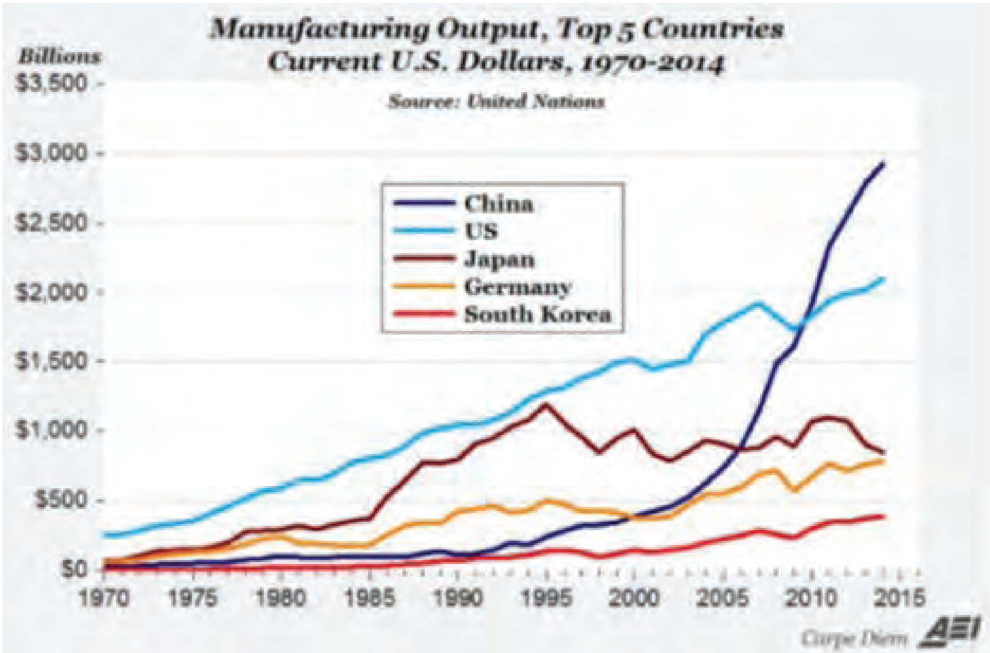


Figure 7. Manufacturing Output [12]

The ascendence of China's manufacturing output and its overtaking of the U.S. is quite obvious from the graph above. Reference 12 provides several explanations and examples regarding this situation including the following:

> "One effect of globalization that helped devastate the casting and forging industry is the suppression of pricing due to non-market competition. China would commonly invade a market with pricing 40% below market prices. Often this pricing was below the cost of production. Multi-national OEMs would pressure domestic casting and forging businesses to match these prices and to support joint ventures at Chinese plants to produce their products. The OEMs wanted not only the cost benefits but also a source in China to support their growth in that dynamic market. These joint venture agreements normally included sharing state-of-the-market technology and proprietary information on the products and processes used. These agreements were abused in many ways. One direct result was the suppression of normal market forces that would have raised pricing in the U.S. market to allow re-capitalization of these casting and forging plants. As discussed above, the sharp rise in prices for castings and forgings in 2004 to 2014 did not result in significant new investment in domestic manufacturing."

Presumably, the sharp rise in prices resulted from a supply/demand dynamic caused by the closing of so many C&F companies. Additionally, Reference 12 explains that the lack of C&F industry investment in better technology and equipment is due to the common interplay between upgrades versus orders. This also can be described as a chicken-and-egg problem. Already in a precarious situation, C&F companies are risk-averse regarding investments due to the capital-intensive nature of these investments. In other words, C&F businesses are unlikely to invest until orders are in place, even though orders would be better obtained if the best technology were applied.

Reference 12 mentions the following as an example of defense related challenges:

> "Perhaps most problematic is the challenges faced by the Navy with their submarine build schedule. At DMC 2018, Draper expressed concern that the number of suppliers for required high yield steels (HY) had fallen by more than 75%. The stock material for welding rod for HY steels required in Tech Pub 200 Mil-100S filler metal comes from a single source in Germany". Another example included, "The Army has challenges because the high-performance steel industry in the U.S. has not been capable of making the Ultra-High Hard (UHH) armor steel. There is also no qualified domestic source for the high performance steel ingots for forging the large cannon tubes."

Reference 12 includes much discussion about stringent DOD requirements and its unwillingness to compromise. One example states, "A 20,000-pound casting with a six-month production cycle that has one tensile result that is 2 ksi below the 80 ksi requirement in one non-critical location will disqualify the part. This is true even though other tensile samples in critical locations exceeded the requirements. This casting will need to be scrapped and another made. This causes a delay of six months in the casting and the new casting is just as likely to have a single value that is problematic." Reference 12 advocates for fit-for-service analysis to deal with situations like this and indicates that the DOD does not show signs of change.

The Steel Performance Initiative (SPI) was mentioned above. Reference 12 states that the following strategic efforts are underway:

1. Improving the manufacturing readiness level (MRL) and technology readiness level (TRL) of advanced high strength steels (AHSS)
2. Developing process-driven performance modeling to enable fitness for purpose (FFP) designs
3. Formulating quantitative nondestructive testing (QNDT) assuring part performance
4. Mining properties of existing materials from the Defense Technical Information Center (DTIC) and commercial data with smart analytics for improved alloys, modeling, and design properties
5. Tailoring Industry 4.0 for short-run steel parts from small and medium enterprises (SME)
6. Coupling manufacturing processes for hybrid capability and geometry with superior properties and cost-effective solutions
7. Providing a guide for the use of current steel specifications for obsolete requirements in legacy weapon systems
8. Enabling predictable blast and ballistic performance from high strain rate data.

Reference 12 lists the following recommendations as a culmination of all topics covered:

- National Security requires domestic production of advanced steel castings and forgings, and public policy has imperiled that supply chain. Finding public policy solutions that allow these businesses to prosper and invest is fundamental to our future.
- The casting industry is likely to be at their production capacity for several years and will have little incentive to invest to become qualified for DOD business. DOD will need to find ways to have persistent and profitable arrangements with the supply chain to become a preferred customer.
- Innovative purchase mechanisms that partner and collaborate with industry would allow a more comprehensive relationship with the supply chain.
- Open-ended liability requirements like those from ITAR or cybersecurity make it undesirable to do business with the DOD. In the current system, the supplier bears the full cost of these requirements without any clear way to establish whether they comply or what additional future requirements there may be.
- ManTech funds technology development and improvement for existing suppliers but does not support the qualification of new sources and their technology development costs.
- There is no point of contact with the responsibility and authority to answer ordinary questions on process and schedule for suppliers trying to get qualified or approvals for parts.
- U.S specialty steel producers for high-performance steels will require advanced refining capability that is not currently supported by their financial performance or the market demands. Foundries have some limited argon oxygen decarburization (AOD) capability, but the reliable high performance will require vacuum treatment.
- The U.S. needs a large HIP vessel if it expects to have the highest quality large steel components. It should be possible to have a government-owned contractor-operated (GOCO) at Rock Island.
- Suppliers need the ability to identify the market characteristics for the planned build schedule for castings and forgings needed for Navy vessel construction so potential and current suppliers can be more capable and responsive.
- A system needs to be created for modification of NAVSEA Technical Publication 300, Revision 2 (T300Rev2) patterned after the ASME BPVC (Boiler and Pressure Vessel Code) consideration of code cases, to allow a case-by-case modification to NAVSEA Technical Publication 300Rev2 that would be allowed without a full revision being required for any changes. Full revision is problematic since each drawing that included T300Rev2 would have to be reviewed and approved for the new standard, at a cost of millions (billions?)
- A system is needed to facilitate approvals for first article castings and forgings that require agreement between the Navy and then OEM.
- Suppliers should be able to request waivers for errant test results from a knowledgeable purchase authority to enable the use of reliable and capable components that have minor variations from non-critical requirements.
- Support for the Steel Performance Initiative with additional funding could be useful in accelerating the development of steel casting and forging technology directed at DOD needs.

- One innovative opportunity to promote DOD technology and engage the future workforce would be to sponsor the Cast in Steel Competition organized by SFSA for the past three years.

3.2.2 Qualification Cost Drivers and Ancillary Issues for Castings and Forgings Suppliers to DoD. Steel Founders' Society of America [21]

Summary

Reference 21 is a five-page commentary of unidentified origin and date. The subject matter is the component qualification burden carried by C&F suppliers for DOD applications. Internet searches were unable to identify this document, but the style appears very similar to Reference 12, which was a monthly commentary posted on the SFSA website. References 12 and 21 have the same format, namely (1) an introduction of a challenge for the C&F industry, (2) background information, and (3) a question-and-answer section. Many of the same topics are in both documents, and some language appears verbatim. Reference 21 appears to have resulted from a "a submission from industry" to Executive Order 14017 (President Biden's initiative on America's supply chains).[22] Although the author of Reference 21 is unknown, it is extremely similar to the writings of R. Monroe.[12] An extract from the action plan developed in response to Executive Order 14017 – Castings and Forgings can be found in Appendix D.

The "submission from industry" makes two criticisms of DOD practices. The first is addressed below in the Document Overview because it only receives brief attention. The bulk of Reference 21 is associated with the second criticism. It states that the Army and Navy lack a development path that allows collaboration and shared risk between the OEMs, industry service providers, and steel producers: "DOD expects their suppliers including foundries and forge shops to bear the cost of becoming qualified for blast testing, first articles qualification, source qualification to stringent DOD specific standards like the Navy requirements for HY materials that typically take over a year and cost on the order of millions of dollars. This initial investment gives no guarantee that if successful, they will get the business required to recover the costs. This qualification investment includes creating a cybersecurity system compliant with DOD requirements that remain undefined." Reference 21 makes an estimate of costs and delays encountered as a DOD supplier.

DOD's acquisition practices have built-in assumptions that no longer "reflect reality."[21] According to this position, DOD does not hold the market position it did in the past. It is no longer a coveted customer. DOD processes are too far removed from the practices in other industries, and because the C&F industry has lost many companies in the past 20 years, there exists a smaller pool of suppliers from which DOD must pull. The supplier companies that have survived have other options besides DOD.

The bulk of Reference 21 deals with a hypothetical question: how much does it cost (casting, testing, reporting) to become qualified for DOD work? A couple of example estimates are given, including Navy HY80/100 to T300R2. This HY example is estimated to cost from $1 million to $3 million, take 18-48 months (wait time is ~50% of the total), and involve $3 million to $35 million worth of work in progress on hold at any time. Other certifications are required to engage in this work including $50,000 to $250,000 for test machine certifications, heat treat furnace certifications, etc. Personnel handling controlled unclassified information (CUI) require around $200,000 setup costs and ~$1000 per employee. ITAR are estimated to cost $50,000 for setup and $200 per employee. Cybersecurity requirements were also mentioned. The example indicates a cumbersome supplier experience.

Another hypothetical question is posed: how much capital investment would be required by the C&F industry to modernize/automate to DOD requirements. The estimate is $100 million.
The overarching points made by Reference 21 are that DOD is a difficult customer that is expensive to work with, and 100% of the burden of time-consuming qualifications must be carried by the C&F supplier with no guarantee of actual orders. This may have worked in the past when more C&F companies existed, but this is no longer the case, and suppliers have other choices. The SFSA is working with government entities to improve this situation.

Topics within RAPLSS Scope

To understand topics within the scope of RAPLSS in the area of C&F, Reference 12 provides more information than Reference 21. The reference does, however, provide detailed estimates that indicate the magnitude of certain DOD-related challenges for C&F companies.

Document Overview

Because Reference 21 is rather short (five pages), and the summary above provides a suitable overview, only limited information will be provided here.

As noted above, Reference 21 includes a “submission from industry” with criticism of DOD processes. One criticism was for raising property requirements above the minimum lower bounds of the specified material, this being related to a “drive to raise performance.” Reference 21 states that for non-critical components, the DOD should align quality requirements with the capabilities of the material and also claims that no additional benefit has been achieved by this change in material specifications. Although the application and context is not known, in other industries, it is not unusual to use the core requirements of industry standards as a design basis, but then to overlay additional “company” requirements at the discretion of the owner’s engineers. It could be that the DOD engineers had good cause to specify enhanced properties or perhaps enhancement was justified for a few cases but that this was extended universally without case-by-case consideration. Without detail, the claims of this DOD criticism cannot be assessed.

In the final section of Reference 21, a road mapping session is proposed to improve the C&F supply chain, but details are not given. It is speculated that the hosting organization is SFSA. Four major themes stand out:

1. Current suppliers are inadequately capitalized to support the DOD mission with reliable supply for critical castings and forgings. Developing a more robust supply base for advanced requirements likely requires "… on the order of $100,000,000."
2. Supply chain management needs reorganization to address the current weaknesses and systemic limitations. Expecting potential suppliers to self-fund qualification, to carry the costs of work in progress (WIP), and to wait an indeterminate amount of time for responses make this market unsustainable for current suppliers. Purchasing needs to aggregate orders into large buckets to support the fixed costs of DOD work, have staged payments, have response time requirements with payments for slow response, and support the infrastructure and qualification costs in some responsible way.
3. The difficulty of being a supplier to OEMs who are DOD providers makes decision making opaque, slow, and unresponsive. There needs to be a clear structure for resolving ordinary approvals and questions to suppliers like C&F producers.
4. Market uncertainty makes planning and investing to meet current and future requirements challenging. The inability to plan beyond the current orders with no clear guidance on future demand and likely production requirements makes this market difficult.

3.3 Manufacturing, Welding, Joining and Forming

3.3.1 NIST Project 14H050, A Comprehensive Advanced Joining and Forming Technology Roadmap, Edison Welding Institute, 2016 [23]

Summary

Reference 23 is a 133-page report that provides an advanced joining and forming technology roadmap for the needs of the U.S. manufacturing industry during the period 2017-2024. This report resulted from an EWI-led group called the Advanced Manufacturing Technology Consortia (AMTech) that was funded by the National Institute of Standards and Technology (NIST). The project team identified and prioritized materials joining and forming technology needs and provided an R&D portfolio to impact U.S. manufacturing competitiveness. The project took more than two years and incorporated feedback from 409 companies. The information on which the report was based came from reviewing key industry literature and conducting focus groups, surveys, and interviews.

This report begins by explaining the importance of U.S. manufacturing to the economy and national security. It also covers key challenges and describes the health of manufacturing in the United States. Insightful data, statistics, and graphs emphasize the points. In recent decades, U.S. manufacturing has declined, and manufacturing jobs have lost status due to the perception that such jobs are dark, dirty, dangerous, and dying – the 4Ds. Finding a sufficient workforce in the future will be the manufacturing industry's biggest challenge.

After eight market drivers and five technology gaps were identified, the following development priorities were established:

- Workforce skills development encompassing the emerging and incumbent labor force, including technician, skilled trades, and professional staff
- Development of advanced weld distortion control methods
- Development of next-generation prediction tools: automata materials exploration and optimization for joining processes
- Development of advanced high-productivity fusion processes
- Development of joining processes for hybrid materials and mixed metals
- Implementation of advanced measurement, prediction, and control technologies in forming processes
- Development of practical warm/hot forming technology for aluminum, titanium, nickel alloys, and steels
- Development of advanced technologies for lightweight forgings.

For each of these priorities, the consortia created objectives, the approach, and an estimated time frame. The report suggests that if these priorities are addressed and technology advancements are delivered to the manufacturing floor, the improvements would reduce waste, scrap, and rework and would increase productivity of joining and forming operations. Additionally, the advancements would enable the manufacturing of products with material combinations that are not currently feasible.

Topics within RAPLSS Scope

Many of the topics covered in Reference 23 are within the scope of RAPLSS. Reference 23's justifications are shown through statistics, graphs, and studies that pertain to the magnitude of U.S. manufacturing. Much of this information, like decade-by-decade statistics and the results from studies by the American Welding Society and International Institute of Welding, are time dependent. Because Reference 23 is eight years old, it is recommended that updated information be considered.

Reference 21 states that needs in workforce development dominated all other topics by a wide margin. [Note: The same, or analogous, sentiments were stated in nearly every document of this review]. In Chapter 7 of Reference 23, contains a literature review and also summarizes previous studies. Many of the studies addressed workforce limitations and ideas for development. The organizations that performed these studies have connections to manufacturing. Furthermore, Reference 23 incorporates the reviews into its own recommendations for workforce development. This includes ideas for a national training center for technical disciplines, a national apprenticeship program (same concept strongly supported in References 16 and 17), and a national co-op program.

On workforce challenges, this report indicates a three-pronged dilemma: (1) the 4Ds, (2) the clean environments of many advanced manufacturing companies (e.g., microelectronics), and (3) the realities of large structure fabrication. The 4Ds negatively affect public perception of manufacturing jobs. A counterpoint is that many modern industries are automated, clean, and relatively non-physically demanding. On the other hand, a challenge is that large structure fabrication (including subcomponents) is typically conducted in facilities that are arguably dark, dirty, dangerous, but not necessarily dying. The future of large structural and systems fabrication must address the 3Ds.

Because the 3Ds are a reality for large structures, one approach is to dispense with narratives about pristine facilities and to simply find people who will not recoil from the realities of large structures. Ex-military, farming communities, and immigrant communities are a few examples more likely to yield suitable personalities as compared to the average big city suburb. Studies might consider approaches aimed at identifying if certain communities are, in fact, a better bet when choosing where to advertise or focus workforce initiatives. If such studies indicate promise with certain communities, then follow-up efforts would be useful to determine how to recruit and train from any specific community.

Nearly all of the identified priorities from Reference 23 are useful (perhaps warm/hot forming for transportation is an exception). For example, distortion control is always a challenge for large structures. Consider shipbuilding, which is an industry that is ascending in the U.S. due to offshore wind as will be explained below.[24] Any structures incorporating stiffened panels interconnected by butt welds will inevitably experience departures from a flat surface and fit-up challenges due to distortion. Furthermore, in large structures, fixturing is sometimes used for distortion control, and the resulting restraint and residual stresses can cause cracking problems. The modeling and smart welding systems recommended in Reference 23 for distortion control are useful in shipbuilding and other LSS-aligned industries.

Regarding the priority on “Next-Generation Prediction Tools …,” one connection to LSS is associated with materials development for the nuclear industry. As noted elsewhere, the nuclear industry has plans for advanced reactors which will operate in never-before-experienced conditions that require new materials.[20], [25], [26], [27] The materials modeling technologies mentioned for the prediction tool priority of Reference 23 can be used for preliminary materials screening. Such tools enable digital experiments using databases (e.g., Thermo-Calc) where large numbers of chemistries are “tested” according to important physical attributes like phase transformation temperatures, stacking fault energy, diffusion coefficients, etc. Likewise, model-based screening can greatly accelerate weld consumable development programs that must otherwise depend on trial-and-error and a limited number of chemistries and experiments.

High-productivity fusion processes are critical for LSS due to the volume of welding. High-speed and high deposition rate processes are needed, but not all desired developments are weld pool centric. Reference 23 recommends efforts on integrating NDE techniques “in-situ” with welding systems to provide real-time feedback that will lead to fewer repairs and less downtime. This aligns well with the focus on sensors and smart machines for Industry 4.0. Sensors that provide input to advanced welding and forming automation will enable improved efficiency.

Joining for hybrid materials will find alignment with LSS in niche areas. These applications include dissimilar metal joining that will likely be useful for large systems like piping networks in oil and gas installations, refineries, and chemical plants, and for the systems below deck in advanced naval vessels. Systems transitions from more-to-less harsh environments, particularly regarding service temperatures and/or chemicals will create the need. It is also likely that newer, lighter, or stronger materials (composites, layered materials, etc.) will need to be joined within large systems, although the use may be limited.

One priority identified in Reference 23 is “Advanced Measurement, Prediction, and Control Technologies in Forming Process.” The envisioned application was related to thinner materials and lightweight structures. For RAPLSS, similar concepts and technologies still apply (sensors, measurement, prediction, control), but the focus must change to larger, thicker, and heavier structures including large-scale forging operations. This ties in directly to the Reference 4 priority, “Advanced Technologies for Lightweight Forgings.” As new technologies and approaches are applied to this application, challenges will arise for large structures and related components within the LSS sphere.

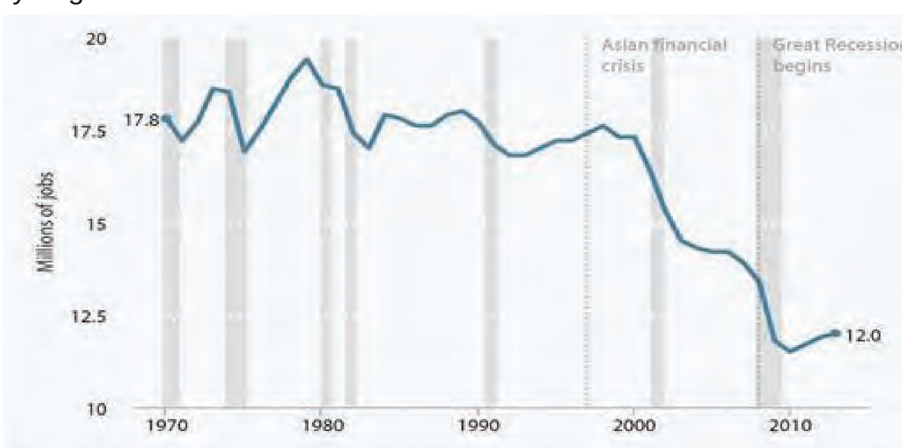
Document Overview

To initiate this AMTech project, several governing principles and focus statements were established.

- **Vision Statement**. The vision for this national technology roadmap for materials joining and forming is to identify broad and compelling technology development initiatives that would positively transform these technologies and their application in industry to enhance the global competitiveness of the U.S. manufacturing sectors and the economy at large.
- **Main interest**: Of primary interest are metals, plastics, ceramics, and advanced composites such as metal-matrix composites (MMCs), ceramic-matrix composites (CMCs), and polymer-matrix composites (PMCs). These are the materials from which the vast majority of engineered and manufactured components are produced.
- **Joining processes of relevance:** All forms of electric arc welding, resistance welding, solid-state welding, brazing, soldering, adhesives, high energy welding processes such as laser, plasma, and electron beam, and hybrid variations of these processes.
- **Metal-forming operations:** stamping, punching, deep drawing, crimping, forging, extruding, roll forming, powder forming, and wire drawing.

A few of the facts, data, and statistics mentioned in Reference 23 as reasons that manufacturing, joining, and forming are important and that some undesirable trends have occurred in the U.S. include the following:

- By the 1980s, U.S. manufacturing jobs and contribution to gross domestic product (GDP) began to decline. This has continued in the 2000s and the financial standing of the middle class has suffered (See Figure 8 below).
- By 2020, the number of U.S. manufacturing jobs was about 11 million, approximately half the number in 1980 (reported by the U.S. Department of Labor). Also, the U.S. was ranked third in the world in manufacturing competitiveness compared to first in 1980.
- Since 1990, the manufacturing trade balance in the United States has declined by $500 billion.
- Today, manufacturing supports nearly 12 million direct and more than 29 million indirect employees, which is more than 20% of the total domestic workforce.
- Manufacturing is the largest segment of the U.S. economy, generating over $2 trillion in annual sales, which is roughly one-eighth of the GDP ($17 trillion). Of that, close to $890 billion is within markets that rely heavily on forming and joining technologies.
- Nearly 60% of all manufactured goods include some joining and/or forming operations.
- Joining and forming contribute around $200 billion in value to U.S.-manufactured products annually.
- In the 2012 *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing*, it was identified that joining and forming technologies are "pivotal in enabling US manufacturing competitiveness, both in terms of differentiation and tradability of goods."



Note: Shaded areas denote recessions.

Figure 8. U.S. Manufacturing Jobs and Contribution to Gross Domestic Product (GDP). Note: The Drop in Manufacturing Jobs Happened Mostly between 2000 and 2010

Reference 23 states that the future success of U.S. manufacturing depends on how well manufacturers navigate challenges. The following are "macro" challenges that cut across industry sectors and geographies:

- Increased global competition for markets and resources
- Aging technical workforce and difficulties growing tomorrow's workforce
- Decline in perceived value of manufacturing.

Reference 23 describes that a number of focus groups (Table 3) were convened as industry canvassing methods and were successful in collecting and ranking answers to topic questions. They were particularly useful in gathering detailed materials joining and forming technology gaps within key industrial sectors. Meetings were typically one-half to one-day sessions and were held in geographic regions consistent with the industry sectors (automotive in Detroit, oil and gas in Houston). Sixteen sessions were held with more than 650 participants attending as summarized in the adjacent table.

Table 3. Listing of Industry Focus Group Sessions for AMTech Report

Event	Location	Date	Technology	Attendance
Oil & Gas Industry	Houston, TX	Sep. 16, 2014	Joining	16
EWI Forming Center	Columbus, OH	Oct.16, 2014	Forming	80
EWI IAB	Columbus, OH	Nov. 19, 2014	Joining	15
FABTECH Conference	Atlanta, GA	Nov. 10, 2014	Joining	12
FABTECH Conference	Atlanta, GA	Nov. 13, 2014	Forming	22
AWS TAC Meeting	Miami, FL	Jan. 15, 2015	Joining	11
OSU Dissimilar Metals Workshop	Columbus, OH	Jan. 28, 2015	Joining	41
PRCI Meeting	Houston, TX	Feb. 3–5, 2015	Joining	253
Northwestern University Joint Meeting	Chicago, IL	May 4–5, 2015	Forming	35
Aerospace Industry	Huntington Beach, CA	April 16, 2015	Forming	13
Aerospace Industry	Huntington Beach, CA	April 16, 2015	Joining	15
Aerospace Industry	Cincinnati, OH	May 22, 2015	Forming	14
Aerospace Industry	Cincinnati, OH	May 22, 2015	Joining	16
Automotive Industry	Detroit, MI	Aug. 11, 2015	Joining	21
Ohio Manufacturers	Columbus, OH	May 27, 2015	Forming	> 80
Ohio Manufacturers	Columbus, OH	May 27, 2015	Joining	

The focus groups and surveys identified the following business factors as drivers for innovation:

- A decrease in available labor, particularly with respect to the technical labor force
- Lightweighting
- Improved productivity
- Improved product reliability and performance (and reduced warranty claims)
- Reduced product manufacturing costs
- Reduced time to market cycles (get new products to market faster)
- Improved energy efficiency (greener manufacturing processes)
- Reduced environmental impact (such as reduced water usage in manufacturing).

These business drivers were then linked to the following technical gaps that were determined to be critical to undermining global competitiveness:

- Development of a sufficiently sized and skilled technical labor force
- Technologies to reduce the current design-to-market cycle
- Technologies to reduce rates of scrap and rework
- Development of advanced real-time in-process monitoring and control technologies (improved first-time quality)
- Development of new or improved joining and forming processes for next generation materials.

To address these gaps, eight technology development priorities were identified. These were listed above in the Summary and are listed here again for completeness:

- Workforce skills development encompassing the emerging and incumbent labor force, including technician, skilled trades, and professional staff
- Development of advanced weld distortion control methods
- Development of next-generation prediction tools: automata materials exploration and optimization for joining processes
- Development of advanced high-productivity fusion processes
- Development of joining processes for hybrid materials and mixed metals
- Implementation of advanced measurement, prediction, and control technologies in forming processes
- Development of practical warm/hot forming technology for aluminum, titanium, nickel alloys, and steels
- Development of advanced technologies for lightweight forgings.

Global events can create more abrupt industrial changes than would have taken place otherwise. Since the completion of the AMTech project and the writing of Reference 23, a few world events have occurred, namely Covid (and related supply chain disruptions), the war in Ukraine, and increased inflation. The Ukrainian conflict has caused many countries to curtail or eliminate their dependence on Russian oil and gas. Prior to the war, Germany imported about 55% of its gas from Russia; they have ceased imports. This has caused Germany to reverse some green energy initiatives (coal plant closings) while simultaneously increasing other green energy efforts like offshore wind. In fact, since 2022, the U.K. and the entire European continent has dramatically increased its pursuit of offshore wind as a reaction to the war in Ukraine. The heavy manufacturing companies that make monopiles (the tubular steel foundations that sit on the ocean floor and support wind towers and turbines) are struggling to meet the demand. Seven day-per-week, 24-hour schedules are commonplace at European monopile companies, and several new facilities are under construction as well.

The changing offshore wind market and demand for monopiles has reverberated across the Atlantic because the United States, which are just getting started with offshore wind, was depending on European supply of monopiles. The resulting cost pressures have contributed to rapidly changing industry dynamics within the monopile industry, which is one of the best examples of a topic aligned with LSS. Additional discussion on offshore wind and monopiles is given in the review of Reference 24 and in the Summary for all document reviews.

3.3.2 Strategy for American Leadership in Advanced Manufacturing (Oct. 2018), Subcommittee on Advanced Manufacturing (SAM), Committee on Technology of the National Science and Technology Council (NSTC) [16]

Foreword

References 16 and 17 are closely related. Both emanate from the same initiative (same government office, same intent); however, Reference 16 was created in 2018 by and for the Trump administration, and Reference 17 was created in 2022 by and for the Biden administration. In the summary for Reference 17, there is a brief analysis of the policy differences between References 16 and 17.

Summary

Reference 16 is a 40-page report prepared by the Subcommittee on Advanced Manufacturing (SAM), a subcommittee within National Science and Technology Council (NSTC). After extensive public outreach, the goal of this report is to advise the Executive Branch (office of the President) on advanced manufacturing in the United States. The report is prepared every four years. Through this effort, NSTC aims to ensure science and technology policy decisions and programs are consistent with the President's stated goals. SAM is fully aware of how important manufacturing is to the economy, global leadership, and national security. The report is organized around three goals:

- Goal No.1: Develop and transition new manufacturing technologies
- ➢ Goal No. 2: Educate, train, and connect the manufacturing workforce
- – Goal No. 3: Expand the capabilities of the domestic manufacturing supply chain

Thirteen strategic objectives are identified along with program priorities, specific actions, and expected outcomes to be accomplished during the next four years. These objectives are organized within the three goals above and are marked with the same bullet styles.

Goal No. 1:

- Capture the Future of Intelligent Manufacturing Systems
- Develop World-Leading Materials and Processing Technologies
- Assure Access to Medical Products through Domestic Manufacturing
- Maintain Leadership in Electronics Design and Fabrication

- Strengthen Opportunities for Food and Agricultural Manufacturing

Goal No. 2:

- Attract and Grow Tomorrow's Manufacturing Workforce
- Update and Expand Career and Technical Education Pathways
- Promote Apprenticeship and Access to Industry-Recognized Credentials
- Match Skilled Workers with the Industries that Need Them

Goal No. 3:

- Increase the Role of Small and Medium-Sized Manufacturers in Advanced Manufacturing
- Encourage Ecosystems for Manufacturing Innovation
- Strengthen the Defense Manufacturing Base
- Strengthen Advanced Manufacturing for Rural Communities

Topics within RAPLSS Scope

There are topics in Reference 16 aligned with RAPLSS; however, there are also key differences. Whereas RAPLSS mentions industries that use large structures and systems (nuclear, oil and gas, rail, shipbuilding, etc.), Reference 16 rarely mentions such and as a result, there is limited direct connection between Reference 16 and RAPLSS. Instead, Reference 16 focuses on <u>technologies and policies</u> that will facilitate advanced manufacturing. A number of these *are* consistent with RAPLSS. Reference 16 does mention a few high-tech industries by name (electronics, semiconductor, and biotechnologies), but these have limited relation to RAPLSS.

Goal No. 1 in Reference 16 includes technologies that are aligned with RAPLSS: digital/smart manufacturing technologies, internet of things, machine learning, artificial intelligence, cybersecurity, and real-time modeling. Reference 16 mentions high-strength lightweight metal alloys, ultra-high temperature structures for more efficient turbines in power generation, additive manufacturing, and 3D printing.

Goal No. 2 covers the most notable area of alignment between Reference 16 and RAPLSS — workforce limitations. It identifies science, technology, engineering, and mathematics (STEM) education as vital to advanced manufacturing. It acknowledges that attracting qualified workers to manufacturing fields is a problem. The United States lacks national requirements for government, educators, labor representatives, and employers to coordinate on workforce development policies and practices. This gap makes it crucially important to support secondary- to post-secondary career and technical education (CTE), project-based curricula, competency-based training, career pathways, and self-directed learning programs. Further support is needed with two-year community college programs and four-year university programs, particularly for software design, engineering technology, systems engineering, and robotics. Manufacturing apprenticeships that are nationally recognized and portable between industries are recommended. The report also recommends continued investments in federal initiatives like the DOD Manufacturing Engineering Educational Program and the NSF Advanced Technological Education program.

Associated with Goal No.3, Reference 16 discusses aspects of the U.S. manufacturing supply chain. That most manufacturing companies in the U.S. are small and medium-sized manufacturers (SMMs) is a key focus, and policies/initiatives directed at SMMs are discussed. Considering the focus of RAPLSS, this discussion should be useful. For example, C&F companies fall into the SMMs category. Reference 16 states that SMMs must be connected to sources of technologies, technical infrastructure, and specialized knowledge through vendors, universities, federal laboratories, Manufacturing USA institutes, and others. SMMs, however, are often not aware of public-private partnerships, or do not see the networking benefits of these groups. SMMs need awareness of major and minor technological changes that will affect their businesses. They need input into the research agenda of the consortium so the results can be adopted by SMMs; need trajectory tracking of a new technology to know when to invest; and they must be engaging in R&D activities with potential customers to enhance technical reputation with these customers.

Document Overview

In an early section of the report, Reference 16 spends ample time describing the decline of the manufacturing sector in the United States during the 1990s and another decrease during the 2008 recession. It emphasizes that the manufacturing sector cannot be allowed to decline any further and the U.S. government must provide leadership, guidance, and long-term support for this industry. The economy and national security are linked to the health of manufacturing in the U.S.

Goal No. 1: Develop and Transition New Manufacturing Technologies

Reference 16 communicates strong support of public-private partnerships that bring together diverse stakeholders with overlapping interests. Large-scale consortia with shared resources, such as physical infrastructure and colocation of tools, technology, and embedded expertise, can expand regional innovation ecosystems and drive economic growth. This focus plays a role in all three goals.

On smart manufacturing, the benefit of in-situ sensing and correcting anomalies to ensure product uniformity, quality, and traceability is discussed. Such advances depend on the internet of things, machine learning algorithms that can be applied across a range of manufacturing processes, and machine tools and controllers that can plug-and-play in an integrated, information-centric system. Additionally, because this advanced technology requires connected hardware and a highly technical workforce, it can often be a challenge for SMMs to adopt the latest advances. This is where collaborative networks and consortia can play a role in providing technology and guidance that might otherwise be beyond their reach. With digital manufacturing in mind, Reference 16 outlines the following action:

> "Facilitate a digital transformation in manufacturing by enabling the application of big data analytics and advanced sensing and control technologies to a host of activities. Prioritize support for real-time modeling and simulation of production machines, processes, and systems to predict and improve product performance and reliability; mine historical design, production, and performance data to reveal the implicit product and process know-how of the expert designers who created them. Develop the standards that will enable seamless integration between smart manufacturing components and platforms."

On advanced robotics, the benefits of human-robot co-work is recognized and discussed. Reference 16 states:

> "Promote development of new technologies and standards that enable wider adoption of robotics in advanced manufacturing environments and promote safe and efficient human-robot interactions."

Regarding artificial intelligence (AI), the importance of AI for manufacturing is recognized:

> "Develop new standards for AI and identify best practices to provide consistent availability, accessibility, and utility of manufacturing data within and across industries, while maintaining data security and respecting intellectual property rights. Prioritize R&D to develop new approaches to data access, confidentiality, encryption, and risk assessment for U.S. manufacturers."

On cybersecurity, a connection was made between this topic and the size of SMMs. Smaller companies sometimes struggle to be on the cutting edge of cybersecurity due to the pace of this challenge. Therefore, public-private partnerships and consortia can play a role to assist SMMs with maintaining up-to-date cybersecurity technology:

> "Develop standards, tools, and testbeds, and disseminate guidelines for implementing cybersecurity in smart manufacturing systems. Move American manufacturers towards better cybersecurity."

On additive manufacturing (AM) the need for new activities is recognized:

> "Continue advancements in process control and process monitoring to secure AM technologies as viable production alternatives. Develop new methods to measure and quantify the interactions between material and processing technology to better understand material-process-structure relationships. Establish new standards to support the representation, presentation, and evaluation of AM data to ensure part quality and reproducibility. Expand research efforts to establish best practices for applying computational technologies to AM, including simulation and machine learning."

Goal No. 2: Educate, Train, and Connect the Manufacturing Workforce

Reference 16 discusses the many challenges that the manufacturing sector faces in attracting a sufficient workforce. Despite the benefits of high-paying manufacturing jobs, many young people miss out due to outdated presumptions that all manufacturing jobs are still repetitive, labor-intensive, low-paying, or have a limited future in the U.S. Some of the stated initiatives include:

- "Provide school districts with the appropriate resources to incorporate manufacturing and engineering technology education programs into their science standards, engage and retain younger students in STEM, particularly across underrepresented groups, and better inform parents and other members of the public on the benefits of manufacturing and advanced technology careers."
- "Establish a strong talent pipeline ready for advanced manufacturing by increasing investments in manufacturing engineering education that leads to two-year, four-year, and advanced degrees. Create more technical curricula and research programs that prepare graduates to tackle real-life challenges and innovate future novel manufacturing technologies."
- "Strengthen public-private partnerships to include industry-relevant training in advanced manufacturing curricula with opportunities for students and teachers to receive mentorship from industry members, keep up to date on new technologies, and share educational materials."
- "Leverage opportunities in the reauthorized Carl D. Perkins Career and Technical Education Act to promote high-quality advanced manufacturing programs aligned to local demands and incorporating strategies allowing students to work and learn through apprenticeships."
- "Accelerate development of quality industry-recognized apprenticeship programs to provide manufacturing workers with greater access to portable, industry-recognized, competency-based credentials."

Goal 3: Expand the Capabilities of the Domestic Manufacturing Supply Chain

Support for SMMs is prominent in this chapter of Reference 16. Connecting SMMs to sources of information like consortia, public-private partnerships, federal labs, Manufacturing USA Institutes, etc. and making sure SMMs have access to the latest cybersecurity technology are important. [Sidenote: An idea (not in Reference 16) to assist SMMs is as follows: Establish a government agency or government-sponsored program that compiles an annual report (and inter-year updates for time-critical items) devoted to the status, trends, and developments for advanced manufacturing in foreign countries. Call it GTAM (Global Trends in Advanced Manufacturing). Countries like China, Japan, and Germany are strong in manufacturing and are global competitors for SMMs; however, SMMs are not likely to have the capabilities or resources to monitor foreign trends particularly if the information is in a foreign language. GTAM would follow foreign trends, translate as necessary, and provide intelligence summaries. GTAM intel gathering sources, and reports would be in the public domain. Therefore, this effort would not run afoul with international law.]

Concerning technology transfer from “lab-to-market” (i.e., commercializing promising technology), Reference 16 recognizes that this step is often a sticking point. A number of government programs are mentioned and then this statement is given:

> “Coordinate across the agencies and between Federal technology transfer-related policy groups to identify technologies suitable for transition from laboratory to market within the United States. Prioritize funding for research into measurement science and standards development to speed the transition of R&D to commercial practice.”

Two items that received attention in Reference 16, but will not be covered here are (1) strengthening the defense manufacturing base, and (2) strengthening advanced manufacturing in rural communities.

Progress Made in Achieving the Objectives from the 2012 Strategic Plan

As mentioned previously, this report of strategy for advanced manufacture in the United States is compiled every four years. A standard part of the report (the last chapter) is an assessment of the progress made toward the previously documented objectives. Reference 16 states that the establishment and growth of the *Manufacturing USA* (MUSA) institutes has been an important accomplishment. In FY 2017, MUSA institutes included 844 manufacturing firms and 297 educational institutions. A useful reference is given of an independent assessment of MUSA’s progress.(28) It provides an analysis of the various institutes and makes recommendations about what does, or does not, work. Reference 28 is a good resource for organizations interested in running/managing industry consortia.

Included in Reference 16’s last chapter are two tables (Table 4 and Table 5, shown below) listing federal programs that have contributed to progress in manufacturing. These may be of use in searching for RAPLSS opportunities.

Table 4. Federal Programs Contributing to Manufacturing Progress

Agency	Education and Workforce Development Programs	
DHS	• DHS HS-STEM Summer Internship Program	
DOC	• Manufacturing USA Institutes, Education and Workforce Programs	• MEP Centers, Workforce Development Programs
DoD	• Army Educational Outreach Program • STARBASE • Manufacturing USA institutes, Education & Workforce Programs • Veterans To Energy Careers • Manufacturing Engineering Education Program	• Science, Mathematics, and Research for Transformation Defense Education Program • STEM Outreach Programs • Systems Engineering Capstone • Transition Assistance Program • SkillBridge • National Defense Education Program
DOEd	• Carl D. Perkins Career and Technical Education Act	
DOE	• Manufacturing USA institutes, Education Workforce Programs • Lab-Embedded Entrepreneurship Programs	• Advanced Manufacturing Traineeships • EERE Robotics Internship Program • Industrial Assessment Centers
DOL	• Apprenticeship Programs • Trade Adjustment Assistance	• Workforce Innovation and Opportunity Act
NASA	• Space Technology Research Grants Program • Faculty Fellowship Program	• Established Program to Stimulate Competitive Research Program
NSF	• Advanced Technological Education Program • Broadening Participation in Engineering Program	• Research Experiences for Undergraduates Program • Research Experiences for Teachers Program
USDA	• Academic Scholarships and Aides • 4-H Science Program	• Enhancing Agricultural Opportunities for Military Veterans

Table 5. Manufacturing Programs by Federal Agency

Agency	Manufacturing and Related Programs	
DOC (NIST & ITA)	• Manufacturing USA • Manufacturing Extension Partnership • Additive Manufacturing • Smart Manufacturing Systems • Robotics for Smart Manufacturing • Advanced Materials Measurements • Standard Reference Materials	• Materials Genome Initiatives • Physical Measurements • Biomanufacturing • ITA Global Markets • ITA Industry & Analysis • ITA Enforcement and Compliance
DoD	• Manufacturing Technology Programs • Manufacturing USA institutes • Defense Industrial Base Modernization	• Industrial Base Analysis and Sustainment Program • Defense industrial base scale-up • Defense Production Act Title III
DOE	• Clean Energy Manufacturing Institutes • High Performance Computing for Manufacturing • Lab-Embedded Entrepreneurship	• Energy Innovation Hubs • Manufacturing Demonstration Facility at Oak Ridge National Laboratory • Critical Materials Hub
HHS/FDA	• Advanced Research and Development of Regulatory Science for Continuous Manufacturing • Centers for Innovation in Advanced Development and Manufacturing	• Bio-Medical Advanced Research and Development Authority • Medical Countermeasures Advanced Development and Manufacturing
NASA	• Game Changing Technology Program • Advanced Exploration Systems Program, In-Space Manufacturing Project	• Advanced Manufacturing Technology Project • National Center for Advanced Manufacturing
NSF	• Engineering Research Centers • Industry/University Cooperative Research Centers • Advanced Manufacturing • National Robotics Initiative 2.0	• Secure and Trustworthy Cyberspace • Cyber Physical Systems • Cellular and Biochemical Engineering • Designing Materials to Revolutionize and Engineer our Future
USDA	• Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program • Business and Industry Guaranteed Loan Program • Biofuel Infrastructure Partnership • Rural Utility Service	• Rural Business-Cooperative Service • Research grants • Small Business Innovation Research • Support for export-related activities and marketing, including USDA BioPreferred Program

3.3.3 National Strategy for Advanced Manufacturing (Oct. 2022), Subcommittee on Advanced Manufacturing (SAM), Committee on Technology of the National Science and Technology Council (NSTC) [17]

Foreword

References 16 and 17 are related. They are from the same initiative (same government office, same intent); however, Reference 16 was created in 2018 by the Trump administration and Reference 17 was created in 2022 by the Biden administration. The review of Reference 17 will sometimes be explained in contrast to Reference 16.

Summary

Reference 17 is a 53-page report prepared by SAM (subcommittee within NSTC) after extensive public outreach, the goal being to advise the Executive Branch (office of the President) on advanced manufacturing in the U.S. The report is prepared every four years. Through this effort, NSTC aims to ensure science and technology policy decisions and programs are consistent with the President's stated goals. SAM is fully aware of how important manufacturing is to the economy, global leadership, and national security. The report is organized around three goals:

- Goal No.1: Develop and Implement Advanced Manufacturing Technologies
- ➢ Goal No.2: Grow the Advanced Manufacturing Workforce
- – Goal No.3: Build Resilience into Manufacturing Supply Chains

The three primary goals are further broken down into eleven strategic objectives. For each objective, the program priorities, specific actions, and expected outcomes for the next four years are defined. These objectives are organized here according to the same bullet styles as noted above.

Goal No. 1:

- Enable Clean and Sustainable Manufacturing to Support Decarbonization
- Accelerate Manufacturing for Microelectronics and Semiconductors
- Implement Advanced Manufacturing in Support of the Bioeconomy
- Develop Innovative Materials and Processing Technologies
- Lead the Future of Smart Manufacturing

Goal No. 2:

- ➢ Expand and Diversify the Advanced Manufacturing Talent Pool
- ➢ Develop, Scale, and Promote Advanced Manufacturing Education and Training
- ➢ Strengthen the Connections Between Employers and Educational Organizations

Goal No. 3:

- Enhance Supply Chain Interconnections
- Expand Efforts to Reduce Manufacturing Supply Chain Vulnerabilities
- Strengthen and Revitalize Advanced Manufacturing Ecosystems

Topics within RAPLSS Scope

Compared to Reference 16, Reference 17 is less aligned with RAPLSS. Both documents start with an overview of the vision/goals. In Reference 16, the vision stays relatively consistent with advanced manufacturing. In Reference 17, the vision is to use advanced manufacturing to accomplish bigger goals related to environmental sustainability, climate change, underserved communities, and healthcare. There is still, however, alignment among several technologies and policies described in Reference 17 and RAPLSS. The aligned topics include additive manufacturing, smart/digital manufacturing, artificial intelligence (AI) in manufacturing, cybersecurity, workforce education and training, and ensuring a robust manufacturing supply chain.

Goal No.1 in Reference 17 covers some technologies aligned with RAPLSS including digital/smart manufacturing, internet of things (IoT), machine learning (ML), artificial intelligence (AI), cybersecurity, digital twins, simulation/modeling, and robotics. Associated with materials and processing, Reference 17 mentions lightweight, high strength, high conductivity, corrosion-resistant metals, and AM. Neither Reference 16 nor Reference 17 mentions large-format AM. Any interests by RAPLSS to align with these programs on AM can concentrate on modeling, in-situ sensors, and post-AM inspection, or perhaps to grow the scope, making a case to SAM/NSTC to include large-format AM.

A particular focus in Reference 17 is using AI for management of production data across companies in a way that protects intellectual property (IP). Additionally, on cybersecurity, an executive order (EO 14028) is mentioned that includes helping manufacturers maintain security of their equipment and operations.[(1), (2), (3)]

Goal No. 2 in Reference 17 (as was the case for Reference 16), covers the most notable area of alignment with RAPLSS, workforce challenges. It identifies STEM education as vital to advanced manufacturing. It acknowledges that attracting qualified workers to manufacturing fields is a problem and recommends strong support for middle schools to showcase cutting-edge technologies and to prepare teachers with updated information and instructional methods. Support is also encouraged for secondary-to-postsecondary CTE and work-based learning programs like *Registered Apprenticeship*, which is discussed later in this report.

For goal No. 3, Reference 17 includes attention to the U.S. manufacturing supply chain and support for SMMs. A lack of trust/transparency across the supply chain is highlighted as a contributing factor to the chicken-and-egg problem (described in Reference 20). Public-private partnerships are encouraged to build trust and improve collaboration. The *AM Forward* initiative is cited as an example.[29], [30] Reference 17 mentions increasing the sharing of information/data between lead firms and suppliers. Ideas to mitigate concerns about privacy and IP concerns are discussed.

Like Reference 16, Reference 17 notes the challenges with SMMs and access to resources. It mentions the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs as examples to provide capital to SMMs with new ideas.

Document Overview

Since the previous quadrennial report on advanced manufacturing, two occurrences shaped Reference 17: Covid and the Inflation Reduction Act (IRA). Covid increased attention to healthcare, and the IRA brought focus to climate concerns. Mostly, these events decreased commonality between advanced manufacturing and LSS. One exception is that the IRA increased the pace of offshore wind, a new industry in the U.S. that is perhaps the most notable example of building large structures well into the future. Reference 17, though, makes no mention of offshore wind.

While Reference 16 describes the decline of U.S. manufacturing in the 1990s and during the 2008 recession, Reference 17 notes the decline but then provides data highlighting the sector's apparent comeback. The position is that government must provide leadership, guidance, and long-term support for manufacturing due to its critical influence on the economy and national security.

Reference 17 is explicit in its vision to use advanced manufacturing efforts as a step in achieving larger goals related to environmental sustainability, climate change, underserved communities, and healthcare. The only parallel to this within the previous quadrennial report, is that the Trump administration contained an explicit focus to assist the economic development and wellbeing of rural communities.[16]

Goal No. 1: Develop and Implement Advanced Manufacturing Technologies

Roughly one-third to one-half of the content within Goal No.1 includes such topics as decarbonization, energy efficiency, electrification, emissions reduction, high energy density batteries, smart electrical grids, sustainable materials, recycling, microelectronics, semiconductors, quantum computing, biomanufacturing, bioprocessing, biosecurity, clean bioenergy, pharmaceuticals, healthcare, and vaccines. These topics will not be covered in this review.

Reference 17 communicates an understanding that innovative materials and processes are important to enable next-generation nuclear reactors, defense systems, and other applications with harsh service conditions. Accelerated materials testing and other predictive capabilities for materials behavior are deemed important. These topics are aligned with RAPLSS. In particular, there is one specific recommendation (Section 1.4.2) on additive manufacturing that mentions topics such as advanced sensors, machine learning algorithms, feedback controls (in-process monitoring), and performance modeling. The challenges of lack of repeatability and predictability are noted. The section recommends Federal assistance to help AM overcome key technological barriers. The AM Forward is mentioned, and references are given.[29], [30] The section does not mention large format AM.

Critical materials such as rare earth elements, lithium, cobalt, nickel and platinum are noted as important to technologies for energy, transportation, health, and defense industries. Attention to the supply chain for these materials is discussed. In-space manufacturing is also mentioned but will not be covered here.

Smart manufacturing receives ample attention in Reference 17. Advanced sensing, machine learning, digital twins, 3D visualization, etc. are noted as important to productivity gains as well as the use of high-speed computing and communications technologies. The report recognizes that many technologies will only be useful if the information technology can be integrated with manufacturing operations. It states that smart manufacturing needs to transition from a few “heroic demonstrations” to routine use.

Consistent with the emphasis on smart manufacturing, Reference 17 covers AI and states a need or desire to enable access to production data and other information across companies but in a way that ensures proprietary data is not compromised. This would appear to be a difficult challenge considering that manufacturing companies may resist sharing production data. Even in a sanitized format, a trained specialist may be able to extract intelligence about competitors. Speaking of the common practice of “local solutions” kept as trade secrets, Reference 17 states, “Such siloed development inevitably results in massive, economy-wide inefficiencies due to the costly reinvention of solution that are routinely applied elsewhere.” While reinventing the wheel is possible, so is losing competitive advantage; therefore, the government may experience an uphill struggle to convince companies to share data.

As a result of accelerated use of digital information in advanced manufacturing, Reference 17 recognizes the importance of cybersecurity and threats to the enormous amounts of information stored in the cloud and on servers. It recommends developing standards, tools, and testbeds to protect smart manufacturing. Because of the vulnerability of SMMs and their need to be protected, the report explains the concept of a Software Bill of Materials for industrial equipment and references the President’s Executive Order 14028 on cybersecurity[1] This executive order and related activities at NIST are aimed at ensuring that manufacturers (and certainly this includes large component/structure manufacturers) maintain adequate security of their equipment and operations against cyber-attacks.[1], [2], [3] Small and medium-sized manufacturers (SMMs) can be particularly vulnerable to cyber-attacks because SMMs may be understaffed regarding the latest cybersecurity technology. The pace of new industry threats is very dynamic. Therefore, public-private partnerships and consortia can play a role in assisting SMMs with maintaining up-to-date cybersecurity technology.

Goal No. 2: Grow the Advanced Manufacturing Workforce

Approximately one third of the material for this goal is related to promoting awareness and engaging communities that are referred to as underserved and underrepresented. It suggests addressing social and structural barriers for these groups to achieve diversity, equity, and inclusion.

There exists some concern by the public that automation, artificial intelligence, and robotics will eliminate jobs, but Reference 17 maintains that the opposite is the case. Reference 17 advocates for developing advanced manufacturing technologies in a way that complements workers' skills rather than substituting for them. This will require distinct government support for STEM education, and promotion of advanced manufacturing, engineering, and technology at all levels beginning with middle school. The report discusses adequate preparation of teachers (training) and providing teaching staff with adequate resources and teaching materials. Reference 17 also mentions support for student competitions that incorporate the skills needed (digital skills, systems thinking, robotics) for manufacturing jobs/careers.

One item pertaining to workforce training can be extrapolated from a concept given under Goal No. 1, Recommendation 1.5.3, Human-Centered Technology Adoption. Whereas Reference 17 advocates for augmented/virtual/extended reality (AR/VR/XR) to assist workers in advanced manufacturing environments, the same technology can be invaluable for accelerating the experience of human-machine interactions. Virtual welding technology and EWI's Tele-manufacturing are a good examples of such a capability.

Facilitating connections between employers and educational organizations is a priority. Industry is encouraged to clearly define skill needs and to set standards – industry recognized credentials and certifications are discussed. Reference 17 is particularly supportive of high-quality, paid work-based learning and apprenticeships including internships, pre-apprenticeships, and the *Registered Apprenticeship* program. The report provides several references (website links) in this section. This report is particularly supportive of secondary-to-postsecondary career and technical education (CTE), project-based curricula, competency-based training, career pathways, and self-directed learning programs. It advocates support for two-year community college programs and four-year university programs, particularly for software design, engineering technology, systems engineering, and robotics. It recommends manufacturing apprenticeships that are nationally recognized and portable between industries.

Reference 17 states that the gold standard for work-based learning is the *Registered Apprenticeship* program, an industry-driven pathway where individuals obtain work experience, mentorship, classroom instruction, progressive wage increases, and a portable, nationally recognized credential. It acknowledges, however, that many employers find it challenging to meet all the requirements of a fully recognized *Registered Apprenticeship*. SMMs are particularly challenged to provide the resources needed. One remedy to this challenge is explained: the expansion and integration of work-based learning programs within secondary and postsecondary CTE programs.

RAPLSS aligns with the goals stated in Reference 17 regarding workforce training in the areas of welding, inspection, and post-college short courses . Furthermore, additional programs between technology organizations and local secondary schools would be ideal to promote manufacturing concepts.

Goal No. 3: Build Resilience into Manufacturing Supply Chains

Reference 17 highlights the notion of fostering coordination with supply chains and laments poor coordination and communication when the supply chain is "decentralized." It is apparent that Covid has influenced the Biden Administration's approach to supply chains. The report comes close to using the chicken-and-egg analogy by saying, "Major innovations in decentralized supply chains can suffer from a dilemma: upstream firms will not supply something until they see a demand for it, but downstream firms will not invest in products requiring that input unless there is a ready supply (as is the case of additive manufacturing)." Reference 17 promotes the idea of public-private partnerships to improve technology adoption and touts the AM Forward initiative as an example.

Reference 17 is a proponent of digital transformation and specifically mentions several key areas: "robust industrial internet of things; artificial intelligence and machine learning algorithms; robotics that can be applied across a broad range of manufacturing processes." It recommends efforts to trace information and products along supply chains and states that the U.S. "… must expand ongoing R&D efforts to represent, structure, communicate, store, standardize, and secure product, process, and logistical information in a digital manufacturing environment." It says that lack of information is frequently due to lack of trust between original equipment manufacturers and suppliers. It recommends increasing visibility into supply chains. "Transparency" in supply chains is deemed important because it promotes awareness of risks, identifies bottlenecks, and helps organizations determine whether alternative sources of critical inputs are needed. A primary challenge to these desires relates to the willingness of companies to provide information that could very well be considered proprietary. Transparency might also create insight for competitors to glean intel on manufacturing strategies, production capacity, pricing, investment priorities, and changes in business model. While transparency is likely good for supply chain health, it may not be good for the health of manufacturing companies that would prefer their competitors know as little as possible about their operations.

Reference 17 advocates strong collaborations between manufacturing firms to motivate innovation and adaptability to disruptions. It is stated that, "… slowness of suppliers in adopting additive manufacturing (AM) has created bottlenecks for aerospace and defense manufacturers in forging and casting supply chains; in some cases, parts have been delivered nearly a year after they were ordered." This take may actually be a simplistic analysis ignoring other challenges like component quality/reliability and the difficult onboarding process for defense applications.

Objective 3.3 in Reference 17 is "Strengthen and Revitalize Advanced Manufacturing Ecosystems." In discussing this objective, it recommends prioritizing programs that, "… provide key support for new manufacturing business formation and growth, …." It states that breakthrough technologies can take too much time to find their way to market and mentions federal programs to assist small businesses in this regard, namely the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs that provide capital to small companies with new ideas. Reference 17 supports public-private collaborations and similar efforts (consortia) between manufacturing companies to strengthen manufacturing networks.

Comparison of References 16 and 17: Word Count Analysis

Even though References 16 and 17 are aimed at the same application (advanced manufacturing), there are obvious differences in the approaches adopted by the two presidential administrations. One way to highlight the differences is through a word count exercise using the common Adobe word search tool. The following table (Table 6) compiles the statistics of this exercise. The terms were chosen based on a perceived difference during the reading of the reports and based on a few terms that might be of interest.

Table 6. Word Count of Specific Topics in References 16 and 17

Topic	Ref. 0: 2018 Report (Trump)	Ref. 17: 2022 Report (Biden)
Climate, Carbon, Emissions, Clean Energy, Energy Efficiency	2	150
Electric or Electricity	0	14
Supply Chain	46	163
Semiconductors	15	28
Electronics	13	37
Bio, Bio Tech, Bio Fab	41	123
Health	15	26
Workers or Workforce	99	116
Defense Industry	48	14
Equity, Diversity, Underserved, Underrepresented	10	57
Rural	50	5
Nuclear	0	4
Wind	0	1
Ship	0	0
Rail	0	0
Auto (motive, mobile)	0	1
Hydrogen	0	1
Pipe or Pipelines	0	0

Differences are apparent. Some differences can be explained due to natural occurrence (Covid effects on the supply chain that occurred late in the Trump administration. This includes the effect on microprocessor supply.) Some are likely due to political philosophy. For example, even though these reports are on advanced manufacturing, the two administrations show clear differences on climate concerns, and they choose different communities as the focus for certain objectives (e.g., rural, underserved). One takeaway useful to RAPLSS is the emphasis on workforce needs. Both administrations identify this as a critical topic and a primary challenge if the United States is to be globally competitive in advanced manufacturing.

Progress Made in Achieving the Objectives of the 2018 Strategic Plan

As explained in Reference 16 and also in Reference 17, these quadrennial reports include a chapter that assesses the progress made toward the previous administration's objectives. Reference 17 explains the metrics used to evaluate progress during the previous four years and provides data related to government agencies that participated in the initiatives. Table 7, Table 8, and Table 9 below list the names of the agencies and the programs and are organized according to the three primary goals of the 2016 program (Reference 16): technology development, educational/workforce development, and supply chain programs. This information may be useful to RAPLSS if certain topics are to be pursued and the identification of government programs is of interest.

Table 7. Technology Development Programs by Federal Agency

Agency	Technology Development Programs	
DOC	Manufacturing USA Manufacturing Extension Partnership Additive Manufacturing Robotics for Smart Manufacturing Advanced Materials Measurements Standard Reference Materials	AI in Manufacturing Biopharmaceutical Manufacturing Smart Manufacturing Systems Advanced Manufacting Roadmaps Regional Innovation Hubs) Manufacturing USA National Emergency Assistance Program Rapid Assistance for Coronavirus Economic Response
DoD	Manufacturing Technology Programs Manufacturing USA institutes Defense Industrial Base Modernization	
DOE	Manufacturing USA Institutes Manufacturing Demonstration Facility Critical Materials Institute BOTTLE Consortium High Performance Computing for Manufacturing Lab-Embedded Entrepreneurship	Education and Workforce Roadmap (NREL) Robotics, High Performance Computing, and Energy Storage Internships Small Business Innovation Research and Small Business Technology Transfer programs American Made Challenges
HHS	Biomedical Advanced Research and Development Authority Centers for Innovation in Advanced Development and Manufacturing Division of Research, Innovation, and Ventures programs TechWatch Advancing Regulatory Science for Continuous Manufacturing	Regulatory Science and Innovation Grants Centers for Excellence in Regulatory Science Innovation Emerging Technology Team Advanced Technology Team
NASA	Game Changing Development Program Advanced Exploration Systems Program Technology Demonstration Missions Program	Space Technology Research Grants Programs Transformative Aeronautics Concepts Program
NSF	Cyber-Physical Systems Engineering Research Centers Future Manufacturing Program Industry/University Cooperative Research Centers	Advanced Manufacturing Program Foundational Research in Robotics Future of Work at the Human-Technology Frontier National Robotics Initiative 3.0
USDA	Science Theme Teams Small Business Innovation Research Forest Products Lab Pilot Plant Facilities	Bioeconomy, Bioenergy, and Bioproducts Program Intramural and Extramural Research Programs

Table 8. Education and Workforce Development Programs by Federal Agency

Agency	Education and Workforce Development Programs	
DOC	Manufacturing USA Institutes, Education and Workforce Programs NIST Internship Program	MEP Workforce Development Programs NIST Summer Undergraduate Fellowship
DoD	Army Educational Outreach Program STARBASE Manufacturing USA Institutes, Education & Workforce Programs	Veterans To Energy Careers Manufacturing Engineering Education Program
ED	Carl D. Perkins Career and Technical Education Act	WIOA Title II, Adult Education and Family Literacy Act
DOE	Manufacturing USA institutes, Education and Workforce Programs Lab-Embedded Entrepreneurship Programs Better Plants Online Learning for Industrial Partners 500001 Ready Navigator Advanced Manufacturing Education and Workforce Roadmap Nuclear Relevant Scholarships and Fellowships	EERE High Performance Computing for Manufacturing Internship Program EERE Energy Storage Internship Program EERE Robotics Internships Program Nuclear Energy University Nuclear Leadership Program Office of Science Undergraduate Laboratory Internships Office of Science Community College Internships Office of Science Visiting Faculty Program Office of Science Graduate Student Research Program
DOE	Manufacturing USA Institutes, Education Workforce Programs Lab-Embedded Entrepreneurship Programs Better Plants Online Learning for Industrial Partners Ready Navigator	High Performance Computing for Manufacturing Internship Program Energy Storage Internship Program Robotics Internships Program
DOL	Apprenticeship Programs Trade Adjustment Assistance America's Promise Job Training Grants Strengthening Community Colleges Grants Growing Apprenticeships in Nanotechnology and Semiconductors	One Workforce Grants Scaling Apprenticeships Through Sector-Based Strategies Grants Apprenticeship: Closing the Skills Gap Grants
NASA	Faculty Fellowship Program STEM Engagement Programs	Established Program to Stimulate Competitive Research (EPSCoR) Minority University Research and Education Projects
NSF	Advanced Technological Education Program Training-Based Workforce Development for Advanced Cyberinfrastructure Engineering Research Centers Program Future Manufacturing Program Revolutionizing Engineering Departments Program	Broadening Participation in Computing and Engineering Programs Non-Academic Research Internships for Graduate Students (INTERN) Training-Based Workforce Development for Advanced Cyberinfrastructure
USDA	Academic Scholarships and Aides 4-H Science Program Partnerships with Universities Including MSIs and Community Colleges Cooperative Extension Network	Agriculture and Food Research Initiative (AFRI) Education and Workforce Development Grants

Table 9. Supply Chain Programs by Federal Agency

Agency	Supply Chain Programs	
DOC	Manufacturing USA Institutes MEP Centers Cybersecurity Supply Chain Risk Management Program Review of Semiconductor Manufacturing and Advanced Packaging	Advisory Committee on Supply Chain Competitiveness Office of Supply Chain, Professional and Business Services
DoD	Manufacturing USA institutes Industrial Base Programs	
DOE	Manufacturing USA Institutes Critical Materials Institute BOTTLE Consortium Manufacturing and Energy Supply Chain Office	
DOE	Manufacturing USA institutes Manufacturing Supply Chain Program	
NASA	Supply Chain Risk Management (SCRM) Program	
NSF	America's Seed Fund Convergence Accelerator Program Innovation Corps Operations Engineering Program	Partnerships for Innovation Pathways to Enable Open Source Ecosystems Regional Innovation Engines
USDA	Storage Facility Loans Local Food Promotion Program Farmers Market Value Added Producer Grants Regional Food System Partnership Dairy Business Innovation Initiatives Business & Industry Guaranteed Loan	Food Supply Chain Guaranteed Loan Program Meat and Poultry Inspection Readiness Grants Cooperative Extension Network
EPA	Sustainable Materials Management Program	

3.4 Offshore Wind Energy

3.4.1 Offshore Wind Energy in the United States, Emerging Industrial Activity and Heavy Fabrication Opportunities, EWI, Jan. 2022 [24]

Summary

This 69-page document discusses the emerging offshore wind (OW) industry in the U.S. and how heavy fabrication is playing a central role in it. The report explains that although he U.S. OW industry struggled to initiate during the 2010s, it reached a tipping point in 2021. The factors leading to this tipping point include (1) the successful European OW industry that is ~20 years ahead of the United States and (2) the Biden Administration's goal for OW, namely, 30GW installed by 2030 (30-by-30). The report gives background information to explain the pros, cons, and motivations for the emerging OW industry in the U.S.

Reference 24 describes current and future OW structure designs. This introduces the role of heavy fabrication, which is the primary focus of the report. Heavy fabrication includes building the substructures (monopiles, jackets, floating platforms) and towers. These large structures require huge amounts of steel and welding. Monopiles (MPs), for example, routinely use steel thicknesses of 100-150 mm, each MP weighing ~2000 tonnes, and ~50-100 are needed for a typical OW farm. By 2030, the United States will have between five and ten such farms. The report explains that the U.S. East Coast will be first to install OW and will use mostly monopiles (thousands needed). Later in the 2020s, West Coast projects will use floating OW structures.

Reference 24 includes economic data and cost analysis. It shows that the majority of OW farm costs are CAPEX and that heavy fabrication accounts for ~35% of CAPEX. Because the U.S. OW industry has been struggling to initiate, the report suggests that heavy fabrication cost reduction is needed, and this means better welding engineering technology. Roughly one-third of Reference 24 provides detailed descriptions of current OW welding technology and ideas for improvements. It also explains the complicated materials and welding engineering tradeoffs encountered when fabricating large structures.

Reference 24 explains the Jones Act, a U.S. law dating to the 1920s that controls the use of marine vessels for transporting merchandise by water. This law is critical to OW because it controls the ownership and demographics of the crews, which must be U.S.-based, used for OW. OW is an industry that uses large numbers of ships for everything from installation to maintenance work. Currently, there are not enough vessels to accommodate the emerging U.S. OW industry, and this is causing a notable increase in U.S. shipbuilding.

Topics within RAPLSS Scope

Because of the dependence of OW on large structures, this industry is well aligned with RAPLSS. In fact, it may be the best example of an industry building large structures in substantial numbers, and this trend is predicted to last well into the future. Some individual topics that will be of interest are listed below.

- The large structures/systems used in OW that are of interest include:
  - Substructures: monopiles, jackets, transition pieces, substations, and floating platforms
  - Large castings/forgings used for parts of the substructures and in the turbine nacelles
  - Ships: crew transport vessels, service operation vessels, and wind turbine installation vessels
  - Mooring systems: chain/rope tethers and connection hardware
  - Cables: interconnecting cables between turbines and the cable from the substation to shore

- The OW industry will need thousands of large steel structures (monopiles, jackets, floating platforms) in the next 20 years. Most foundations for an OW farm are alike, and between farms, they are similar. The U.S. needs companies capable of serial manufacturing of large OW structures.
- Currently, U.S. OW heavy fabrication demand exceeds capacity, and projects are sourcing millions of tons of steel structures from Europe. The only monopile facility in the U.S. (~50% built as of 2023) is German-owned and, at this time, can only assemble primary tubular units sent from Germany. A second facility has been announced but will not open for several years and will be owned by groups in Italy and Spain. The U.S. industry is falling short of its opportunities for OW applications. To reverse this trend, increased funding/facilitation of ideas is necessary.
- U.S. Gulf Coast fabricators (historically serving the oil and gas industry) are cautious about OW and, so far, are not investing in the opportunity at a rate that some expected. These companies are capable of building jackets for the East Coast. There are cost advantages (thinner steel made in the U.S.) and disadvantages (more complicated welding, towing to the East Coast) for jackets. If a highly automated, serial jacket fabrication facility was established, it might compete well with monopiles and enable 100% U.S.-made structures. A jacket fabrication study, including a cost analysis, would be worthwhile.
- Heavy fabrication of OW structures need advanced welding and inspection technology. This includes faster, cheaper, and more reliable welding and NDE. Due to the serial manufacturing needs mentioned above, welding automation is key. Currently, PEMA (Finland), AWS-Schafer (Germany), and HAANE (Germany) are leaders in welding automation for OW. There is opportunity to develop similar U.S.-based technology.
- Considering the volume of welds for monopiles, the NDE technology lacks sophistication. Often, inspection is by manual ultrasonics.
- It takes huge amounts of steel to produce OW infrastructure, and this is causing great demands on the U.S. steel industry. Whereas the steel industry in the U.S. has declined for decades, OW is causing resurgence. The Nucor facility in Brandenburg, KY, is an example. It is a large, modern facility capable of making large, thick plates for monopiles, and one motivation to build this facility was to serve the OW industry. Recent reports by the National Renewable Energy Laboratory (NREL) suggest that the U.S. steel industry will struggle to meet the demands of OW.[15] If the U.S. West Coast pursues floating OW (as is now planned), and if no new steel-making facilities are built in the United States, then it is likely that the steel will be procured from Asia.
- OW uses large steel castings and forgings, but the U.S. castings and forgings industry will struggle to meet the needs of OW.[15] This aligns with the content of References 12 and 21.
- Floating structure design for OW projects is currently undecided. The Department of Energy (DOE) is sponsoring research and a competition for floater design.[31] Because there are many variables in choosing a design for any one OW project, it is worth considering if all design aspects for this application are being covered. None of the efforts, so far, address the establishment of a modern, serial fabrication facility. No work is being done on welding automation. The philosophy appears to be – design it, and the fabricator will come.
- Even though billions of dollars are being spent on OW projects in the United States, it is often difficult to communicate with owner and developers because they are foreign-based

and/or unapproachable. U.S. government agencies could identify ways to engage these companies to support technology development useful to OW heavy fabrication.

- If one reads OW-related reports written by NREL or the National Offshore Wind R&D Consortium (i.e., DOT sources), it appears as though the authors have limited welding engineering experience related to heavy fabrication for OW. Training programs would be useful for some government employees to understand operations in fabricating large substructures. This is not a criticism as it is unlikely that DOE employees will have spent substantial time working at fabrication facilities. Nevertheless, some kind of short course (a few days or one week) would be useful.

Document Overview

Reference 24 states that as of 2021, Europe leads the world in OW energy with more than 5000 turbines installed. East Asia shows similar trends. The United States has only seven operating OW turbines. However, the upper East Coast of the U.S. has significant OW resources near large population centers and has many OW projects planned. A primary conclusion of Reference 24 is that 2021 was a tipping point for the U.S. OW industry. Arguably, the biggest factors causing the tipping point have been the Biden Administration's support including a goal to install 30 GW (30,000 MW) of OW energy by 2030 (30-by-30) and the passage of the Inflation Reduction Act (IRA). The success of the European OW industry as a model is also an influencing factor. OW wind represents the emergence of a new, $100^{+} billion industry in the U.S. that will require significant heavy fabrication to produce the required infrastructure.

Reference 24 cites a Wood Mackenzie report that predicts the U.S. OW industry will provide 80,000 jobs and a CAPEX investment of $17 billion by 2025, $108 billion by 2030, and $166 billion by 2035.[32] Reference 24 calculates estimates of how much CAPEX will be associated with heavy fabrication to create the infrastructure. Heavy fabrication, defined as building turbine-supporting substructures, towers, and offshore substations, is estimated at 35% of total CAPEX and a per project estimate for heavy fabrication is $245 million, $1.23 billion, and $2.45 billion for small, medium, and large OW projects, respectively.

Using levelized cost of energy (LCOE) data and projections, Reference 24 notes that OW energy costs more than other sources in the U.S.; therefore, cost reduction is of keen interest. The largest contributor to OW LCOE is CAPEX, and as explained, ~35% of CAPEX is for heavy fabrication. It cites several DOE-funded studies that examined OW cost reduction opportunities.[33], [34] These studies identified heavy fabrication, welding, and serial manufacturing technologies as important for CAPEX reduction. Reference 24 makes a case for funding the development of advanced welding technologies as ***the*** key factor in heavy fabrication.

Reference 24 explains that the emerging U.S. OW industry is already creating (1) competition between East Coast states to establish local facilities as OW industry hubs, (2) state government investment and touting of jobs creation, (3) state government legislation for decarbonization goals, and (4) investment by foreign entities in U.S. projects. Also, Gulf Coast fabricators traditionally involved in oil and gas (O&G) projects are assessing OW opportunities due to their experience and the substantial similarities between O&G and OW structures. Despite this activity, very few facilities in the U.S. have either been built or upgraded to provide the heavy fabrication capabilities necessary for the serial manufacture of OW infrastructure.

Because the U.S. OW industry is just emerging, Reference 24 identifies that heavy fabricators have an opportunity to engineer their facilities from the ground up and mate their choices with OW structure design. Although U.S. fabricators lag behind foreign competitors, they can take advantage of known successes/failures to optimize facility design and to make informed investment choices regarding advanced fabrication technologies. OW heavy fabrication entails the making, forming, and welding of thick steel plates. Reference 24 explains that a key challenge is to optimize interacting variables like structural design, steel type, forming/rolling equipment, weld bevel design and machining, weld fixturing, preheat requirements and equipment, weld consumables and storage/handling protocols, welding process selection and equipment, and nondestructive examination technology. These interactions are best managed through expert materials and welding engineering choices.

OW structures worldwide are increasing in size to support larger turbines, and Reference 16 explains that these designs require steel thicknesses in the range of 100-150 mm. High productivity welding is essential to reduce costs, and this motivates use of processes like narrow groove submerged arc welding (SAW). Such processes are an example of complicated tradeoffs as they often come with increased risk of process downtime, welding defects, local brittle zone (LBZ) formation, and low toughness from high heat inputs. LBZs are a potential threat to the integrity of OW structures. Reference 24 states that the O&G industry has decades of experience mitigating LBZs, including steel and fabrication specification philosophies; therefore, the U.S. OW industry can leverage this knowledge. Furthermore, it discusses the nuances of high-heat input welding used for OW structures and describes ideas for improvement.

The OW industry requires marine vessels for infrastructure installation and for maintenance and repair during the many years of operation. The Jones Act restricts transportation in U.S. waters, and Reference 24 explains that in early 2021, a Senate ruling established that only qualified U.S. vessels can be used for OW. Therefore, the emerging U.S. OW industry represents significant opportunities for U.S. vessel builders and operators and, undoubtedly, welding, NDE, and automation will be of interest to these companies.

2024 Update: News Related to Offshore Wind

During 2023, the OW industry encountered many challenges, and commentary is appropriate as an update to Reference 24. The industrial and global economic landscape that matters to OW has incurred dramatic changes since the publication of Reference 24 two years ago. Covid, supply chain disruptions, the war in Ukraine, inflation, and interest rates have had negative impacts. Numerous OW projects on the East Coast have been canceled including Commonwealth Wind, SouthCoast Wind (Massachusetts), Park City Wind (Connecticut), Ocean Wind I and II (New Jersey), and Empire Wind II (New York).[35], [36], [37], [38], [39] These cancellation decisions do not come lightly. The Commonwealth Wind developer Avangrid (Spain) has agreed to pay a $48 million penalty for canceling this project.[35] Orsted (Denmark) stands to lose $100 million for the New Jersey cancellations.[38]

Orsted's case is the most notable because they are the world's largest OW developer. Orsted is the ExxonMobil of OW. With their cancellations, Orsted announced roughly $2.3 billion in impairments, and their stock price dropped 20% in one day.[40] Orsted Americas CEO, David Hardy, was reported as saying, "Macroeconomic factors have changed dramatically over a short period of time, with high inflation, rising interest rates, and supply chain bottlenecks impacting our long-term capital investments."[37] Orsted CEO Mads Nipper stated in a call to reporters, "The situation in U.S. offshore wind is severe."[40] Furthermore, Reference 37 states, "In addition to a strain on supplies like monopiles and other components, there are long wait times for the ships needed to construct the towering wind turbines in the ocean."

Prior to project cancellations, numerous developers attempted to renegotiate their contracts with state governments.[41], [42] These attempts were rejected. However, soon after the cancellations, state authorities announced that the projects will be rebid, and some of the original developers (that cancelled projects) stated their intention to rebid. So, while the financial viability of U.S. OW projects is clearly in a state of flux, it still appears that the industry will move forward. Projects established in the future will see notably different terms and conditions negotiated between stakeholders as compared to the U.S OW startup period of 2021-2023. One takeaway from these events is that OW needs cost reductions now more than ever.

Unfortunately, at a time when OW cost reductions are needed the most, the companies that might fund heavy manufacturing developments (like welding and inspection technologies) have hunkered down. The situation is a "chicken-and-egg" problem. Cost reduction technologies are needed to improve OW viability, but the fabricators and developers who need these improvements the most are not likely to fund discretionary spending development work in the near future due to the recent economic turmoil. One possibility to move OW forward is for a government entity to fund/facilitate development work. On this subject, the government currently has efforts underway (the IRA, FLOWIN, Floating OW Shot),[31] but a counterpoint is that none of these projects involve the technologies presented in Reference 24.

3.5 The Nuclear Industry

3.5.1 Advanced Materials and Manufacturing Technologies (AMMT), 2022 Roadmap, US DOE, Office of Nuclear Energy[25]

Summary

This 53-page document provides technical discussion, identification of key challenges, and a five-year roadmap for advanced materials and manufacturing technologies (AMMT) aimed at the nuclear industry. The AMMT leadership team consists of five members from five different national labs. The overarching vision of this AMMT program is to accelerate the development, qualification, demonstration, and deployment of AMMT to enable reliable and economical nuclear energy. While some emphasis is on existing nuclear materials, more emphasis is on new advanced reactors (ARs): sodium-cooled fast reactors (SFRs), molten salt reactors (MSRs), high-temperature gas-cooled reactors (HTGRs), lead-cooled fast reactors (LFRs), and advanced light water reactors (LWRs). New materials are required to enable these designs. Long term degradation due to high temperature, radiation, and corrosion are the primary technical challenges, while code acceptance and industry uptake are the “soft” challenges.

Optimization of existing nuclear materials will focus on austenitic stainless steels, ferritic-martensitic steels, and Ni-based alloys with additively manufactured 316 SS being selected as the first test case. Regarding new materials, the program will concentrate on advanced manufacturing of the following material classes: advanced metal composites such as oxygen dispersion strengthened (ODS) alloys, refractory alloys, high entropy alloys, ceramic composites, and functionally graded materials. Specific new alloys and materials need to be identified, tested, qualified, and manufactured in a relatively short span of time. Emphasis is placed on enabling fast industry uptake (i.e., commercialization) facilitated through early alignment of stakeholders, aggressive pursuit of ASME code cases, and demonstrations at scale.

Topics within RAPLSS Scope

The following is a list of topics from Reference 25 useful to the RAPLSS objectives.

- The use of additive manufacturing (AM) to build large components or unique components that are difficult to source. This includes the use of directed energy deposition (DED) methods, which is the use of fusion welding processes to digitally manufacture features and components.
- The use of AM to build large, complicated components that are functionally graded, meaning that the properties will be purposefully changed throughout the build.
- The development of a qualification framework for AM components with varying properties.
- The use of in-situ sensors (optical, acoustic, thermal) during AM as a quality control measure to prevent defects during the build and to adjust process parameters on-the-fly.
- The intent is to use advanced NDE for in-situ monitoring of AM.

- The use of powder metallurgy hot isostatic pressing (PM-HIP) for large components.
- An aggressive approach to stakeholder engagement (collaboration) and regulatory acceptance (code bodies). This includes large-scale demonstrations using industry-based partners.
- Extensive use of modeling, machine learning, and artificial intelligence.

Document Overview, Work Scope, and Writing Style

The goals of the AMMT program include the following:

1. To develop AMMT that have cross-reactor impacts.
2. To establish a framework for rapid qualification of new materials made by advanced manufacturing.
3. To accelerate commercialization of new AMMT through demonstration and deployment.

The goals will be achieved through three program elements:

1. Development, qualification, and demonstration
2. Capability development and transformative research
3. Collaborative research and development

Reference 25 contains extensive discussion of the technical challenges, and the authors are obviously highly educated in this field. The document is informative.

Many of the identified challenges in Reference 25 appear daunting. An example is the discussion of the necessity of engineering materials at the atomistic level. The report mentions microstructural imaging techniques using high energy x-rays and neutrons as well as transmission electron microscopy. Some imaging work will be in-situ with applied stress. The advanced imaging will be used to study defect formation (micro voids, vacancies, and dislocation reaction to deformation) and phase transformations. [These imaging techniques are extremely advanced, cumbersome, and time consuming. It could take many years to extract commercially useful observations from such efforts, and, even then, the learnings may only amount to minor improvements. These techniques will eventually lead to discoveries; however, Reference 25 aims to commercialize new reactor materials — including large-scale demonstrations — within five years.] According to Reference 25, the knowledge gained from advanced imaging will be used to develop models from which the new materials will spawn. Furthermore, the model results are expected to be used to accelerate regulatory acceptance. [Caution against this expectation is warranted as regulators and their hired experts prefer hard data and demonstrations.] Note that these plans, along with full industrial commercialization of the new materials, are contained within a five-year roadmap.

The top candidate advanced manufacturing technique identified in Reference 25 is additive manufacturing (AM). Much AM R&D is recommended. Direct energy deposition (DED) is included. AM is described in some detail and certain inherent attributes are acknowledged: local heating, fast cooling (although for large buildups, this is not the case), and inherent chemical heterogeneity. Even though these attributes are difficulties to overcome due to the potential for material inhomogeneity and defects, Reference 25 speaks of these attributes as advantages. The report claims that these attributes will enable the creation of novel materials. The authors state that layer-by-layer buildup will enable functionally graded materials (which is true); however, they seem to underappreciate the downside of qualifying a material/component that may be defect prone or inhomogeneous in its properties. The document does not directly deal with the challenges of inspection (NDE), qualification, code case necessity, and service performance risks.

In later parts of Reference 25, the writing (and logic) becomes somewhat creative. For example, it contends that the inhomogeneity of AM components will be solved by including in-situ monitoring in the build. The report states that using sensors, machine learning, and AI will solve AM's quality and consistency problems. There is no significant explanation of how this happens.

The following are three examples of the writing style that permeates this document:
Speaking of automated microstructural analysis:

- A machine learning-based microstructure feature extraction tool (2D and 3D) from non-destructive and destructive imaging using computer vision is of great importance.

Speaking of accelerated creep and creep-fatigue testing:

- A multi-pronged approach of increasing the throughput of creep and creep-fatigue testing, use of advanced instrumentation and measurements techniques, in combination with modeling and simulation and AI/ML is necessary to decrease time requirements for material qualification.

Speaking of the AM process advantages:

- An agnostic data-driven, physics-based material design and development framework will not only enable optimization of existing materials classes to improve radiation, corrosion, and high-temperature resistance, but also offers opportunities for designing and manufacturing innovative new materials incorporating understanding of new processes.

While this document does an excellent job of identifying new materials and manufacturing technology candidates, and then identifying avenues for R&D, in the opinion of this writer, Reference 25 is over-optimistic and, at times, becomes an exercise in creative writing using fancy terminology.

3.5.2 Advanced Reactor Materials Development Roadmap, EPRI, 2021[26]

Summary

This 24-page document gives a concise roadmap for the development of materials necessary for advanced nuclear reactors, i.e., advanced non-light water reactors (ANLWRs or ARs). The report is primarily organized by two themes: reactor type material type. Reference 26 provides little technology background or analysis. It lists the reactors and materials for which there are gaps, and then for each case it recommends R&D with a single, short statement of the technical challenge. The roadmap itself is a nine-page Ghant chart covering the 2020s. Reference 26 places considerable emphasis on demonstrations of the new technology and the need to prepare code cases for ASME acceptance.

Topics within RAPLSS Scope

If one wants to gain fast knowledge on the nuclear industry's focus for advanced reactor materials, Reference 26 is very useful. Yet there is relatively little **direct** information to glean from this document. To understand how Reference 26 relates to RAPLSS, the reader needs to have some concept of the magnitude of a nuclear facility. With such background, the reader knows that, for example, an extensive degree of large piping systems, large vessels, and reactor-related, large-scale castings/forgings are necessary. Also, considerable facility costs are associated with materials and welding. The nuclear industry definitely has needs consistent with the RAPLSS scope, but Reference 26 does not explicitly make this case. The utility of Reference 26 to RAPLSS includes the following takeaways (some nuclear background required):

- Related to ARs, the nuclear industry has much R&D scheduled for materials, manufacturing, and welding. Many of the nuclear components are large (Figure 9 below from Reference 26, Page 3 showing design schematics). Potential cross-industry collaboration exists for some technologies like additive manufacturing, sensor technology, and use of big data; however, the specific materials needed for high temperature, corrosive nuclear applications are less likely to be of interest outside of nuclear.

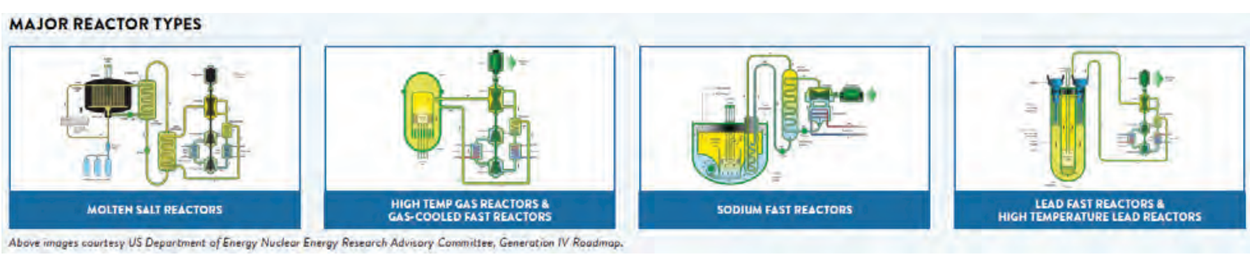


Figure 9. Major Advanced Reactor Types as Described in Reference 26

- A prioritized list of applications and materials is given in Reference 26.
- Nuclear components/materials exposed to radiation will experience decades-long degradation (analogous concerns exist for corrosion behavior), and it is impractical or impossible to run laboratory tests to assess lifecycle performance. There will be dependance on accelerated assessment tools with unknown long-term accuracy. A

mitigation of this risk involves development of in-situ monitoring technologies that provide feedback regarding material health. The goal would be to obtain advance notice of pending problems in a time frame that allows remediation.

- The future of nuclear ARs depends on successful large-scale demonstrations (demos) to convince ASME (and other stakeholders) that the technology works. Such demos require extensive funding, facilities, and time. Significant resources are necessary for demos, but ***not*** conducting a demo makes it difficult to win support from regulators, code bodies, and the public. The demo conundrum is binary; it will happen, or it will not happen. If it happens, then extensive resources must be acknowledged and planned for. If it does not happen, then stakeholder alignment is paramount. A compromise is to reduce the scale of the demo.
- Due to the critical nature of nuclear components, new technologies will be heavily scrutinized leading to heightened proof-of-principle criteria for stakeholders. Therefore, the roadmap in Reference 26 should be viewed with the realization that stakeholders will need to accept the implications of the R&D. There is some risk that different stakeholders will interpret the R&D differently. The RAPLSS project narrative identifies the need for stakeholder alignment and mentions the following entities: industry, academia, professional societies, nonprofit research centers, technology providers, and regional economic development authorities. For nuclear-related work, the effort may want to consider some “naysayers” as stakeholders, which includes technology-based groups like the Union of Concerned Scientists.(43) Reference 43 makes a logical case that the development efforts and time required (decades) to commercialize advanced reactor designs will not be in time to provide the emissions reduction needed. It states that the best approach is to move forward with modernized light water reactors. Alignment (and the definition of alignment might be unconventional in this case) of such stakeholders can be the difference between meeting (or not) a technology delivery schedule.

Document Overview

All AR types operate at higher temperatures compared to conventional light-water reactors; therefore, high temperature mechanical performance and irradiation damage are consistent materials development gaps across all ARs. The ARs use different cooling fluids, and thus, each reactor type has unique high-temperature corrosion challenges. Unless the reader is vaguely familiar with reactor components, it is not straightforward to relate this report to the focus of large structures.

Reactor types are organized as follows:

1. Molten salt reactors
2. High temperature gas reactors and gas-cooled fast reactors
3. Sodium fast reactors
4. Lead fast reactors and high temperature lead reactors

Reference 26 provides a brief summary of the reactor designs and highlights materials development challenges. The identified gaps are actually extracted from previous studies which are covered in four additional reports. Titles, report numbers, and weblinks for these four (downloadable) reports are provided in Reference 26. The reports are very technical in the areas of nuclear chemistry and materials science, but the executive summaries are readable for an informed engineer.

Based on EPRI's previous studies (the four external reports), the primary material categories are:

1. Austenitic stainless steels (SSs)
2. Ferritic-martensitic and low alloy steels
3. Nickel-based alloys
4. Graphite and ceramics
5. Cladding
6. Corrosion

Austenitic SSs are ubiquitous across the reactor types; thus, this material receives much attention within the roadmap.

3.5.3 Advanced Manufacturing Methods Roadmap for the Nuclear Energy Industry, EPRI, August 2021[(27)]

Summary
This four-page document gives a concise roadmap for advanced manufacturing methods (AMMs) and materials technology to enable new nuclear power plant designs and/or to assist repair and replacement of components in existing facilities. Reference 27 provides little technology background or analysis and simply states specific AMMs and materials and puts them on a timeline. Other nuclear-related documents in this review (References 20, 25, and 26) provide more details. The drivers for the recommended work are (1) near-net shaped component production, (2) reduced lead times, (3) flexible production of limited quantities of unique shapes, and (4) cost reduction. The document emphasizes scale-up and commercialization through large-scale demonstrations and code case work with ASME. It places specific recommended initiatives on a timeline (Ghant charts) that ends at "2027+."

Topics Useful for RAPLSS
References 26 and 27 total less than 30 pages, are well organized, and include timelines. They provide the reader with a fast knowledge of the nuclear industry's intent for future development in AMMs and materials.

Because Reference 27 categorizes initiatives according to component size, it is easy to understand how some challenges might relate to RAPLSS. In particular, the document selects powder metallurgy-hot isostatic pressing (PM-HIP) as a process useful in the development of large components. While it relegates DED-AM to small components, a counterpoint is that this process might have RAPLSS applications when the component is difficult to source due to lead time or limited production numbers (one-off). Considering Reference 27 states these factors as drivers, it is surprising that DED-AM has been associated only with small components. This position could be related to the EPRI prioritization process that delivered this roadmap, i.e., there is not enough time and money to pursue everything, thus PM-HIP has greater large structure promise. Nevertheless, if through traditional manufacturing methods a medium-to-large sized component cannot be delivered according to schedule, then DED-AM may be a useful alternative.

Document Overview

The document mentions several advanced manufacturing methods including additive manufacturing (AM) by direct energy deposition (DED-AM) and powder bed (PB-AM), powder metallurgy-hot isostatic pressing (PM-HIP), diode laser cladding (DLC), electron beam welding (EBW), and advanced mechanical connections. These techniques are only mentioned by name without descriptions of the processes or capabilities. The materials mentioned include 316L SS, 508 low alloy steel, 316H, 690, 304H, and 718. Three overarching principles are listed as motivators for the project plan:

1. Understanding AMMs and applicability of each
2. Demonstrations of the AMMs at scale
3. Development of ASME data packages and code cases to support implementation of certain AMMs

Various reactors designs – advanced light water reactors (ALWRs), small modular reactors (SMRs), advanced reactors (ARs) – have been reviewed to better understand which AMMs will be most applicable for specific components. PM-HIP is recommended for large components, DED-AM or PM-HIP is chosen for medium sized components, and PB-AM is selected for smaller components. The size definitions are:

- Large components (~4 - 7.25 ft dia.)
- Medium Components (< 4 ft, > 500 lb)
- Small Components (< 500 lb)
- Very small Components (< 75 lb)

Regarding demonstrations at scale, Reference 27 states as an example that EPRI, U.S. DOE, and several industry partners are working to demonstrate several AMMs and fabrication methods at 2/3-scale for the production of major component assemblies of the NuScale Power SMR design. These include PM-HIP, electron beam welding, diode laser cladding, and DED-AM.

Regarding technology commercialization, Reference 27 clearly states the need for detailed ASME data packages and code cases to justify implementation of the AMMs. Additionally, EPRI feels confident for this undertaking due to past successes with multiple PM-HIP code cases and current work with ASME to recognize laser powder bed fusion AM. Another aspect mentioned for successful technology deployment is the intent to work directly with manufacturers and utilities as important stakeholders.

Reference 27 includes two Ghant charts, the first related to “Class 1 Pressure Boundary” applications, while the second is related to “Reactor Internals.” Most of the categories on the timelines are separated according to the size definitions listed above. Other categories include advanced cladding, mechanical connections, EBW, fuel hardware, and control rod drive components.

Unlike the other documents in this review, Reference 27 contains no reference to social topics such as benefits or attention to underserved, underrepresented, rural, urban, etc. communities.

3.5.4 Supply Chain Challenges and Opportunities for Structural Components in Advanced Energy Systems, EPRI Workshop Summary, EPRI, Office of Nuclear Energy, 2022[20]

Summary

This 58-page document is from an EPRI workshop involving 70 attendees from 48 organizations. Reference 20 outlines key industry themes and potential actions for AES with a focus on the supply of structural components for advanced nuclear technology, transformational thermal generation, concentrating solar power, and advanced power cycles. Decarbonization is a primary motivation (net zero by 2040-2050), and electrification is seen as key in this goal. Gaps and initiatives are to enable new technology in the 2030-2035 time frame. There is emphasis on nuclear power, although it is not the sole emphasis.

Rather than cover design specifics of new energy systems, Reference 20 concentrates on materials, manufacturing technologies, and commercialization hurdles necessary to build the systems. Primary themes include high-temperature materials, workforce needs (machining, welding), code and industry acceptance of new manufacturing technologies (PM-HIP, AM), difficulties in getting suppliers to invest in new technologies, difficulties in getting suppliers to collaborate (IP concerns), and the difficulty in demonstrating and qualifying large, first-of-a-kind components.

Reference 18 mentions the so-called “chicken-and-egg” problem several times. In short, potential suppliers perceived as vital for AES are hesitant to invest in modern technologies without concrete incentives – a solid business case through guaranteed orders. Such guarantees are not a realistic expectation for this industry unless there is a change in business format. The workshop explored ways to alter the format, and one initiative, called fit-for-nuclear (F4N), was highlighted.

Topics within RAPLSS Scope

Many topics, identified gaps, and recommendations from Reference 20 are useful to the RAPLSS goals. There was a dedicated session at the workshop called “Advanced Manufacturing of Large Components.” The following is a partial list of topics from this workshop for RAPLSS to consider.

- Joint industry projects would be useful to accelerate the qualification of new materials.
- Industry should find ways to increase the numbers of welders and machinists including efforts to make skilled trades an attractive career choice.
- Increase attention on qualification of new, advanced manufacturing methods, particularly with code bodies like ASME. Improve early, broad engagement with codes and regulators.
- Support for establishment of test loops, pilot facilities, and demo projects to gain experience, prove technology, and adopt new materials.
- Support for new/upgraded manufacturing infrastructure, e.g., large-scale forging operations.
- Improve coordination, collaboration, and qualification between AES developers and prospective supply chain partners and with partners from other industries. Continue to hold AES supply chain workshops to facilitate early and continuous industry collaboration.

Reference 20 highlights one development by the Stack Metallurgical Group and an industry consortium to install a 4.05-m diameter by 4-m tall HIP unit which would be the largest in the world. A number of other industries have expressed interest in large HIP units.(12) There may be opportunities for cross-industry collaboration on HIP technologies.

Document Overview

Reference 20 first introduces the potential opportunities for industrywide activities related to advanced energy systems. Recent EPRI modeling suggests that the opportunity for AES by 2050 in the United States alone is on the scale of replacing the entire fossil and nuclear fleet. The second section of the document outlines the key industry themes that were heard across multiple presentations and discussion sessions and includes potential actions based on this collaborative workshop. The third section of Reference 20 summarizes the various supplier sessions, with additional specific details on capabilities and activities. The final section summarizes key actions and records additional workshop details.

Regarding limited workforce for machining and welding, the EPRI workshop covered the typical ideas of engaging community/technical colleges that support skill trade programs, but there was also discussion of bringing workers from other industries, specifically, the O&G industry. Although not explicitly stated, there seems to be an undercurrent within the AES community to see AES as a growing opportunity, while O&G is dying. One “call to action” statement in Reference 20 states, “Work with suppliers from the oil and gas market to integrate them into the AES supply chain.” While the workshop encourages the concept of cross-industry collaboration, caution is in order regarding the idea of collaboration for mutual benefit but then "poaching" workers from the collaborative partners.

Reference 20 mentions an EPRI effort started in 2022 called Advanced Manufacturing Methods and Materials (AM3) aimed to aid the industry in addressing the AES challenges. Prominent in this effort are the identification of AM, PM-HIP, and other advanced welding and cladding processes. The workshop identified that commercialization efforts of the AM3 technologies can be accelerated through increased collaboration via joint industry projects (JIPs) as well as early and more aggressive efforts with codes and standards.

Regarding technologies like PM-HIP and DED-AM, much attention was paid to the concept of getting new methods "over the finish line." While these techniques are already being pursued through ASME code cases, other techniques like laser PBF-AM are not ASME-recognized. Often the commercialization efforts, particularly with code cases, are ad hoc and not an industry-focused effort. The EPRI workshop gathered ideas into an ASME code development strategy. Hurdles in need of significant work and perseverance included the need for methods to accelerate shorter term testing as needed for long term service applications.

The document describes fit-for-nuclear (F4N), a program in the United Kingdom and proposes that an analogous effort be established in the U.S. F4N assists companies in measuring their operations against nuclear industry standards with the goal of identifying gaps and establishing plans to upgrade.

For certain AES systems where an operating plant does not yet exist, the need for test loops and other demonstration facilities was identified as a gap. Pumps and valves made from new materials or by new manufacturing methods require test runs in a controlled setting to meet commercialization requirements. Demo facilities were identified as a gap requiring industry collaboration and government support.

A key gap identified by the workshop is that only a handful of large fabricators exist in the U.S. As AES advances towards commercialization, there will not be enough fabrication capacity. The "chicken-and-egg" conundrum was cited as a significant contributing factor. Increased fabrication capacity for large components or structures requires investment, and the resources cannot be justified without a solid business case which means product orders or commitments. Free enterprise in the United States often struggles with the chicken-and-egg scenario: the end user (owner) will not commit to contracts until designs, plans, demos, and financial resources are finished/secured, but by the time this happens, it is too late for a large fabricator to materialize from scratch or for an existing fabricator to upgrade with advanced manufacturing technologies. Reference 20 does not identify any ready solutions to alleviate the problem, but it does highlight the following to improve the situation:

- Increased collaboration between AES providers and the industrial supply chain. This includes involving suppliers early in the design stage of new plant projects. It also includes collaboration through Joint Industry Programs (JIPs), industry focus groups, and code committees. Furthermore, it includes finding ways for competing AES providers to find common ground for JIPs and demonstrations.
- Partnerships between AES providers and material suppliers well in advance of schedule pinch points.

Reference 20, more so than other documents in this review, provides many images of large component manufacturing. Below (Figure 10) are a few examples. These were provided by workshop participants, and the names of these companies appear in the document.

Examples of forging during heat treatment and after machining. *Image supplied by Lehigh Heavy Forge Corp.*

EBW: 1.8-m flange weld, 47 minutes

Large component machining. *Images supplied by R-V Industries Inc.*

Advanced manufacturing. *Image supplied by Nuclear AMRC*

Images supplied by Sheffield Forgemasters

Steam generator channel head

Images supplied by Doosan Enerbility

Image supplied by Lehigh Heavy Forge Corp.

Figure 10. Large Structural Items for Nuclear Technologies

3.6 Hydrogen Energy Systems

3.6.1 U. S. National Clean Hydrogen Strategy and Roadmap[44]

Summary

Reference 44 is a 97-page document prepared by the DOE for a large group of government agencies and supported in many sections by previous hydrogen reports. The Bipartisan Infrastructure Law required the report.

The first major section describes the national decarbonization goals, the benefit of clean hydrogen for achieving those goals at multiple stages, and the challenges to achieving those benefits. The second major section describes three strategies for enabling clean hydrogen to provide the desired benefits: targeting high-impact uses of clean hydrogen, reducing the cost of clean hydrogen, and focusing of federally-supported regional networks. The third major section describes the guiding principles that direct the actions and lists proposed actions.

Topics within RAPLSS Scope

The most valuable summary of RAPLSS topics for hydrogen systems is in Appendix A Figure D on the last page of the report. Here, the needs of large structures and systems are categorized by upstream, midstream, and downstream, as shown below in Figure 11.

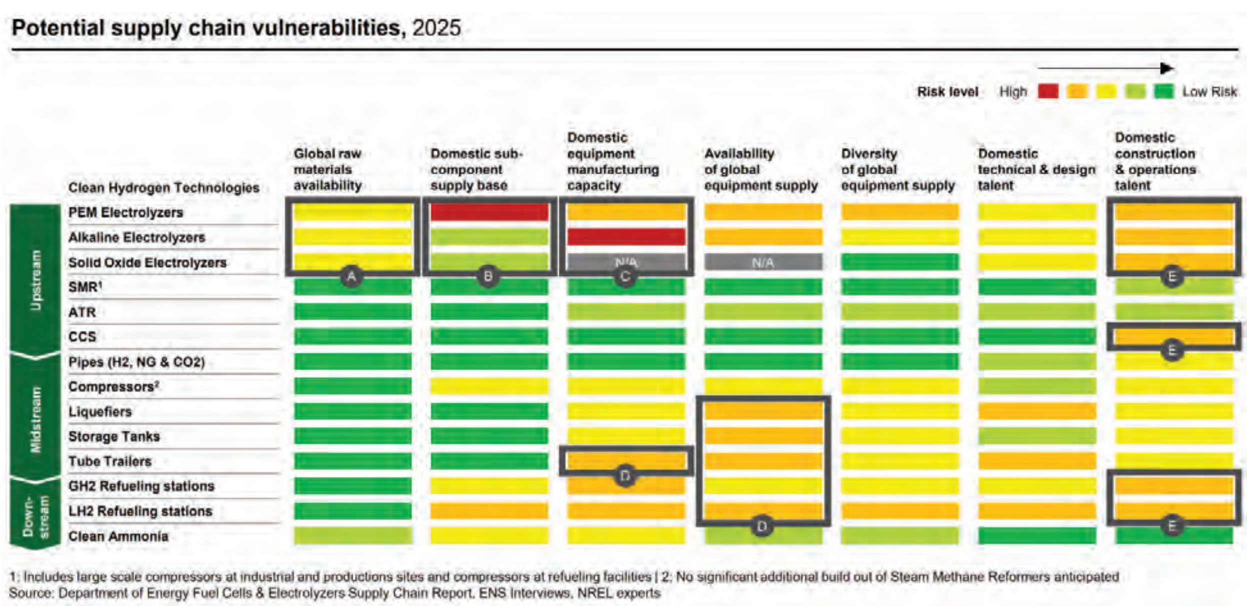


Figure 11. Supply Chain Vulnerabilities Assessment from Reference 44

While not described in the report, the five highlighted categories A-D note areas of greatest concern. Area A notes the limited global raw materials availability for materials for electrolyzers. Area B notes the limited domestic component supply base, particularly for polymer electrolyte membrane (PEM) electrolyzers. Area C notes the limited domestic equipment manufacturing capacity, particularly for alkaline electrolyzers. Area D notes the limitations for equipment manufacturing both domestically and globally for specialized needs for hydrogen in midstream and downstream. Area E notes the limited domestic construction and operations talent for the majority of items both upstream and downstream. These five areas are described in other parts of the report.

Document Overview

The document highlights three industry sectors as primary targets for expanding use of clean hydrogen: industrial high temperature applications like furnaces, transportation like heavy-duty trucks and busses, and power sector applications where hydrogen can provide a storage medium for energy. The definition of clean hydrogen in terms of carbon dioxide equivalent was also promulgated at the same time.

The document also suggests examining all available options to reduce costs. Reference 44 also discusses three primary production sources – water splitting, using fossil fuels with carbon capture and storage – and using biomass and waste feedstocks. Given the broad front approach to costs, there was also a section on the balance of the system costs.

The guiding principles and actions proposed have discussions of phased implementation, but the phases often deal with upstream implementation in types of clean hydrogen production methods or downstream markets penetrated. The difficulty in creating fully functional distributed systems is viewed more as a desire in this document. This desire could be addressed by having co-located facilities for production and use of clean hydrogen that minimize the need for transport and off-take contracts. This approach could also be considered for regional hubs where again the need for long-distance transportation and multiple off-take agreements can be minimized.

Some of the first-wave applications the document proposes, such as remote power to defense facilities, heavy-duty truck fleets, and offroad vehicles, seem to demand a more general availability of hydrogen as a commercial product than is envisioned in the regional hub approach. Others, like refining and clean ammonia, aim to use clean hydrogen in markets where existing industrial sources of hydrogen will need to be out-competed by the new technologies.

4.0 Large Structures and Systems Fabrication Roadmap Development Steps

An industry-driven approach was taken to create and disseminate the RAPLSS. The team leveraged industrial memberships and contacts to create a steering committee that refined and focused on the gaps and needs identified throughout the roadmap development process. The steering committee included a broad range of industry, research, and academic collaborators to cover fully the breadth of opportunities related to accelerating production of large structures. The general steps to complete this work scope included:

1. Reviewed industry reports, roadmaps, and relevant technical works throughout the world
2. Set up a steering committee of varying industries and company sizes in addition to key academic and research partners to provide ongoing input and support to the activities
3. Conducted a series of industry focus group exercises (i.e., combinations of industry sectors, technology focus areas, and geographies) to capture and rank technological needs
4. Conducted electronic surveys to validate findings within a broader range of industry
5. Developed and prioritized a roadmap of research topics with the steering committee
6. Held a national conference to review the roadmap and explore funding opportunities
7. Finalized the roadmap with input from steering committee and national conference feedback

The following information details each task and further defines the steps that were taken.

4.1 Task 1. Review of industry reports, roadmaps, and relevant technical works

The objective of this task was to develop a common baseline understanding of technology trends to be shared with a broad range of industry contacts. This research covered in Section 3 here also informed the industry sectors that are most impacted by the gaps and opportunities identified. A summary report as a set of PowerPoint slides was distributed among the project team and steering committee to guide the surveys and focus group exercises.

Published reports on industry manufacturing trends and needs were reviewed and compiled for relevant sectors. Information on unpublished needs was also compiled from the steering committee organizations. EWI, for example, used several previous surveys and focus group exercises to identify manufacturing technology needs for EWI member companies. The gaps and needs identified in those prior activities were evaluated to determine what efforts were made to fill those gaps, confirm if gaps were met, and whether those gaps were still relevant for current consideration.

Additionally, current work underway or proposed by numerous leading organizations involved in related manufacturing research was assessed to be fully aware of the technology development efforts in-process. This was designed to minimize the chance of proposing duplicate work in the final roadmap document.

This task culminated in a kick-off meeting for the bulk of the road mapping activities. The kick-off meeting disseminated the Task 1 findings and solicited feedback from the technology and industry leaders in the steering committee on the critical gaps in these technologies applied over a range of industrial sectors. The findings from this meeting were used to inform the topical questions and effectively focus the surveys and industry focus group sessions to follow.

4.2 Task 2. Set up a Steering Committee

The project team leveraged their respective industrial, research, and academic collaborators to establish a steering committee to guide the road mapping process. The committee included members across industry sectors (energy, transportation, heavy industrial fabrication, aerospace, and defense) and across company size (see Table 10). The committee also included key resources at universities and research organizations representing multi-disciplinary and cross-functional manufacturing expertise.

Table 10. Members of the Steering Committee

Company	Point of Contact
Banker Steel	Kris Krone
Insyte Consulting	Ben Rand
America Makes	Brandon Ribic
EPRI	Dave Gandy
ATI	Mark Smitherman
SFSA	Raymond Monroe
BP International Ltd.	Charlie Ribardo
Komatsu	Ryan Cross
Caterpillar	Don Stickel
Arcelor Mittal	Murali Manohar
Cloos	Doug Zoller
Visioneering	Ray Kauffmann
Army ERDC	Larry Lynch
ORNL	Lonnie Love
AWS	Peter Portela
AWS	Mario Diaz
GE Power	Attila Szabo
IPG	Dmitri Novikov
Haynes International Inc.	Brett Tossey
Evraz North America	Muhammad Arafin

4.3 Task 3. Conduct a Series of Interviews

Interviews were conducted with key individuals at EWI. This process was repeated with the members of the NSF Industry / University Cooperative Research Center – Manufacturing and Material Joining Innovation Center (Ma2JIC) led by The Ohio State University (OSU). See https://ma2jic.osu.edu/ for more info. Member companies were interviewed by both organizations to gather direct input with question-and-answer sessions to establish baseline needs in preparation for focus groups and future surveys. Interviews were targeted across different sectors and company sizes, including SMEs. EWI's membership extends across many industry segments, including aerospace, automotive, shipbuilding, off-road vehicles, military vehicles, advanced energy, fossil fuels, mining, machine tool manufacturers, primary metal producers, and welding products producers. The interviews were conducted by staff with expertise in targeted sectors and technologies and were structured to allow the compiling of results.

4.4 Task 4. Conduct a Series of Industry Focus Group Exercises

A series of industry focus groups were facilitated to gather detailed data specific to key industrial sectors. These focus group meetings were held in different geographic regions around the U.S. (Columbus, Ohio, Miami, Florida, Chicago, Illinois, and Buffalo, New York) to encourage broad participation across a range of company sizes and sectors. The focus group sessions were developed for combinations of industry sectors, technology focus areas, and geographies to capture and rank technology needs. Special efforts were made to engage small-to-medium-sized businesses in the roadmap development activity. SME participation was encouraged by leveraging relationships with regional economic development organizations, relevant Manufacturing USA institutes, and Manufacturing Extension Partnership service providers in the regions where the focus groups were held.

Invitations to participate in focus group discussions were extended by EWI and Steering Committee organizations. Participants included recognized industry experts who are responsible for developing large structure production and system technologies. A total of 132 participated in the four focus group exercises. The following approaches were used in the focus groups to gather information:

- Presentation to orient the participants and to provide some example technology areas to stimulate creative thinking and encourage participant engagement
- Discussion to ensure all participants understood the scope of the question
- Round robin collection of participant answers to the topic question
- Group consolidation of similar answers
- Structured voting to rank the order of importance of the suggested answers
- Group discussion of the meaning and significance of the highest ranked answers.

This structured approach permitted compilation of data from multiple focus groups to enable aggregate analyzation.

4.5 Task 5. Conduct Electronic Surveys

A series of industry surveys, targeting thousands of respondents, were conducted to gather business/technology needs data from a broad range of industry. The intent was to capture specific input across many industrial sections from a broad range of working professionals engaged in advanced manufacturing and production of large structure and systems. Industry experts were interviewed to help interpret the survey results. In combination, the surveying and interviewing effort were comprehensive in scope and depth while reaching across a broad spectrum of U.S. industry and academia.

Survey respondents were asked a series of multiple-choice questions to characterize their companies (industry segment, size, geographic region, and type of products), their specific manufacturing and production technology challenges, and the business impacts of these challenges. The prior interviews and focus group exercises provided the primary source for the multiple-choice questions for the survey. Survey questions also queried the likelihood of participating in collaborative research programs and implementing new large structure production technologies. The steering committee provided support by leveraging their extensive contacts to email the link to the electronic survey and encourage participation. To increase the potential number of survey participants, the membership and contacts of EWI, OSU, and partner organizations were targeted, thus offering a large contacts database for the surveying task.

4.6 Task 6. Steering Committee Meetings

Steering committee meetings were held during the course of the road mapping exercise along with a series of conference telephone and/or web conferencing calls to discuss:

- Development and coordination of focus groups and survey input
- Results of industry focus group meetings
- Results of industry surveys and interviews
- Review of findings and ranking of gaps identified
- Technology portfolio prioritization
- Research topics based on findings
- Development and review of technology roadmap
- Development of a national conference to review the roadmap and finalize research topic portfolio

The steering committee, with EWI's facilitation, assessed the data gathered during the road mapping process via the review of past data, national conference, industry focus group meetings, and industrial surveys and interviews. This supported the prioritization and ranking of technology needs and provided the necessary input to developing the comprehensive road mapping document. The steering committee identified research topics and scopes of work necessary to close the gaps prioritized in the roadmap. Leading advanced manufacturing and industry research organizations will be asked to provide suggested topics to address the identified needs of industry-specific production of large structures and systems. Topics will be further developed and ranked by a facilitated creative problem-solving group exercise involving divergent and convergent thinking. Analysis of the relative strengths, weaknesses, opportunities, and threats will be conducted to sort the various need/solution combinations into priority bins (urgent, high, medium, low). A draft roadmap document will be disseminated to key stakeholders (from industry, academia, government, professional societies, trade groups and research organizations) for comment and feedback.

4.7 Task 7. Finalize Roadmap

Following development of the roadmap document, a national conference was arranged at EWI headquarters in Columbus, Ohio, to present and discuss the findings of the roadmap and the proposed research topics prioritized in the roadmap. The goals of this conference were to disseminate results, create alignment, and begin to establish collaborative teams to develop solutions. This also provided an opportunity to gather final input to the roadmap priorities and to refine the proposed research topics previously identified. Based on feedback obtained during this conference, the RAPLSS roadmap was finalized, including detailed technology development plans to enhance the potential to meet the technical needs and gaps documented in the roadmap. A copy of the agenda and presentations from all speakers are included in Appendix G.

At the conclusion of the national conference and revision of the roadmap, the roadmap document was submitted to NIST. The roadmap was disseminated by the steering committee to a broad range of stakeholders across the nation.

5.0 Results

5.1 Category Development

EWI and OSU technical SMEs participated in a one-day workshop to develop a group of gap items as suggestions, a “Gap Analysis Matrix,” for the consideration of industry participants. These items were based on EWI’s and OSU’s experiences of working with the relevant LSS industry verticals/segments. These were not seen as final recommendations, but rather as a way to encourage suggestions from industry representatives based on being part of an on-going dialogue with some items that could be worthy of discussion already present. In this matrix, a list of industry verticals along with industry capability areas within each of these verticals were created and later refined by the steering committee based on analysis of results from surveys and interviews. This matrix is presented by industry vertical in Appendix E.

Industry Verticals:

- Offshore Wind/Maritime
- Hydrogen/CCUS/Petro-chemical/Refining
- Nuclear
- Primary Metals
- Mega Building/Bridges
- Rail and Mass Transportation
- Other

Industry Capability Areas:

- Design: Methodologies and Models/Digital Thread and Twins
- Fabrication Technologies
- Integrity: Condition Monitoring/Service Life Extension and Optimization
- Conventional and Advanced Materials
- Supply Chain
- Workforce Development
- CAPEX Costs
- Standards and Codes

5.2 Gap Assessment Inputs

Using the industry verticals and capability areas as the framework for assessment, EWI and team received feedback through various forms to support identifying additional gaps, priorities, and potential solutions. This feedback was from interviews and focus groups. The initial interviews and focus groups led into the development of electronic survey questions. The electronic survey window was open for about eight months in which data was collected and summarized to the steering committee. In the meantime, the interviews and focus groups continued to collect additional input for this roadmap.

One difference between participants in the focus groups, interviews, and surveys is the level and type of connection to large structures and systems of the participating companies. Four general levels of participation were included:

1. Provides large structures and systems to customers
2. Uses large structures or systems to provide goods and services

3. Provides goods and services to fabricators or users of large structures and systems
4. Provides knowledge useful to the above three categories.

Each of these four perspectives expressed a different attitude toward a category like "Supply Chain" for instance.

5.2.1 Individual Interviews

Individual interviews were conducted to establish a baseline of needs and identify industry gaps for technical areas for each industry vertical. The interviews yielded similar feedback among the industry verticals and also enabled a list of questions to support the creation of the industry survey. A summary of the feedback from the individual interviews is in Table 11, followed by an example interview and then more specifics from all interviews conducted.

Table 11. Summary of Interview Feedback

General

- More likely to implement automated processes in the next five years
- The United States has the technology (casting/forgings) but is not willing to provide capital to make equipment upgrades or purchases.
- What capabilities would a new or emerging technology bring that traditional manufacturing processes don't have?
    - Smart Manufacturing / Automation / Artificial Intelligence / Machine Learning
    - New steel grades and coatings
    - Modeling, digital twin, integrated software packages from design to build
    - Advanced NDE; in-process quality monitoring
    - Welding/Materials Joining
    - Large-scale machining capability for large structures is needed
- Top considerations for identifying and selecting emerging technologies for large structure manufacturing:
    - TRL 6 is needed for industry to independently fund and complete development of new technologies (Note: some industries will require TRL 7-8).
    - Workforce readiness
    - Reliability
    - Capital funding for equipment
- Codes and Standards
    - Are not always adequate; codes may be outdated; code body acceptance (e.g., ASME) and regulatory approval.

Supply Chain

- Small manufacture base – small and medium enterprises (SME) – needs to be engaged to successfully demonstrate, transition, and scale up a domestic manufacturing capability. Identify teaming mechanisms and/or best practices across the supply chain.
- Acquisition policies of the government are a burden.
- Foreign competition increasing/increased foreign buyout of U.S. companies
- Manufacturing scalability to address war-time need

Workforce

- Workforce – single-most immediate need is bodies; engage workforce at the onset in developing/introducing any new technology
- Difficulty in finding trained and qualified skilled trades and professional technical personnel

Partnering

- Working groups: industry researchers, universities, government
- Joint industry projects with multiple partners
- Non-profit research organizations leveraging industry and government funding
- Partnerships are key in moving forward to advance technology – need to broker technology

5.2.2 Summary of Interviews

5.2.2.1 Example Interview Feedback Provided by a Retired Oil and Gas Engineer

A retired oil and gas engineer provided a more extensive description of industry needs.
The O&G industry includes upstream, midstream, and downstream operations as well as the petrochemical industry. All segments involve extensive use of very large structures and systems. This includes floating offshore drilling rigs, floating or fixed-bottom production structures, floating storage vessels, wellhead equipment, pipelines, ships, gas plants, refineries, and chemical plants. All offshore structures have topside facilities comprised of thousands of tons of vessels, piping, and other equipment. There are thousands of large components and structures used in O&G projects annually. The O&G industry spends tens of billions of dollars annually on structural steel and is a substantial user of heavy fabrication services.

The O&G industry provides roughly 70% of the United States' energy. While this percentage will decrease in the future due to climate concerns and the ascendance of renewable energy, it is a near certainty that O&G will provide the majority of U.S. energy for the next 20 years. Because the United States depends heavily on this energy source, and the O&G industry relies on large structures and systems to produce this energy, it would seem prudent for RAPLSS to consider O&G applications.

Industry 4.0 is not a popular concept with O&G companies who work independently and do not produce large structures by the thousands on an assembly line. It is not that Industry 4.0 technologies are of no use to O&G; in fact, sensors, cloud computing, smart machines, and AI are all used. Additional work is necessary to identify potential applications for Industry 4.0 technologies.

Another challenge for links to O&G involves how engineering responsibilities for capital projects are conducted. If an O&G company undertakes a large project, execution typically starts by bidding and hiring an engineering, procurement, and construction (EPC) company. The EPC company is responsible for conducting design work according to the owner's specifications which are then reviewed, negotiated if necessary, and approved by O&G company engineers. The EPC then carries out the project, but this may involve hiring separate construction companies that specialize in the large structures needed. The EPC company may also hire an independent inspection company to do the welding NDE. For large capital projects in O&G, there are many stakeholders involved.

While Industry 4.0 technologies are of use to O&G, there are stakeholders to align. For example, a pressure vessel fabricator that serves the O&G industry will be cautious to invest in a new welding process (e.g., hybrid laser arc welding) if it is not recognized by the applicable codes and if O&G or EPC companies will not approve it. Herein lies a parallel to the nuclear industry. O&G companies are reluctant to be the first user of a new technology unless there has been substantial R&D including full-scale demonstrations. Technology developers may struggle to incorporate R&D efforts at this scale.

To the knowledge of the respondent, there exists no O&G documents like the other documents (e.g., roadmaps) in this review. The O&G industry does have consortia, institutes, and joint industry projects for R&D, but they tend to specialize in industry segments. Once project work is complete, the details are confidential unless the group concludes that it is within their interest to either sell the technology or openly publish. One successful group is Pipeline Research Council International (PRCI) who post its priorities and research areas,(45) but the information amounts to a few sentences or paragraphs. One can also find descriptions of industry initiatives and future focus from the API; however, this information is high level.

A few ideas for O&G were given, the first of which is for pipelines. Pipeline fabrication travels across outdoor terrain while the pipe stays in place. This is not the typical Industry 4.0 manufacturing mode where most equipment is stationary in a facility and the work pieces move through. For mechanized pipeline welding, the technology is mature, and it may be difficult to identify Industry 4.0 opportunities. For manual welding, the environment is rugged, variable, and not well suited for Industry 4.0. However, 100% of pipeline welds are inspected, and this is an opportunity for Industry 4.0. The concept is to analyze digitized NDE data with AI algorithms that identify welding problems and whether they are caused by the welder, the fit-up, the pipe geometry (out-of-round or peaking), or something else. The analysis would be in-situ with pipeline fabrication so that feedback can be immediately given to front line welding crews. For x-ray inspection, the data must be digitized; for ultrasonics, it is already digital. Stakeholders for this technology include EPC companies, pipeline welding companies, inspection companies, companies that make the NDE equipment, and O&G companies.

Another idea with potential involves the dimensioning of pipes, pipe fittings, vessel connections, etc. to improve efficiency and prevent welding defects. A primary cause of pipe welding defects (requiring expensive repair) is poor fit-up caused by variations in pipe geometry. An improvement is to use a 3D laser scanning device to dimension the round orifices to be welded (any orifices like pipe, fittings, vessel flanges, etc.) and to create a database of these openings. This data would be analyzed by a smart device, which would provide the welding crew with instructions on fit-up. Welding crews spend significant time using trial and error to obtain desirable fit-up. Take, for example, a project using thousands of pipes and fittings. A smart device would consider all geometries (ovality, peaking, wall thickness variation), and provide guidance for each weld. It could recommend to fit-up pipe number 1042 with pipe 2873 and to rotate the former by 22 deg from 12 o'clock. This would eliminate welding crew trial and error. The smart device could also advise if a particular item is unsuitable for any fit-up and should be discarded. This type of 3D scanning technology exists and has been used in the O&G industry for critical offshore riser welds where fatigue life and smooth weld geometries are paramount, with the goal to minimize stress concentrations. This technology can be extended to more general use. Any technology that is useful to minimize the hands-on nature of pipe and piping work will be of interest to O&G.

These two technology ideas for O&G are just a few of the possible opportunities to consider. For instance, a system that includes a greater network of methane detectors could catch leaks that O&G companies have not detected by other means. Leak control requires leak detection which requires sensors. Sensors, smart technologies, and AI can be used to alert operators and/or perform automated shut down. The vision is to blanket the world of natural gas production and usage with sensors and to mandate a level of control.

Carbon capture and storage (CCS) and hydrogen as a future clean fuel are connections with oil and gas. Both CCS and hydrogen will require equipment (large structures and systems) including pressure vessels, pipelines, and piping systems. For the case of hydrogen, there is substantial work necessary to verify that the materials being used will withstand the presence of hydrogen as this element is known to damage the metals commonly used for large structures and systems.

5.2.2.2 Details from Interviews

Many of the individual interviews looked at a somewhat broader view than that of any individual organization.

Raymond Monroe of the Steel Founders Society of America not only responded with an individual interview, but also presented at several focus group meetings. He indicated that castings would remain important for higher strength steel as American capacity for large structure fabrication increases. Since they can outcompete additively manufactured material for properties, size, and especially cost when enough production volume is desired, castings will be in demand for larger sizes and thicknesses provided the standards and specifications are not biased against casting. Indeed, a large problem is providing competitiveness when dealing with overseas competition that has been set up more recently to dominate world commercial markets in an environment with worldwide price competition for commercial items.

The casting industry response included that the most pressing need was in unskilled labor rather than trades or technical. New technology has an entry into the industry in additively manufactured molds. One area that would add valuable technology to the casting industry is the conversion to digital radiography, which would need to be led by the risk-averse government customers. Most commercial customers not using government specifications have already converted to digital radiography, which has outstripped traditional methods for sensitivity and reliability. This is an interesting area for standards development, since it is a complaint about un-changing older standards rather than a need for new standards.

Scott Shurgot of BWXT presented at the fourth focus group. He described the innovations and hurdles in the nuclear industry. He said that adding just one reactor to plans for construction can stress the American manufacturing industry. He is working with both space-based and ground-based reactors. A particular problem he sees is the current limits of ASME Section II Division 5 for building of high-temperature reactors. It only allows five materials and has not been approved by the Nuclear Regulatory Commission. Advanced designs lead to there being no established supply chain.

The bridge industry response from AISI indicates the importance of pre-fabricated segments or components for current and future designs, which improves the capability to apply shop automation.

The U.S. Navy shipbuilding initiative indicates a need for all sorts of automation, given that the state of American technology has been held back for years by contracting difficulties between suppliers and the government. Innovations used in foreign shipyards have not come to the United States.

The additive manufacture industry response from America Makes indicates the importance of developing standard qualified materials, so the rapid deployment capabilities of additive manufacturing can be used without an extensive series of qualification and certification tests.

A company representative from the pipeline industry responded that the industry is seeing opportunities to add or convert large-scale infrastructure to hydrogen and CCUS uses. The approach to standards in the pipe material and welding has been left to the API industry consortium. The representative indicated that the most critical actions were improving workforce skills and permitting reform to prevent complicated repeating roadblocks to construction. Technologies in adjacent areas to large system constructions are needed in medium- to large-scale electrolysis, small- to medium-scale pyrolysis, and in the connection of CCUS to concrete production and use.

Some of the interviews provided insight into additional gaps that had not been identified. One indicated the need for welders, machinists, equipment operators, and truck drivers right away, supporting the idea that staffing support positions is a difficulty. Another mentioned a shortage of special skill personnel with ability to travel for a high percentage of the year, such as advanced ultrasonic technicians and on-location welders. Individual technologies mentioned as gaps were control systems, rapid prototype castings, and integrated computational materials engineering (ICME). Several of the responses mentioned the difficulties of specific kinds of interactions, from the choices of “safe” research and development projects to the difficulties of university-industry collaborations, as well as the normal focus on project-driven activities drowning out the capability for development of improved overall methods.

5.2.3 Focus Groups

Four focus groups were held throughout the development of this roadmap to identify gaps and to gather detailed data specific to key industrial sectors.

The first focus group was held in Columbus, Ohio, with 28 attendees. This focus group was intended to brief the participants on the RAPLSS roadmap and better define the gaps listed in the Gap Analysis Matrix EWI SMEs created (Appendix E). These gaps were presented by industry vertical and discussed among the attendees. EWI also provided an electronic copy of this matrix to all attendees and requested their feedback. This feedback was rolled into a new version of the matrix that was used to support development of survey questions and interview content. Appendix E is the most current version with all feedback received.

The second focus group, in Miami, Florida, was held in conjunction with OSU's NSF IUCRC Ma2jic IAB meeting and was comprised of 64 attendees. During this focus group, the attendees ranked gaps in three industry capability areas: Fabrication Technology, Conventional and Advanced Materials, and Workforce Development. A detailed discussion of these findings is in Appendix F.

The third focus group was held in Chicago, Illinois, in conjunction with FabTech. At this focus group, 15 attendees gathered to have an open discussion about the Gap Analysis Matrix. This session was an open conversation where each participant shared what they identify as the biggest gap in their industry vertical and less of EWI presenting on the gaps already identified.

The fourth focus group was held in Buffalo, New York, with 18 attendees. EWI presented results from this project thus far, including feedback from other focus groups, surveys, and interviews. Featured speakers included Ray Monroe (SFSA – Castings and Forgings) and Scott Shurgot (BWXT – Advanced Technologies for Nuclear). This focus group followed a similar format to the third, with an open conversation among all participants discussing gaps in their industry vertical.

5.2.4 Electronic Surveys

The electronic survey was released in August 2023 and closed in April 2024. The survey was primarily comprised of sixteen closed-ended questions with a fixed set of responses from which to choose. Two additional open-ended questions were provided to obtain further information and to ask if follow-up would be necessary to provide response clarity. Each question along with a summary of the results and a chart portraying these results is described on the following pages.

- Question No.1 requested the contact information of the respondent.
- Question No.2 was to determine the respondents' industry/organization type based on the large structure and systems (LSS) industries. More than 33% of the respondents were from equipment or service providers. The equipment/service provider is a cross-cutting category with relevance to all the industry verticals.

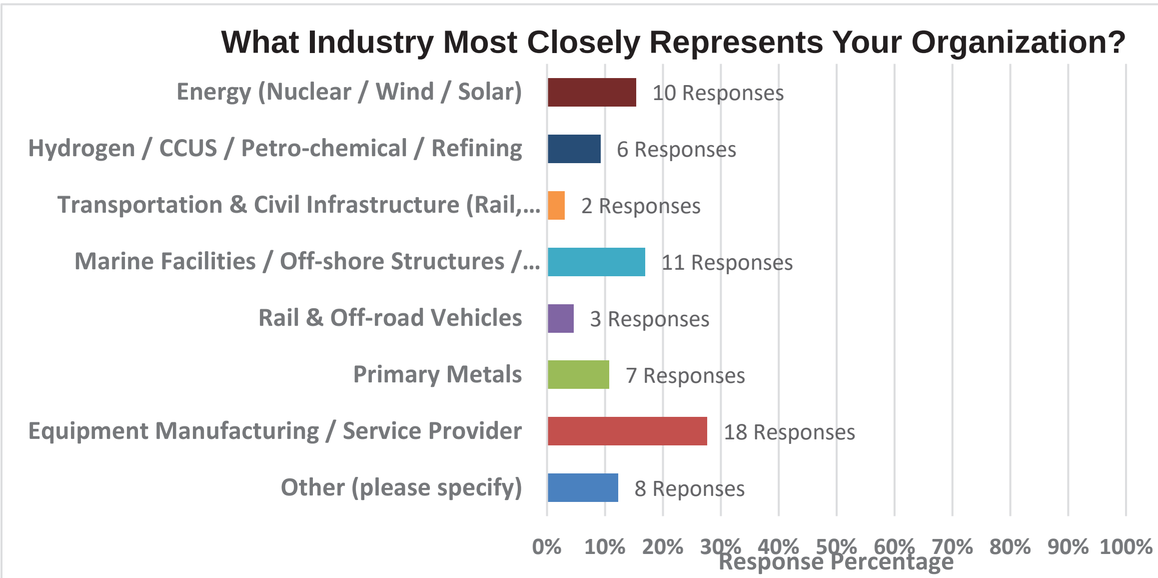


Figure 12. Question No. 2 Responses – Industry Survey Respondents

- Question No.3 asked if respondents felt that competition from foreign companies would be increasing or decreasing for the next five to seven years. More than 50% answered that they expected an increase in foreign competition for their organization.

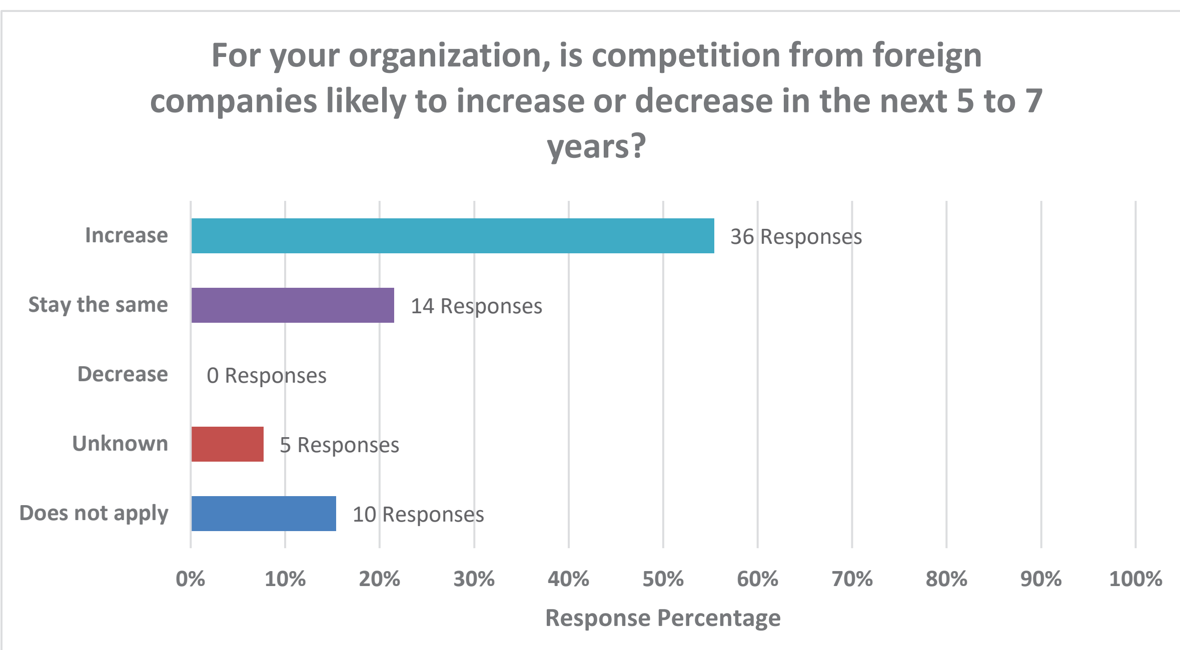


Figure 13. Question No. 3 Responses – U.S. Company Foreign Competition

- Question No.4 was to determine what functional capabilities are critical to the future of the organization. More than 50% of the respondents answered positively for a) research and development, b) production and manufacturing engineering, and c) material and component supply chains. Also of significance is the need for workforce education and automated fabrication processes.

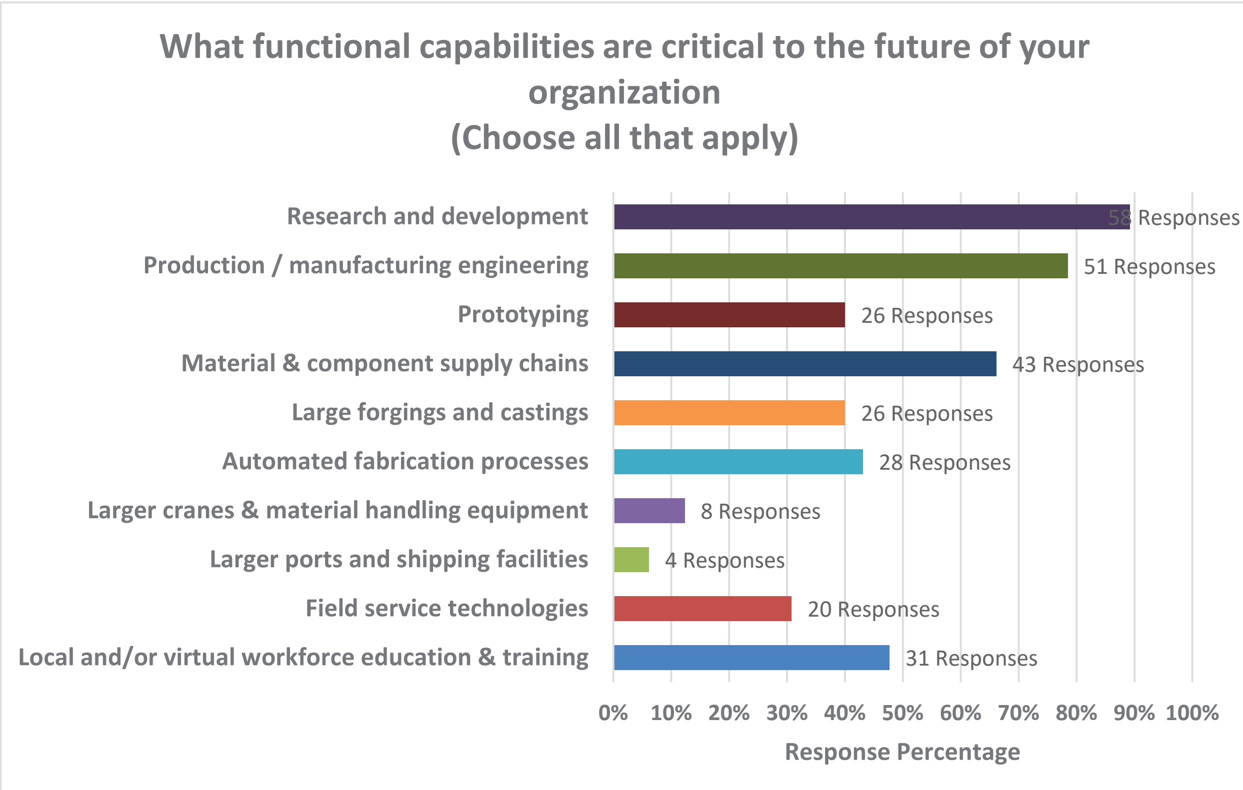


Figure 14. Question No. 4 Responses – Critical Functional Capabilities Needed

- Question No.5 delved into technical and production processing challenges that were most likely to impede performance and/or increase costs. In this question, the respondents were able to select all topics they deemed applicable to their organization. Workforce readiness and supply chain readiness were considered to be the greatest impediments to organizational performance and increased costs at a survey response greater than 75%.

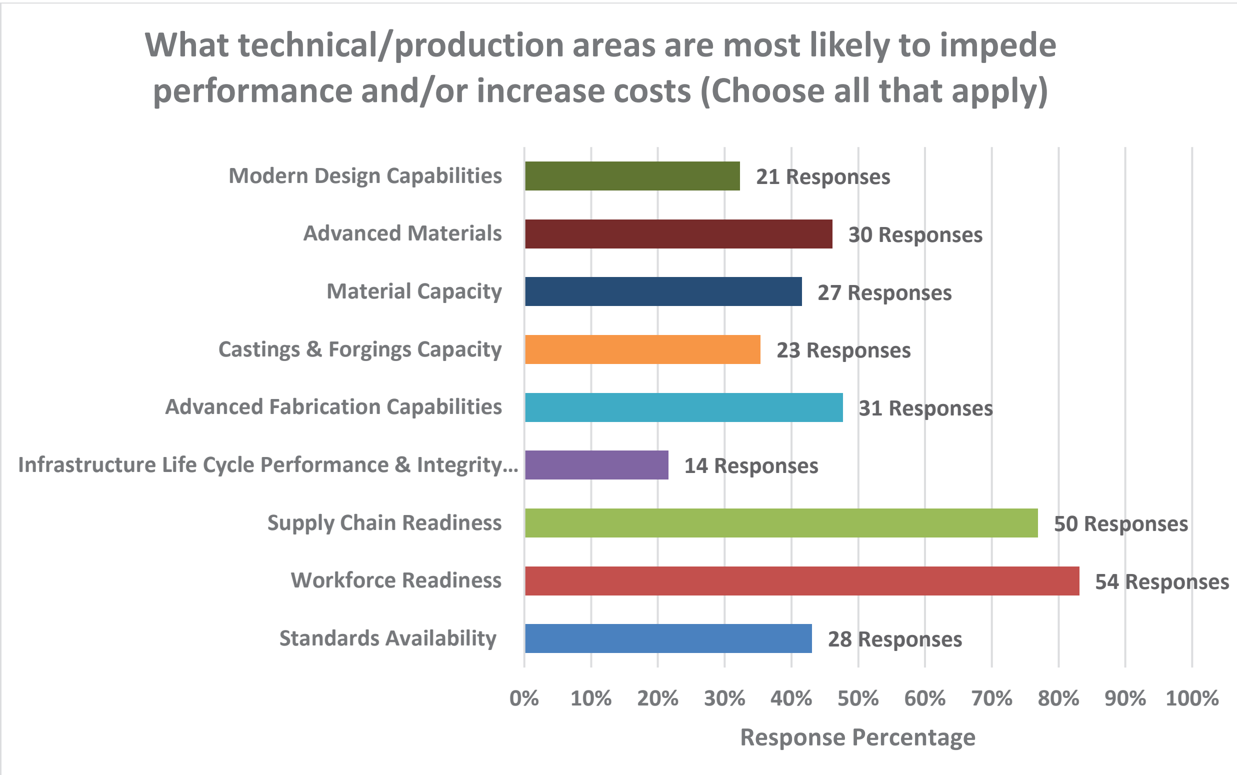


Figure 15. Question No. 5 Responses – Impediments to Performance and/or Increase Costs

- Question No.6 was about Industry 4.0 technology and what was the highest priority for the respondents organizations. Several options received similar results on a weighted average bases: data science, AI, and machine learning; simulation, digital twin, and digital thread; sensors and internet of things; and portable robotics. Respondents gave augmented reality a lower rating.

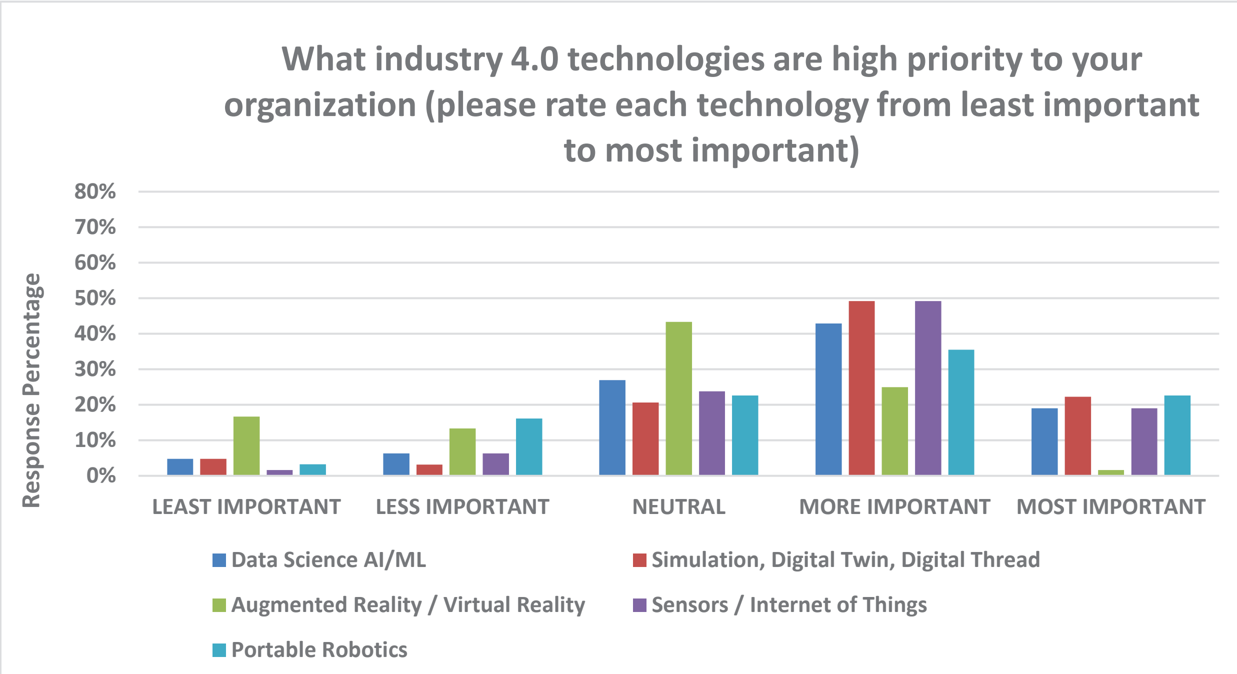


Figure 16. Question No. 6 Responses – Industry 4.0 Technology Priorities

- Question No.7 focused on with materials that were widely used either internally to the organization or to its contractors. This question provided the respondents the ability to select all topics they deemed applicable to their organizations. The most widely used materials were stainless steels and high-strength (70-100 ksi YS) carbon steels. There was a wide variety of additional materials listed. This shows the multi-material nature of current and future large-scale fabrication.

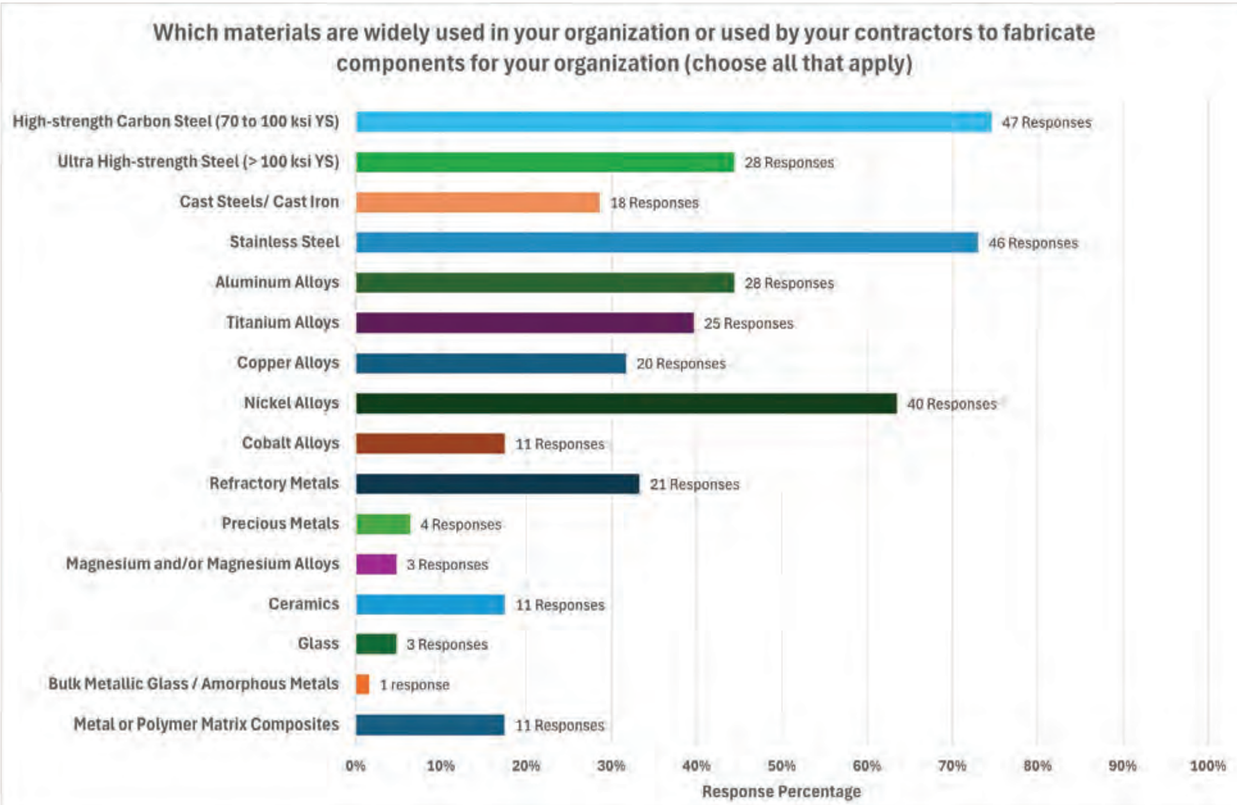


Figure 17. Question No. 7 Responses – Materials Widely Used

- Question No.8 dealt with which fabrication technologies were important to the organization. This question provided the respondents with the ability to select all topics they deemed applicable to their organizations. More than 90% of the responses indicated that welding and joining processes are important to their organizations.

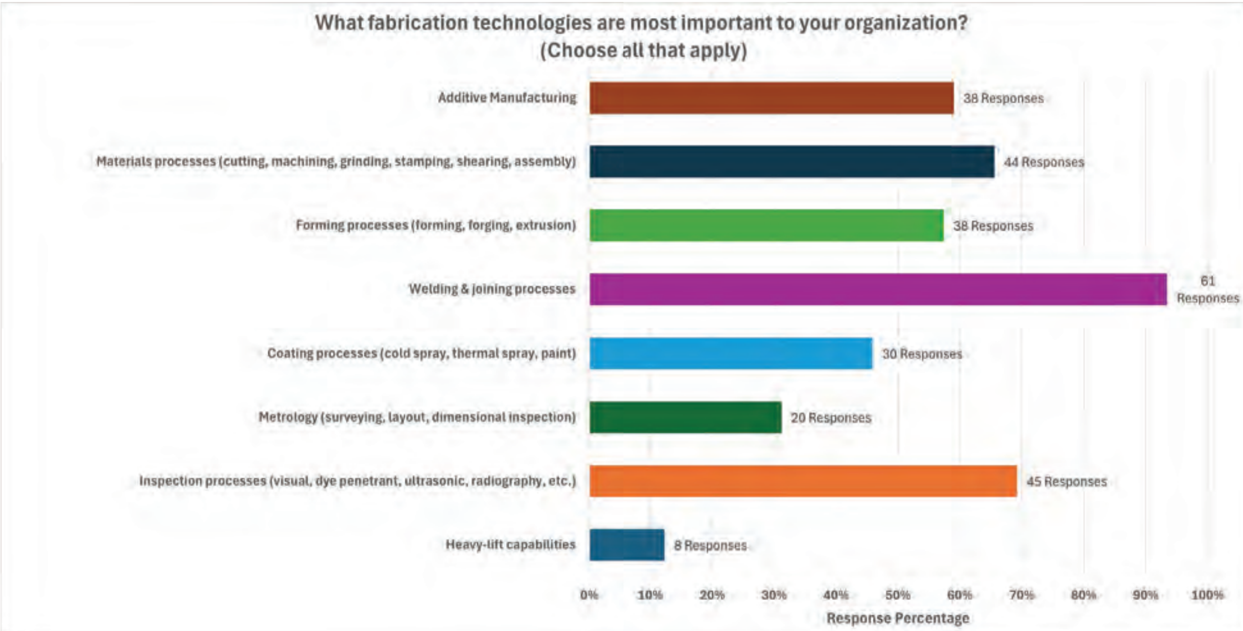


Figure 18. Question No. 8 Responses – Important Fabrication Technologies

- Question No.9 dealt with the services that the organization needs to advance research, engineering, and technology objectives. All of the service categories received between 36 and 72% of the responses, indicating that while not all companies used the same strategies, they will likely use multiple service strategies concurrently.

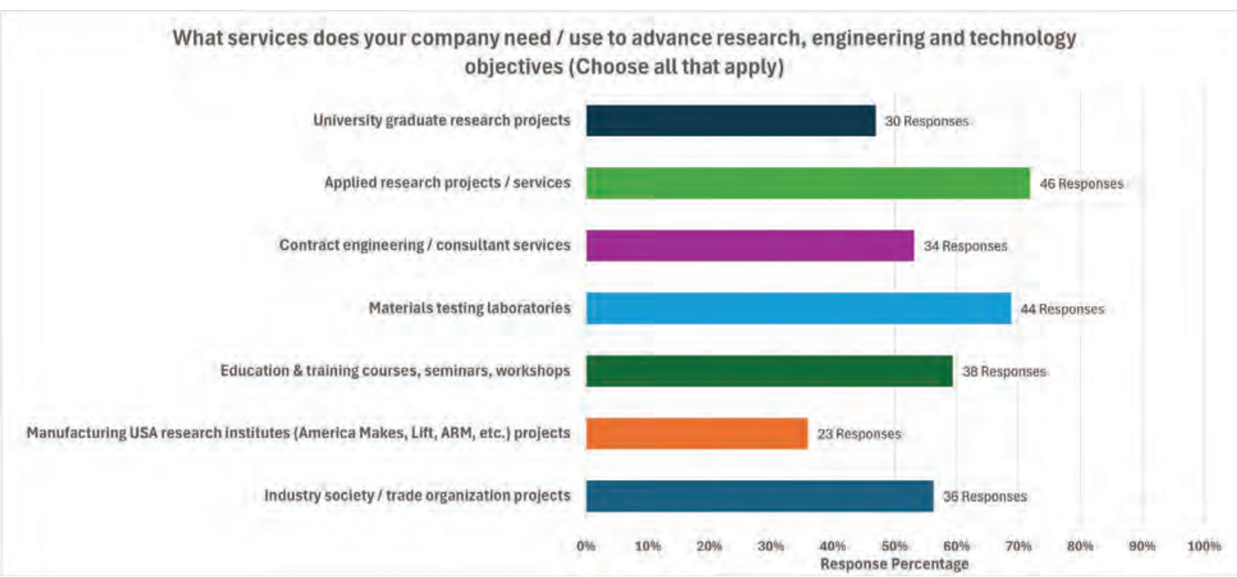


Figure 19. Question No. 9 Responses – Services Used to Advance Technology

- Question No.10 dealt with the types of collaborative development approaches that would be most useful to improve production capabilities and implement new technologies. The highest outcome for this question was for "Joint Industry Projects With Multiple Partners," although all of the options showed more favorable responses than unfavorable responses.

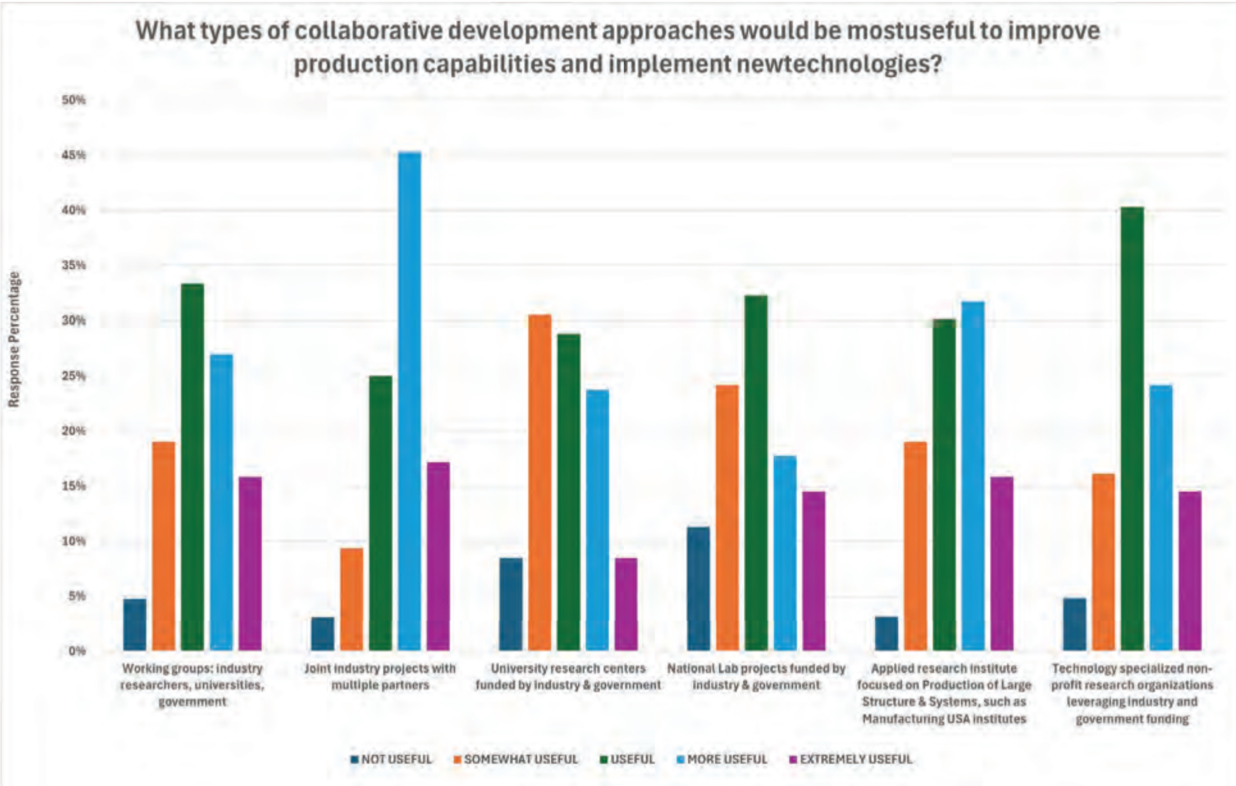


Figure 20. Question No. 10 Responses – Collaborative Development Approaches

Question No.11 asked respondents if it is easier or more difficult today compared to 10 years ago to find trained and qualified skilled trades personnel. More than 80% of the respondents indicated that this had become more difficult over the past 10 years.

Figure 21. Question No. 11 Responses – Ability to Find Skilled Trades Personnel

Question No.12 (like Question 11) asked if it is easier or more difficult today compared to 10 years ago to find trained and qualified professional technical personnel? More than 70% of the respondents indicated that this had become more difficult over the past 10 years.

Figure 22. Question No. 12 Reponses - Ability to Find Professional Technical Personnel

- Question No.13 addressed whether the number of trained and qualified skilled tradespeople in the organization assigned to advanced manufacturing activities would likely increase in the next five to seven years. More than 64% answered increase, while less than 13% answered decrease.

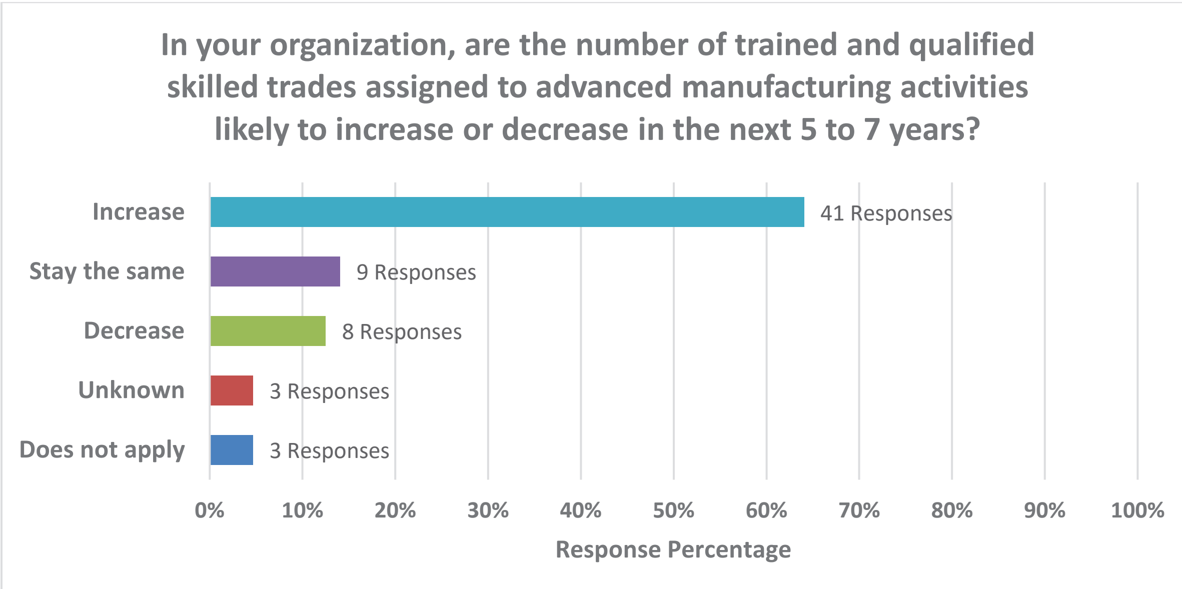


Figure 23. Question No. 13 Responses – Future Outlook for Skilled Trades

- Question No.14 was whether the number of trained and qualified professional technical personnel in the organization assigned to advanced manufacturing activities would likely increase in the next 5 to 7 years. More than 70% answered increase, while less than 10% answered decrease.

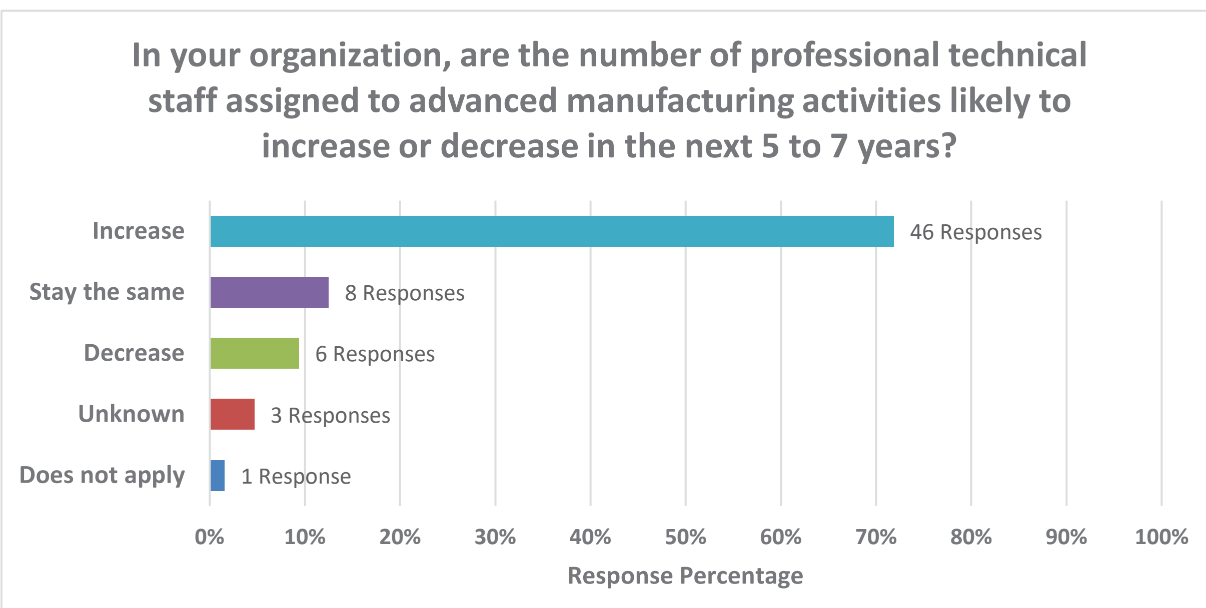


Figure 24. Question No. 14 Responses - Future Outlook for Technical Professionals

- Question No.15 dealt with the technology areas that need new or advanced training to meet production capabilities. This question allowed respondents to select all topics deemed applicable to the organization. Several topic areas were over 50%: welding and joining, additive manufacturing, inspection processes, and materials processing.

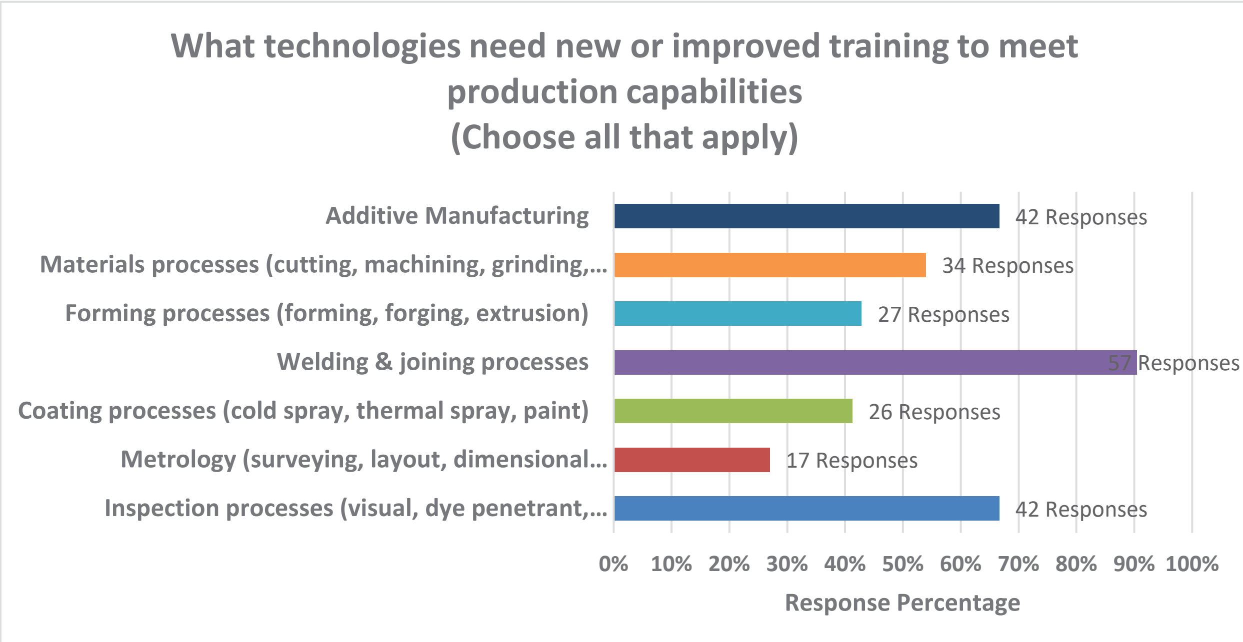


Figure 25. Question No. 15 Responses – New Technology and Improved Training Needs

- Question No.16 dealt with the technology areas that need new or improved automation to meet production capabilities. Respondents could select all topics they deemed applicable to their organizations. This had similar results to Question 8. Several areas were over 50%: welding and joining, additive manufacturing, inspection processes, and forming processes.

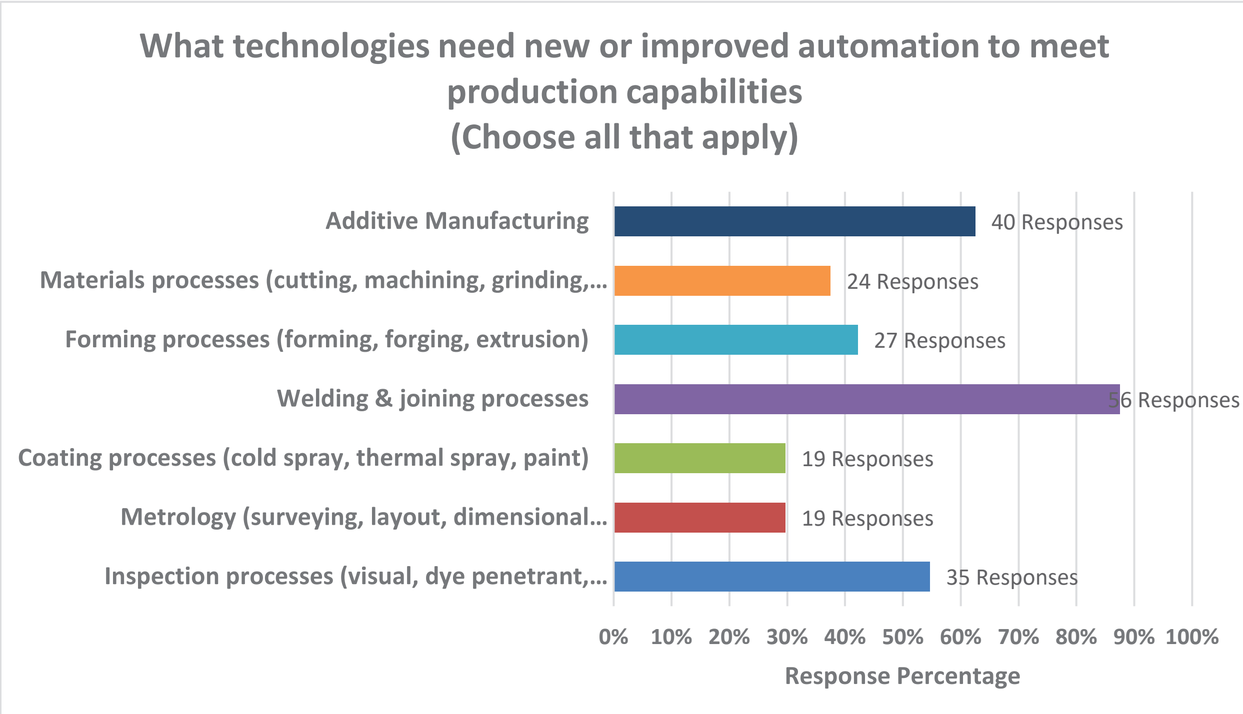


Figure 26. Question No. 16 Responses – New or Improved Automation Capability Needs

- Question No.17 permitted the respondent to describe additional gaps that were not included in the other questions. A summary of additional gaps is provided in Table 12.

Table 12. Survey Summary Responses of Industry Additional Gaps

Industry Vertical	Missing gaps in your organization that are not included in our industry capability areas?
Energy (Nuclear/Wind/Solar)	• Supply chain readiness and capacity are not a technical issue. A likely way to advance the supply chain ahead of actual orders is significant government investment. • Where is PM-HIP in the overall discussion? This is one of the major paths forward for U.S. manufacturing.
Equipment Manufacturing/ Service Provider	• What is the failure rate of domestic R&D, innovation, angel investment groups? Failure rate is low but no break-thru technology, very risk adverse. Need to push the envelope. • Domestic sourcing of materials, hardware and components – taking too long to re-shore. • Skilled trades education pipeline is dismal. • Need more competent welders, machinists, and heavy lift crane/other equipment operators and truck drivers in heavy industry ASAP. • More control systems needed. • We will use universities for smaller projects, but we really struggle with joint projects. • Our efforts and focus are dictated by project-driven activities.
Hydrogen/CCUS/Petro-chemical/Refining	• Need prediction tools for life assessments. • Need an increased understanding of corrosion and materials related to decarbonizing the energy sector. • Fundamental training at the undergraduate and graduate level in basic materials science and metallurgy.
Marine Facilities/Offshore Structures/Shipbuilding	• Need more actual production capacity and competition in supplier base. • Need large scale additive manufacturing.
Rail and Off-road Vehicles	• Industry needs a data standard for weld information that can start in the CAD model and extend into "smarter" manufacturing engineering systems. • Rapid prototype castings
Transportation and Civil Infrastructure (Rail, Bridges, Buildings)	• Practical manufacturing statistical analysis • Ultrasonic technicians, specifically advanced UT, i.e., phased array for austenitic and carbon steels. • Welders, those willing to travel.
Other	• Domestic raw material supply sources • Integrated Computational Materials Engineering (ICME)

- Question No.18 asked whether more follow-up would be valuable. This provided the opportunity for additional interviews, with the outcomes reported within the interview section of this report.

5.3 Roadmap Results by Technical Area

5.3.1 Design: Methodologies and Models/Digital Thread and Twins

Computer-aided design (CAD) and manufacturing (CAM) are widely used by most structural metal industries. For LSS, CAD models are critical for configuration management of large-format components. The digital thread seeks to capture the attributes of each component over its life: from material properties used to design components for fitness for service to production CAM material-process models that are used in machining, automated welding, and NDE to in-service inspection and ECA of flaws' effects on remaining life. The more information cataloged on each component, the lower the costs to maintain, repair, and sustain LSS structures and systems.

For fabrication of LSS, multi-process digital manufacturing systems are needed that maximize the use of automation while minimizing programming costs for a wide range of metalworking processes including machining, forming, welding, thermal spray coatings, and NDE to name a few. Robotic CAM tools allow rapid CAD to path programming for high-mix, low-volume production of large structures and systems. This previous point is very important for LSS. As mentioned elsewhere in this document, large structures are not typically manufactured by the thousands (at least not annually). But technologies useful to the high-mix, low-vol nature of the beast are very important to LSS. An emerging need is informatics that can drive digital manufacturing workflows between digital manufacturing processes.

Convergent manufacturing is a new digital manufacturing term that is synonymous with intelligent multi-process digital manufacturing systems. It creates a platform for extending the digital thread, minimizing programming costs, and ensuring first-time quality for high-mix LSS fabrications. For example, a convergent manufacturing technology could be used for automated inspection and repair of in-service LSS components. A multi-process robotic system could be used to inspect, identify unacceptable flaws, remove flaws for repair welding, repair component, finish grind weld repair area, and then perform final NDE to certify integrity for service. To perform convergent manufacturing workflows, digital twins are needed for each machine and process, and informatics are needed to drive the multi-process data workflow.

DED processes can be used for welding, cladding, additive manufacturing, and repairing LLS components. Here, commercial automated or robotic systems are converted into DED by developing a digital twin of the machine and a material deposition model for fusion welding (arc, laser, or electron beam) deposit processes using CAM software tools. DED technology is being extended to thermal spray and cold spray processes since models can be used to describe the coating deposition spot behavior and automate conformal coatings of corrosion or wear resistant surfaces.

Many industries are pursuing models and digital applications so they can automate the most difficult welding challenges in module building and leave the more standard welding to field erection. This is similar to the role that the use of interchangeable parts in the nineteenth century played in increasing and simplifying industrial production of complicated devices. Depending on the LSS segment, use of digital manufacturing models and CAM tools are further advanced in some areas than in others.

5.3.2 Fabrication Technologies

Fabrication technologies scored very high among those who thought that increased value could be provided to new large structures and systems. Each segment has some unique fabrication technology challenges. For example, shipbuilding still needs to develop neat construction capabilities especially for Naval ships that are erected using numerous, complex modules that are all structurally unique. This is in comparison to container or double-hull tanker ships that have unique bow and stern structures but may use a range of similar structural modules within the ship’s length. The latter is significantly more friendly for factory automation on modular structures and for the use of ICME tools to accurately predict and accommodate shrinkage.

Welding based distortion and shrinkage prediction is still a major challenge for building large structures neatly. As noted above, many large structures follow the 1/5/9 construction cost model. What costs 1X in the factory, increases to 5X in the yard, and increases to 9X during erections due to the difficulty of working on large structures, up on scaffolds, in dry docks, in the field, or offshore. Welding distortion results in poor fit up, over welding, and the need to flame-straighten structures to meet dimensional requirements like fairness.

In addition, distortion can cause gap and edge misalignment during erection welding. A common need for LSS components is adaptive automation technology that can analyze fabrication conditions and make in-situ changes to ensure first-time quality and to accommodate a range of gaps and joint mismatch. Smart robotics and convergent manufacturing systems are critical to LSS fabrication affordability.

Another LSS challenge is the sourcing and use of higher strength materials that minimize total weight of steel and provide better structure performance. Many large structures and systems are not limited by the material properties available alone, but rather by those that can be obtained and reliably joined into the entire structural system. While higher strength materials can be beneficial to some designs, the choice involves risks associated with a structure that is less stiff (more compliant) and with potential cracking problems during welding. Design challenges require updated design analysis and potential model testing. Welding challenges can typically be addressed with laboratory trials.

The availability of large castings and forgings is cited as a supply chain problem across many of the LSS verticals. Large-format additive manufacturing using DED is being developed as an alternative to castings and forging. Large-format DED offers shorter delivery schedules but at higher costs, especially if there are needs for component production volumes. For nuclear, the need for a national mega-HIP facility is critical for making next-generation nuclear components with advanced materials.

5.3.3 Integrity

The digital thread and transferability of information are crucial to integrity assessment. Information such as strength, crack resistance, and presence and sizing of imperfections is critical to the fatigue and fracture tolerance of LSS. What people "think that they know" is crucial. This relates to the expectations built up by material test reports and existing qualification information. Automated NDE is critical to enable complete inspection coverage of high integrity structures and components. The use of flaw recognition software and machine learning can be used to provide upstream feedback to improve fabrication processes, and downstream data for informed NDE during service. Smart components are needed in the most severe applications that have embedded sensors for analyzing structure health and integrity. One area in which gains in integrity information can be enabled more rapidly is through experiential knowledge-based prototyping/modeling, using differing processes that work better for one-off and small batch production.

5.3.4 Advanced Materials and Performance

This area had the least consensus among the areas reviewed in Focus Group 2. The variety of material needs in different systems (perhaps symbolized by the different meaning of "high-strength steel" or "light-weight alloy") in different industries is likely to play out here. Surveys also showed that many companies use multiple different materials. Sustainability and recycling was the highest ranked item in the focus group. A key need is materials for multi-purpose pipelines that can support natural gas, H_2, and CO_2. There is a specific need to develop improved steel composition and processing methods for H_2 and CO_2 service. An open-source, but reliable property database with properties relevant to the design of large-scale structures was the second highest ranked item.

From the roadmap reviews, EPRI has the most comprehensive plan that defines specific material needs for a range of advanced non-light water reactor designs or simply advanced reactors (ARs) (Figure 9). AR materials must endure higher temperatures for long periods of time, resist corrosion and temperature transients that may induce thermal fatigue and have resistance to the irradiation-induced swelling. EPRI's advanced material roadmap divides material development needs by AR type and material categories that include austenitic stainless steel, ferritic-martensitic steels, nickel-based alloys, and graphite and ceramics and then by service needs such as corrosion, cladding, and dissimilar metal welding. A key outcome on any material development program is American Society of Mechanical Engineer (ASME) code cases for the Boiler and Pressure Vessel Code (BVPC). This code and many more set the construction and operation rules as required by law to build and operate nuclear energy facilities. New material code cases are very expensive. ICME tools and advanced testing techniques are needed to get new materials approved in a reasonable time frame of years versus decades.

5.3.5 Supply Chain

Two types of supply chain items received the most comments. One was the need for capability for the largest items: forgings, castings, and structural shapes (I and T beams), for example. For steels, this limitation has been the result of turning toward production of more steel and other alloy products from scrap rather than ore.

The other was that equipment for factories for large structural item production was more likely to be imported. Supply chain readiness is a cross-cutting item through many industry verticals. A particular and growing difficulty with the American supply chain is the expectation of general availability of items that may actually have quite limited sourcing. The United States needs to account for international connections of the supply chain, since many supply chain companies reduce their risk by becoming international.

5.3.6 Workforce Development

EWI's previous roadmap on joining and forming followed the lead of industry representatives, who described a culture and mindset gap that was making it difficult to hire for technical and trades jobs.

The responses this time indicated an even more drastic need to get people to the entry level job, given the need to train-up those inside industry to greater skills. The highest ranked item was for technical and trades education to provide effective capability transformation that the large structural and systems creating industries can use. Workforce readiness is a cross-cutting item through many industry verticals.

A particular and growing difficulty with the American labor market is the availability of staff who can be at remote locations and not available to family for emergencies or care. As the United States population has aged and more people need part-time care, this prevents workers from taking otherwise attractive jobs that involve remote locations.

5.3.7 CAPEX Costs

Both large systems and large machines to build their parts are expensive capital items that will need the right kind of financial environment to show a positive return on investment. Most corporate decisions will have a "will it be susceptible to supply chain disruption?" component.

Singular capabilities need special kinds of customers to maintain their interest.

5.3.8 Standards and Codes

Standards for fabrication technology for new methodologies were listed as a critical need by Focus Group 2. One area of standards difficulties is new technologies, where the effort to include new materials is slowed by a combination of incomplete testing and questions about final application needs. Another area of standards difficulties is the inability to change outdated standards, where technical requirements can now more easily and cheaply be achieved by other means.

5.4 Industry Vertical High Priorities

The industries contacted had different priories. This section describes priorities for the industry groups.

5.4.1 Offshore Wind and Maritime

Everyone surveyed from the maritime industry indicated workforce readiness as a critical item holding back the industry's production capability.

A close second critical item was supply chain readiness. Supply chain readiness can be several layers deep, with needs for offshore support vessels that themselves need shipyard capacity which also need shipyard inputs, such as plate, welding systems and hardware.

One specific item mentioned is heavy steel plate for wind turbine structures offshore.

5.4.2 Hydrogen/CCUS/Petrochemical/Refining

Interviews with this sector indicated that many capabilities for building large systems are in place, but that large systems are limited by permitting that allows many respondents to object to routing or locating infrastructure.

In some areas of new service (hydrogen, CCUS), new standards are needed to determine what to build, since the most similar current systems do not operate under the same constraints of pressure, impurity content, and capacity.

There are new connections that will be needed for such systems where piping systems are connected to new pieces of physical plant such as electrolyzers, pyrolysis units, and CCUS units at concrete manufacturers.

5.4.3 Energy (Nuclear/Wind/Solar)

Survey respondents were nearly unanimous on the need for advanced materials as being a capacity limitation in energy systems.

There is a tendency to look at optimizing individual modules for size, given the expense of site work. This has been particularly notable for nuclear power with the rise of interest in small modular reactors and the segmentation of towers for wind turbines.

Regulatory approval is needed to convert to in-process and in-situ monitoring from NDE after production.

5.4.4 Mining and Primary Metals

The mining and primary metals industries are limited by large CAPEX costs. They also affect a wider region around their production sites, so they need a lot of lead time to begin.

One area of difficulty for casting suppliers is the use of outdated standards. Government purchasers, particularly, are still using requirements for film radiography. Commercial pressures have allowed digital radiography to catch up to and now outstrip film radiography, but the rigidity in the government contract system prevents these gains from being incorporated.

5.4.5 Mega Buildings and Bridges

As in nuclear, there is a strong tendency to use modular approaches, providing pieces that can be shipped to the job site.

Like rail and mass transportation, limitations of the site often dominate planning, and planning software that accommodates site limits is needed.

5.4.6 Rail and Mass Transportation

As stated above, limitations of the site often dominate planning, and planning software that accommodates site limits is needed.

Modularity has been built into these systems from the beginning.

Large-scale construction with lengths of many miles requires personnel to be at many locations for limited time periods, which is difficult when the workforce is limited.

5.4.7 General Supply Industries

Two areas lead the responses from general supply industries: supply chain readiness and workforce readiness. These two items indicate the general operating difficulties for businesses crucial to the large structure and systems ecosystem but without their own large size to insulate their environment.

6.0 Discussion

6.1 Combining Roadmaps from Other Organizations and Project Data

The summary begins with topics common across all industry sectors and then continues with sections summarizing the seven chapters in this report.

Large structures and systems mean that the annual output involves dozens of units or, at best, hundreds of units. The annual output may be just a few units if structures/systems are very large. Examples include reactors for the nuclear industry, ships of all kinds, offshore O&G structures, and vessels for the chemical industry. LSS production rates indicate the types of technology needed.

6.1.1 Technical Area

6.1.1.1 Design Methodologies and Models/Digital Thread and Twins

Many industries are developing models and digital applications so they can take the most difficult welding challenges in module building and leave the more standard welding to field erection. This is similar to the role that the use of interchangeable parts in the nineteenth century played in increasing and simplifying industrial production of complicated devices.

The growth of models and digital applications is further advanced in some areas than in others. RAPLSS-aligned companies will have less need for the internet of things and edge computing and a greater need for smart machines, sensors, digital twins, simulation modeling including 3D visualization tools, and cybersecurity than that of manufacturing companies in other industries.

Computation for production will include tools and processes for facility design, automation of manufacturing processes, inspection and quality control, and digital platforms and architecture.

Challenges in field erection for repeated parts can have Industry 4.0 technological improvements in the areas of fit-up and inspection. These would provide additional value in both new energy industries and existing pipe and pipeline industries.

6.1.1.2 Fabrication Technologies

Fabrication technologies scored very high among those who thought that increased value could be provided to new large structures and systems.

Many large structures and systems are not limited by the material properties available alone but rather by those that can be obtained and reliably joined into the entire structural system.

Additive manufacturing adds prototyping and limited number production capability.

Cybersecurity in industrial operations will directly affect Industry 4.0 opportunities for fabrication technologies.

6.1.1.3 Integrity: Condition Monitoring/Service Life Extension and Optimization

Transferability of information is crucial to integrity assessment for such information as strength, crack resistance, and presence and sizing of imperfections. Demonstrations of integrity for further service, such as life extension assessments, need this information. This connects with a desire expressed in a focus group for a standard material database.

What people “think that they know” is crucial. This relates to the expectations built up by material test reports and existing qualification information.

One area in which gains in integrity information can be enabled more rapidly is through experience of prototyping – using differing processes that work better for one-off and small batch production.

6.1.1.4 Conventional and Advanced Materials

This area had the least consensus among the areas. The variety of material needs in different systems (perhaps symbolized by the different meaning of “high-strength steel” or “light-weight alloy”) in different industries is likely to play out here. Surveys also showed that many companies use multiple different materials.

Sustainability and recycling was the highest ranked item in the focus group. A big hurdle here connects with the standards and codes regarding the use of recycled material in products.

An open-source, but dependable, property database with properties relevant to the design of large-scale structures was the second highest ranked item.

The advanced reactors portion of the nuclear industry was the industry group pushing most strongly for the rapidly advanced use of new advanced materials among those contacted.

6.1.1.5 Supply Chains

Capability is needed for the largest items: forgings, castings, plates, and beams, for example. For steels, this limitation has been the result of turning toward production of more steel and other alloy products from scrap rather than from ore.

Equipment for factories for large structural item production was more likely to be imported. This has been based on export and tariff support in different countries. A particular and growing difficulty with the American supply chain is the expectation of general availability of items that may actually have quite limited sourcing. The United States needs to account for international connections of the supply chain, since many supply chain companies reduce their risk by becoming international.

Several documents touted collaboration (seen as important to Industry 4.0) as a way to improve industry efficiency and resilience. When this principle is applied to companies within a sector, however, there are nuances to consider. The upside of collaboration occurs when companies share data and information. This leads, for example, to the foresight of problems like lack of supply and enables the supply chain to adjust. However, when competitors share information about their operations, even the best efforts to sanitize will not prevent a savvy competitor from gleaning useful intelligence. Many senior-level managers, for example, see this risk as a reason not to collaborate. Most LSS-related companies will regard their data, information, and intellectual property as needing protection, not dissemination. The intel leak risk must be low and the payoff high.

Cybersecurity comes under this topic because of the use of computers in industrial cooperation. As an example, information is transferred between suppliers both for technical data and finance relationships. Supply chain companies may be limited in their ability to serve clients within the limits of cybersecurity protections.

6.1.1.6 Workforce Development

EWI’s previous roadmap on joining and forming followed the lead of industry representatives, who described a culture and mindset gap that was making it difficult to hire for technical and trades jobs. The responses this time indicated an even more drastic need to even get people to the entry level jobs at all, given the need to train up those inside industry to greater skills.

The highest ranked item was for technical and trades education to provide effective capability transformation that the large structural and systems creating industries can use.

A particular and growing difficulty with the American labor market is the availability of staff who can be at remote locations and not available to family for emergencies or care. As the United States population has aged and more people need part-time care, this prevents workers from taking otherwise attractive jobs that involve remote locations.

Several reviewed documents indicate that work-based learning models yield the best results. A program called *Registered Apprenticeship* is mentioned specifically, and attributes include work experience, mentorship, classroom instruction, progressive wage increases, and a portable, nationally recognized credential on completion.[17]

No documents mentioned mobile training centers, but these might be a valuable approach when prospective workers may not be able to travel to a training facility. A mobile facility concept would involve tractor-trailers equipped with the necessary welding machines, CNC machines, NDE instruments, etc. A local manufacturing company could cosponsor the training, offer classroom space, and collaborate with a government entity. The sponsor would benefit because it would obtain a firsthand look at potential employees.

6.1.1.7 CAPEX Costs

Both large systems and large machines to build their parts are expensive capital items that will need the right kind of financial environment to show a positive return on investment. Most corporate decisions will have a “will it be susceptible to supply chain disruption?” component. Singular capabilities need special kinds of customers to maintain their interest.

6.1.1.8 Standards and Codes

Standards for fabrication technology for new methodologies were listed as a critical need by a focus group. One area of standards difficulties is new technologies, where the effort to include new materials is slowed by a combination of incomplete testing and questions about final application needs. Another area of standards difficulties is the inability to change outdated standards, where technical requirements can now more easily and cheaply be achieved by other means.

6.1.2 Industry Verticals

6.1.2.1 Offshore Wind and Maritime

Everyone surveyed from the maritime industry indicated workforce readiness as a critical item holding back the industry's production capability. A close second critical item was supply chain readiness. Supply chain readiness can be several layers deep, with needs for offshore support vessels that themselves need shipyard capacity that need shipyard inputs, such as plate, welding systems and hardware. One specific item mentioned is heavy steel plate for wind turbine structures offshore.

The U.S. OW industry has just emerged in the 2020s. Reference 24 explains that a tipping was reached in 2021 as influenced by the Biden Administration's policies. OW is a $100+ billion industry that has large structures at its core: monopiles, jackets, and towers. Hundreds of these structures are needed within years and thousands within a decade. Not only does OW require the largest structures of all industries considered in this review, but it requires the largest number of structures as well. It is the best example of an industry aligned with the large structure focus.

Reference 24 explains that the majority of OW farm costs are CAPEX and that heavy fabrication of large structures accounts for ~35% of CAPEX. During 2023, U.S. OW experienced challenges caused by supply chain disruptions (Covid, Ukraine), inflation, and interest rates. A number of OW projects were canceled. This industry needs cost reductions. Any topics that further the advancement of welding and inspection technologies are paramount.

U.S. OW needs an unprecedented number of ships. A U.S. law called the Jones Act requires that these ships be U.S.-made and crewed. This has motivated a resurgence in U.S. shipbuilding, an industry aligned with RAPLSS, and that uses all the basic metal fabricating technologies: cutting, forming, welding, and NDE. Topics aligned with RAPLSS include automation, sensors, high-rate welding, and fast and accurate NDE.

Currently, the need for heavy fabrication of large structures in the U.S. OW industry exceeds the capacity. U.S. projects are sourcing millions of tonnes of steel structures from Europe. The U.S. industry is failing to capture opportunities regarding large structures for OW applications. Increased funding and facilitation are necessary to reverse this trend.

Cost reductions in OW are needed, but fabricators and developers are not likely to fund R&D work due to the current OW industry turmoil. One option is for a government entity to fund/facilitate development work. On this subject, the government has some efforts underway (the IRA, FLOWIN, Floating OW Shot),[31] but a counterpoint is that none of these projects involve the RAPLSS-aligned technologies presented in Reference 24.

6.1.2.2 Hydrogen/CCUS/Petrochemical/ Refining

Interviews with this sector indicated that many capabilities for building large systems are in place, but that large systems are limited by permitting that allows many respondents to object to routing or locating infrastructure.

In some areas of new service (hydrogen, CCUS), new standards are needed to determine what to build, since the most similar current systems do not operate under the same constraints of pressure, impurity content, and capacity.

There are new connections for hydrogen and CCUS systems that will be needed for systems where piping systems are connected to new pieces of physical plant, such as in electrolyzers, pyrolysis units, and CCUS units at concrete manufacturers.

While much of pipeline fabrication does not lend itself to Industry 4.0 concepts (explained in the section on O&G), there is opportunity with welding NDE. The concept is to analyze digitized NDE data with AI algorithms that identify welding problems and whether they are caused by the welder, the fit-up, the pipe geometry (out-of-round or peaking), or something else. The analysis would be in-situ with pipeline fabrication so that feedback can be immediately given to front line welding crews.

Another idea involves the dimensioning of pipes, pipe fittings, vessel connection flanges, etc. to improve efficiency and prevent welding defects. A primary cause of pipe welding defects is poor fit-up caused by variations in pipe geometry. An improvement is to use a 3D laser scanning device to dimension the round orifices to be welded and to create a database of these openings. This data would be analyzed by a smart device that would provide the welding crew with fit-up instructions for each joint including which specific pipes, fittings, flanges to connect along with the relative orbital rotation to use.

Gaseous leaks from pressurized components (e.g., piping systems, vessels, etc.) are a significant risk for this sector. Leak control requires leak detection which requires sensors. Sensors, smart technologies, and AI can be used to alert operators and/or perform automated shut down. The vision is to blanket the world of natural gas production and usage with sensors and to mandate a zero-tolerance level of control. This likely means financial repercussions (fines) for leaks and that the leak data is transparent to the regulators. Policies can extend to residential use requiring that all gas operating appliances be outfitted with sensors and alarms. The approach of promoting natural gas as an energy source with emissions reducing potential compared to other fossil products might garner more appeal if strict leak control was a requirement. The tradeoff of “no leaks” offers something for both sides. Emission reductions will be substantial, leaks will be given ample attention, and the United States will use a natural resource that outcompetes other options to support the economy.

6.1.2.3 Energy (Nuclear/ Wind/Solar)

Survey respondents were nearly unanimous on the need for advanced materials being a capacity limitation in energy systems.

There is a tendency to look at optimizing individual modules for size, given the expense of site work. This has been particularly notable for nuclear power with the rise of interest in small modular reactors (SMR) and the segmentation of towers for wind turbines.

Regulatory approval is needed to convert to in-process and in-situ monitoring from NDE after production.

Once in service, ARs will experience decades of radiation exposure under severe conditions. Before AR technology is commercialized, the equipment must be vetted. It is unrealistic to test for decades, but if time dependent, material performance models can be developed, then virtual acceleration can take place (time-dependent digital twins). Another approach is to develop in-situ monitoring technologies (sensors) that provide feedback on material health. Problems can be identified in time for remediation. These elements of Industry 4.0 would assist the nuclear industry.

Because ARs involve public safety risks, some documents discuss that vetting should include full-scale or, at least, large-scale demonstrations. Demos will be costly and time-consuming. Challenges include (1) how to do it, and (2) stakeholder alignment. It might be suggested that AR demos are not worth the effort. Demos may be either cost prohibitive or so time-consuming that on completion, the technology is too late. On the other hand, ***not*** conducting the demo may preclude stakeholder support (regulators, codes, the public), and this could prevent commercial success. A compromise is for the parties to agree on the scope of the demo – not too big or too small.

6.1.2.4 Mining and Primary Metals

These industries are limited by large CAPEX costs. They also affect a wider region around their production site, so they tend to need a lot of lead time to begin.

Large structures are dependent upon castings. All steel components start by castings derived from liquid steel heats. The steel heats are used to produce cast parts or to provide ingots to enable production of forgings, plate, and wire stock. Castings are an information technology, providing the complex geometry needed for performance. It is not always an option to consider alternative methods of processing to produce huge components. When a large steel structure (10 tons) has shape, casting quickly becomes the only economic and structurally capable method of production. In contrast, additive manufacturing would require melting more than 10 tons of steel, forming wire, and then re-melting to produce the part by DED. Currently, it is not feasible to produce that much wire, remelt/process by DED, make and inspect the part, and resolve schedule, cost, and performance challenges. Castings are essential for nuclear power plants, offshore platforms, and naval vessels. It is not clear how a DED-produced additive component could be a rational alternative.

One area of difficulty for casting suppliers is the use of outdated standards. Government purchasers, particularly, are still using requirements for film radiography. Commercial pressures have allowed digital radiography to catch up to and now outstrip film radiography, but the rigidity in the government contract system prevents these gains from being incorporated.

Regarding large structures, C&Fs are ubiquitous across all industries. The top challenges for C&Fs were identified as adequate workforce and capital investment in technology, equipment, and automation. Workforce challenges are consistent with those described above. The capital investment scenarios are essentially chicken-and-egg problems.

6.1.2.5 Mega Buildings and Bridges

As in the nuclear industry, there is a strong tendency in the building and bridges sector to go to modular approaches, providing pieces that can be shipped to the job site.

Like rail and mass transportation, limitations of the site often dominate planning, and planning software that accommodates site limits is needed.

6.1.2.6 Rail and Mass Transportation

As mentioned above, limitations of the site often dominate planning, and planning software that accommodates site limits is needed.

Modularity has been built into the rail and mass transportation systems from the beginning.

Large-scale construction with lengths of many miles requires personnel to be at many locations for limited time periods, which is difficult when the workforce is limited. This is similar to issues already encountered in rail for hiring of personnel on the trains.

The documents reviewed for the U.S. rail industry were created by the Federal Rail Administration. One document compiled descriptions of ~150 R&D projects. The primary motivation for Rail R&D is safety (not economics). The main topics of interest that are aligned with Industry 4.0/RAPLSS are inspection technologies, digital simulation, management of big data, and cybersecurity. One document reported the results of a workshop on alternative fuels and propulsion technologies.[7] This study identified diesel-battery hybrid technology as promising in the near term and hydrogen as the priority for the long term.

Inspection technologies are important to the rail industry to identify defects in the infrastructure because these can lead to failure and derailment. Technologies like ultrasonics, eddy current, non-contact vibration analysis, rail surface imaging, and flaw characterization were mentioned. Additionally, when in-situ sensors are used on moving railcars, the data collection is substantial. This explains part of the interest in big data.

Hydrogen was selected as the most promising future fuel technology due to the scale of the U.S. rail network. North America has the largest single integrated rail system in the world. It took 25 years to convert from steam to diesel when the network was much smaller. A fuel changeout in the future will require a large investment in infrastructure. Although fuels like LNG have been studied, two extensive changeouts (first to LNG, then some years later to a clean fuel) were not deemed prudent. It is believed that any changeout must be to 100% emission-free technology.

6.1.2.7 General Supply Industries

Two areas lead the responses from general supply industries: supply chain readiness and workforce readiness. These two items indicate the general operating difficulties for businesses crucial to the large structure and systems ecosystem, but without their own large size to insulate their environment.

Reference 15 was a previous road mapping exercise for joining and forming technologies. It was an exhaustive study with many parallels to RAPLSS. Several focus areas for future effort included distortion control, next-generation prediction tools, materials modeling, high-productivity fusion processes, and integrating NDE sensors with welding processes.

Two documents, References 16 and 17, are an accounting of government policy on advanced manufacturing from the office of the President (Trump, Biden). Workforce challenges were the top priority. STEM education was deemed vital to the future of U.S. manufacturing. Support starting at the middle-school level as well as for two-year community colleges was recommended. The documents discussed specific programs and their attributes and recommended hands-on learning.

With regards to advanced manufacturing technologies, many Industry 4.0 topics are mentioned in References 16 and 17 including digital/smart manufacturing, internet of things, machine learning, artificial intelligence, cybersecurity, and real-time (in-situ) modeling. Both documents, and other government-based reports, speak highly of AM. Building large structures by AM presumably means AM-DED. Whereas some documents (Reference 25) indicate that AM-DED has more advantages than disadvantages, this may not be the case for large structures. Large structure AM-DED will be difficult due to the probability of defects and problematic qualifications due to heterogeneity (how to verify consistency).

6.2 Comparison to the Defense Industry

The defense industry has a culture that includes roadmap development. The DOD published the National Defense Industrial Strategy 2023, which applies to a much wider range of industries than large structures and systems, but large structures and systems are inherently part of the consideration.

The cover art for the report shows a welder. There is also explicit discussion of the castings and forgings industry. In 2023 a presidential waiver changed the requirements of the Defense Production Act to allow additional government support for the government operation of manufacturing locations and for five industries of which one was castings and forgings.

The four main areas discussed in the document are resilient supply chains, workforce readiness, flexible acquisition, and economic deterrence. The first two of these are also a large part of the considerations in this report.

7.0 Description of Roadmap Priorities

The general challenges for large structure and system production that are described in the first section and the specific items noted by industry are described in the following section.

7.1 General Challenges for LSS Industries

The most common topic across all industry sectors was workforce challenges. There is a shortage of workers for technical positions and in the skilled trades. The biggest need is for workers in industrial settings and for the training of these workers. Skilled construction workers can quickly find good employment and may not be attracted to LSS industries positions. Many entry-level workers do not understand there are major opportunities for those who enter the LLS industries. Capable entry-level workers and professionals will find near-term advancement opportunities to replace a range of manager and senior-level workers who are retiring. Compared to other industries such as automotive and information technology that no longer show rapid promotion and employment growth and are more cyclic, large structure industries offer a range of work-based learning models and apprenticeships (iron workers, boilermakers, pipefitters, etc.) that build skills quickly. In conjunction with retirement, employers also complained about “brain-drain” as senior-level employees are retiring too fast without time for succession planning and replacement training.

Public perception is that manufacturing jobs are dark, dirty, dangerous, and dying (the 4Ds). The first three of these Ds are true for many facilities that build large structures or their components. This is especially true for advanced material mills and foundries that need cutters and grinders to post-process raw materials and castings. One approach for recruiting is to find communities that are less likely to recoil from the 3Ds and to determine how to recruit/train from any specific community. One tactic to improve recruiting is embrace automation, which changes the skilled workers' conditions to clean, cool, and high-tech. Work-based learning models yield the best results, and a program called *Registered Apprenticeship* is mentioned specifically.

Understanding technologies useful for LSS means noting the size/scale of large structure operations where annual production can range from a few units to a few hundred units. RAPLSS-aligned companies will have less need for the internet of things and edge computing, and a greater need for smart machines, sensors, digital twins, simulation modeling including 3D visualization tools, and cybersecurity than manufacturing companies in other industries.

Many industries with high-volume products develop specific quality standards through statistical process control. Industries for large structures and systems may achieve less benefit from statistical process control because of the need for a smaller number of units. This tends to make requirements for quality depend on standards and specifications. Large structures are critically dependent on quality because failure could mean loss of life, environmental disaster, and/or severe economic consequences. LSS technology needs should consider whether the primary goal is production rate or quality as this may help in evaluating technologies.

Smart sensors that improve the dimensional accuracy of sub-components in fabrication are important Industry 4.0 technologies for large structures. They can improve welding fit-up, identify sub-components needing rework or rejection, provide warnings to the operator, and notify upstream processes (cutting, machining) that are causing the problem. While sensors were mentioned in the documents reviewed, this application for large structures was not mentioned in roadmaps reviewed. The improvements from smart sensors were noted from the survey and interviews, particularly for industries, like maritime, that have many sub-system manufacturing steps.

Cybersecurity is vital for industrial operations because of the ubiquitous use of computerized control and data/information storage. Many manufacturing companies are small and medium-sized (SMMs) businesses that may not have the resources to maintain the latest in cybersecurity technology. The Presidential Executive Order 14028 [(1)] and activity at NIST pertain to cybersecurity.[(2), (3)] Both the roadmaps reviewed and interviews conducted brought up the need for government help in cybersecurity.

It will be important for the RAPLSS community to provide support to SMMs in the supply chain and facilitate their involvement with universities, federal laboratories, Manufacturing USA institutes, industry consortia, and joint industry projects. Advanced technology providers can use

SMM guidance to ensure that the technology delivered is in a format that can be implemented efficiently.

Collaboration is an Industry 4.0 principle that can improve industry resilience, but the RAPLSS community must address the challenge of competitors that are reluctant to interact for fears of exposing proprietary data, information, and intellectual property. Those who are reluctant are right, but standards and specifications for communications can use the example of standards and specifications where the methods and deeper specifics are not specified.

The chicken-and-egg problem is a common scenario. It happens when a business might attract orders by investing in new technology, but the cost is too high without the orders being placed first. Customers are interested in placing orders, but only if the new technology is in place. When large structures are involved, the cost can be tens, if not hundreds, of millions of dollars. A useful role for the RAPLSS effort is to identify improvements or solutions to these challenges that can be implemented for the most important cases.

Two public policy documents were reviewed that outlined the Trump and Biden Administration's approaches to supporting advanced manufacturing in the United States.[(16), (17)] Workforce challenges are the top priority. A number of Industry 4.0-type technologies were highlighted including smart manufacturing, internet of things, machine learning, artificial intelligence, cybersecurity, and real-time modeling. The public policy documents References 16 and 17 and documents from the nuclear industry tout additive manufacturing (AM) as promising for large structures. Among the perceived difficulties are the probability of defects and problematic qualifications due to inherent heterogeneity (how to verify consistency and quality).

7.2 LSS Challenges by Industry

The U.S. OW industry is the best example of an industry aligned with the large structure focus of RAPLSS. U.S. OW depends on the fabrication of monopiles, jackets, towers, and floating platforms. Hundreds are needed within years and thousands within a decade. There are many opportunities in the areas of automation, sensors, high-rate welding, and fast and accurate NDE. Due to a U.S. law, the Jones Act, the OW industry will need dozens, if not hundreds, of new ships, and this is causing a resurgence in the U.S. shipbuilding industry. Shipbuilding can use many Industry 4.0 technologies including simulation and modeling, sensors, smart machines, and automation. In 2023, the OW industry experienced economic problems. Projects were canceled, but new leases have been announced. OW needs cost reductions, and heavy fabrication is an opportunity for RAPLSS because it accounts for ~35% of wind farm capital costs. Currently, the need for large structures in U.S. OW exceeds the capacity. U.S. projects are sourcing millions of tonnes of structures from Europe. U.S. industry is failing to capture the available large structure opportunities, and increased funding/facilitation is needed to reverse this trend. As noted above related to OW, the growth of staff and capabilities for the shipbuilding and ship operating industries in the United States is needed.

The hydrogen industry for energy is still developing, but like the oil and gas energy industry it needs long-distance networks and many individual pressure containers that are built to standards and specifications. Many of the large systems and structures approaches from the oil and gas industry transfer along with contracting approaches and multiple stakeholders. CCUS will also need a piping network. Both hydrogen and CCUS will need connection standards to the affected equipment whether upstream (an electrolyzer or a cement factory) or downstream (an industrial hydrogen fuel user or a storage well). Two specific ideas for improving fluid energy system construction pertain to using sensors and AI to improve efficiency when welding pipelines, pipes, pipe fittings, and vessel connection flanges.

Of the nuclear industry documents reviewed, most are focused on advanced reactors, (ARs) which operate at high temperatures and involve unique corrosive fluids. These severe conditions motivate the need for new reactor materials and joining methods. Due to the time-dependent degradation mechanisms within reactors, AR developments can use material performance models capable of virtual test acceleration (time-dependent digital twins). Another need is to develop in-situ monitoring technologies (sensors) that provide feedback on material health. Problems can be identified in time for remediation. The nuclear industry will consider large-scale demonstrations to vet new technology and to align stakeholders. However, these demos can be prohibitive from the standpoint of time and cost. A potential compromise is to scale down the demo scope or to rely on simulative technologies, but some stakeholders may balk at these approaches. Demos are a primary challenge for AR developments. Several nuclear-related documents and the C&F industry have identified hot isostatic pressing (HIP) and particularly the powder metallurgy option (PM-HIP) as extremely useful for advanced manufacturing.

Castings and forgings (C&F) are used by all RAPLSS-type industries that fabricate large structures and systems. In recent decades, the C&Fs industry has experienced many plant closures. The top challenges for the C&Fs industry were identified as adequate workforce and capital investment in technology, equipment, and automation. The main focus of the C&F documents reviewed was this industry’s interaction with the DOD. Detailed examples were given with the conclusion that the “DOD is a difficult customer to serve.”

The more general primary metals industry is less dependent upon one source of revenue than just indicated for C&F, but it is quite dependent upon enormous amounts of capital with long time horizons to payback.

Mega building and bridges have moved down a path similar to the rail industry toward modular segmented pieces that can be reliably put together to make the structures and systems. From an Industry 4.0 perspective, the industry can use both situational awareness for the jobsite and improved local automation to allow specialized segments to be made with automation in a remote factor.

The main rail and mass transportation industry topics of interest aligned to RAPLSS are location situation awareness, inspection technologies, digital simulation, management of big data, and cybersecurity. Inspection technologies mentioned include ultrasonics, eddy current, non-contact vibration analysis, rail surface imaging and flaw characterization. A rail industry workshop on alternative fuels identified diesel-battery hybrid technology as promising in the near term and hydrogen as the priority for the long term. Although liquified natural gas has been studied and deemed successful as a rail fuel, hydrogen is believed to be a better choice.

General supply industries were numerically the most numerous among survey participants. This shows the large number of interested parties related to large structure and system production.

For large projects, O&G companies hire engineering, procurement, and construction companies. They hire specialized construction companies and may also hire independent inspection companies. Imitating this in other industries may be both desirable and difficult since the immediate profit potential and payback through the project life are less assured in other LSS industries.

There are shortages of welders, machinists and inspectors in the United States. These skilled positions are a significant need to prepare metal components, join them together, and then ensure their quality. Virtual and augmented reality offer potential to attract and train these types of positions faster. As an example, virtual welder training is now widely used at technical schools to prepare and recruit individuals into welding and helps develop motor skills for process control. Another high potential technology is tele-manufacturing. Here, vision sensors are combined with process monitoring and haptic controls to enable operator-supervised controlled welding, cutting, and inspection using portable robotics. Tele-manufacturing will be combined with augmented reality in the future to support in-situ precision fabrication remotely using portable robotics. These technologies help fill critical needs and require ongoing investments to change the image of and technology for production to large structure and systems.

7.3 Roadmap Priorities by Industry Segments

<u>Offshore Wind / Maritime (port facilities, transportation and erection vessels) / Shipbuilding</u>

- Workforce readiness is a critical item holding back the industry's production capability.
- Supply chain readiness is also critical in the following:
  - Heavy fabrication capacity/facilities

    - Offshore installation and support vessels
    - Domestic shipyard capacity
    - Shipyard supply chain inputs – plate, welding systems, hardware.
- Heavy steel plate industrial base

Hydrogen / Carbon Capture and Utilization and Storage (CCUS) / Petro-chemical / Refining

- Many of the capabilities for building large systems are in place
- Incentives for permits to counter localities object to routing or locating infrastructure
- New standards are needed to determine what to build for hydrogen production and CCUS
- Connections to new pieces of physical plant
    - Electrolyzers
    - Pyrolysis
    - CCUS units at concrete manufacturers
- Automation of NDE and fit-up for pipe girth welds are opportunities.
- Prediction tools for life assessment

Nuclear energy

- Advanced materials as a capability limitation in energy systems
    - Integrated materials computational engineering ecosystem to accelerate new material design, qualification, and implementation
- Optimization for module fabrication versus expense of site work
- Incentives for SMR (small modular reactors) demand to drive affordability
    - Provide clean base load versus other green alternatives
- Mega hot isostatic pressing (Mega-HIP) for complex reactor head production in lieu of forgings and welding complex assemblies
- High productivity electron beam narrow groove vessel joining capabilities
- Regulatory approval for in-process and in-situ monitoring from NDE after production

Primary Metals (i.e., large plate, beams, pipe, castings, forgings)

- New standards as casting suppliers are using outdated standards
    - Example: Government purchasers are still using requirements for film radiography.
- Incentives to invest in large CAPEX capabilities
    - Large forging and casting facilities near point of need
- What is “large” in tonnage?

- Nuclear: tens of tons (high-ton plate and forgings sections, low volume)
- Wind structures: (high volume, thick, wide, and long plate sections. Also, Thick forged rings and high volume plate welding assembly)
- Shipbuilding: (marine grade aluminum alloys, high volume high strength steel plate and beams, and nonferrous castings for ship systems)

Mega Building / Bridges

- Modular approaches, providing pieces that can be shipped to the job site
- Planning software that accommodates site limits

Rail and Mass Transportation

- Flexible personnel – need to be at many locations for limited time-periods, which is difficult when this workforce is limited
- Automated inspection is an opportunity area.
- Hydrogen is a future fuel opportunity for rail.

8.0 Summary – Technology Solutions

The most common topic across all industry sectors was workforce challenges. There is a shortage of workers for technical positions and in the skilled trades. The biggest need is for workers in industrial settings and for the training of these workers. Some industries like maritime and castings and forgings also noted limited capability to hire even for non-skilled positions. Work-based learning models yield the best results, and a program called *Registered Apprenticeship* is mentioned specifically.

Public perception is that manufacturing jobs are dark, dirty, dangerous, and dying (called the 4Ds). The first three of these Ds are true for many facilities that build large structures or their components. One approach for recruiting is to find communities that are less likely to recoil from the 3Ds and to determine how to recruit/train from any specific community. Another tactic to improve recruiting is to embrace automation which changes the skilled workers' conditions to clean, cool and high-tech. Virtual and augmented reality offer the potential to attract and train these types of positions more quickly. Tele-manufacturing is another high potential technology that will be combined with augmented reality in the future to support in-situ precision fabrication remotely using portable robotics. These technologies help fill critical needs and require ongoing investments to change the image of and technology for production to large structure and systems.

Understanding technologies useful for LSS means noting the size/scale of large structure operations where annual production can range from a few units to a few hundred units.

RAPLSS-aligned companies will have less need for the internet of things and edge computing and will have a greater need for smart machines, sensors, digital twins, simulation modeling including 3D visualization tools, and cybersecurity than manufacturing companies in other industries. Smart sensors that improve the dimensional accuracy of sub-components in fabrication are important Industry 4.0 technologies for large structures. They can improve welding fit-up, identify sub-components needing rework or rejection, provide warnings to the operator, and notify upstream processes (cutting, machining) that are causing the problem.

For fabrication of LSS, multi-process digital manufacturing systems are needed that maximize the use of automation while minimize programming costs for a wide range of metalworking processes including machining, forming, welding, thermal spray coatings, and NDE. Robotic CAM tools allow rapid CAD to path programming for high-mix, low-volume production of large structures and systems. An emerging need is informatics that can drive digital manufacturing workflows between digital manufacturing processes.

Convergent manufacturing is a new digital manufacturing term that is synonymous with intelligent multi-process digital manufacturing systems. It creates a platform for extending the digital thread, minimize programming costs, and ensuring first-time quality for high-mix LSS fabrications. For example, a convergent manufacturing technology could be used for automated inspection and repair of in-service LSS components. A multi-process robotic system could be used to inspect, identify unacceptable flaws, remove flaws for repair welding, repair component, finish grind weld repair area, and then to perform final NDE to certify integrity for service. To perform convergent manufacturing workflows, digital twins are needed for each machine and process, and informatics are needed to drive the multi-process data workflow.

DED processes can be used for welding, cladding, additive manufacturing, and repairing LLS components. Here, commercial automated or robotic systems are converted into DED by developing a digital twin of the machine and a material deposition model for fusion welding (arc, laser or electron beam) deposit processes using CAM software tools. DED technology is being extended to thermal spray and cold spray processes since models can be used to describe the coating deposition spot behavior and automate conformal coatings of corrosion or wear-resistant surfaces.

Many industries are pursuing models and digital applications so they can automate the most difficult welding challenges in module building and leave the more standard welding to field erection. This is similar to the role that the use of interchangeable parts in the nineteenth century played in increasing and simplifying industrial production of complicated devices. Depending on the LSS segment, use of digital manufacturing models and CAM tools are further advanced in some areas than in others.

Cybersecurity is vital for industrial operations because of the ubiquitous use of computerized control and data/information storage. Many manufacturing companies are small and medium-sized (SMMs) businesses that may not have the resources to maintain the latest in cybersecurity technology. The Presidential Executive Order 14028[1] and activity at NIST pertain to cybersecurity.[2], [3] Both the roadmaps reviewed and interviews conducted brought up the need for government help in cybersecurity.

Collaboration is an Industry 4.0 principle that can improve industry resilience, but the large structure and systems community must address the challenge of competitors that are reluctant to interact for fears of exposing proprietary data, information, and intellectual property. Those who are reluctant are right, but standards and specifications for communications can use the example of standards and specifications where the methods and deeper specifics are not specified.

The chicken-and-egg problem is a common scenario. It happens when a business might attract orders by investing in new technology, but the cost is too high without the orders being placed first. Customers are interested in placing orders, but only if the new technology is in place. When large structures are involved, the cost can be tens, if not hundreds, of millions of dollars. A useful role for the RAPLSS effort is to identify improvements or solutions to these challenges that can be implemented for the most important cases.

Some industries like buildings, bridges, and transportation are well down the road of standardizing pieces and individual on-location fabrication activities. U.S. offshore wind, hydrogen, and advanced nuclear reactors need to move in this direction. This leaves opportunities for fabrication of more complicated configurations to be standardized in factory settings and for on-site fabrication to use more standardized support services, such as for fit-up and NDE. There are many opportunities in the areas of automation, sensors, high-rate welding, and fast and accurate NDE.

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Appendix A

FRA Research Topics – A Selection with Comments

FRA Research Topics – A Selection with Comments

The following (non-exhaustive) list provides a quick glimpse of the project names/subjects, and, in some cases, a few additional details are included.

Track

1. Bridge Condition Assessment Using Smart Sensors. $650,000. Nine years. Univ. of Illinois.
2. Investigation of Timber Crosstie Spike Fastener Failures. $610,000. Three years. Univ. of Illinois. Volpe.
3. Automated Track Change Detection. $556,000. Univ. of Illinois.
4. Drone Inspection of Grade Crossings. $900,000. Michigan Tech.
5. Drone Inspection of Track Centerline. $163,000. VisioStack
6. Machine Vision Tech for QC of Pre-stressing Wires on Concrete Ties. Appears to be rebar and wire indentations are mentioned. $100,000. Kansas St.
7. Large Diameter Rebar Pre-stressing. Appears to be associated with the bumps on rebar and how it affects adherence to concrete.
8. Drones and Digital Image Correlation. Early detection of rail problems.
9. Satellite Radar
10. Concrete Crosstie Structural Performance. Compressive strength. Univ. of Illinois.
11. Autonomous Track Inspection
12. Heavy Axle Load Research. Designs and materials. How heavy loads deteriorate rails. $600,000.
13. Field Testing Support at FRAs Trans Tech Center (TTC). NDE probability of detection. Rail flaw detection. Includes sharing with tank car industry. $1 million. TTC.
14. Artificial Intelligence (AI) to Evaluate Crossing Safety. The AI system analyses videos of train crossings.
15. Evaluation Procedures for Track Inspection Technologies. ENSCO. $500,000.
16. High Speed Rail NDE Using Anomaly Detection. Univ. of Utah. $180,000.
17. Develop Predictive Analytics Using Autonomous Track Geometry Measurement Systems. Preventative maintenance. ENSCO. $688,000.
18. AI Aided Track Risk Analysis
19. Machine Learning Methods for Track Condition Assessment. Uses anomaly detectors. Goal is to reduce laborious manual data processing.
20. Intelligent Risk Assessment System. There appears to be a challenge with large volumes of track inspection data.
21. Deep Learning for Large Scale Rail Defect Inspection. Rail surface imagery. TTC.
22. Ground Truth Measurement of Track Geometry. Set up dummy track with known displacements that are evaluated with the track geometry measurement system (TGMS). This sets baseline of threshold data. ENSCO. $621,000.

23. Adjustable Precision Curved Track Anomaly Test Section. Construction of curved test track on high-speed rail at FRAs TTC facility (must be quite a full-scale facility). TTC. $5.7 million.
24. Vehicle-Track Interaction Testing, Modeling, and Analysis. ENSCO. $161,000.
25. Influence of Track Irregularities on Derailment Safety. Develop models for dynamics of speeds up to 220 mph. Identify safe speeds, maximum geometry deviations, etc. Volpe. $400,000.
26. Wear and Fatigue of Rails and Wheels. International Collaborative Research Network.
27. Rolling Contact Fatigue (RCF) Qualification. Metallography and eddy current.
28. Coil Spring Characterization and Modeling
29. Advancement of Rail Integrity Inspection. Make library of rail flaws. Collect samples.
30. Defect Growth Characterization in Modern Rail Steels. Includes 3D FEA. Lehigh Univ. $336,000.
31. Automated Railhead Flaw Characterization and Remaining Life Prediction
32. Rail Flaw Imaging Based on Ultrasonic Tomography
33. Fatigue Crack Growth Rate Material Characterization of Targeted Microstructures of Welded Rail. UC SanDiego.
34. High Speed Non-Contact Rail inspection. Ultrasonics. Probability of detection (POD). Joints, welds, internal flaws. UC San Diego.
35. Rail Defect Detection by Non-Contact Vibration Measurements. Laser Doppler Vibrometer. Univ. of TX at Austin.
36. Field Testing of Welding Repair of Railhead Defects. Metallurgy, NDE. Thermite welds. Tuskegee Inst. and EWI. $284,000.
37. Longitudinal Rail Stress Measurement Using UT
38. Image Processing and Machine Learning Algorithms to Measure Axial Rail Stress
39. Enhanced Acoustic Birefringence Method for Measuring Long Rail Stress
40. Innovative Track Inspection Technologies
41. Rail Bridge Strike Characterization Using Artificial Neural Networks
42. Several “Ballast” studies. Foundation under RR ties. Inspection, monitoring, characterizing.

Rolling Stock

1. Analysis of Diesel Fuel Tanks under Dynamic Loads. Impact loads.
2. Waste Heat Recovery Systems
3. Fire Safety Emergency Egress. Passenger Railcars.
4. Alternative Fuels – Hydrogen and Fuel Cells
5. Safety and Efficiency of Alternative Fuels. $1million. Volpe.
6. Fire Engineering Research

7. Alt Fuels Efficiency and Emissions
8. Alt Fuels Safety Analysis
9. Inclusive Accessibility for Next Gen Passengers
10. Next Gen Brake Technology
11. Technology and Network Operations
12. Improved Freight Car Truck Performance and Safety. TTC.
13. Prevent Water Ingress to Railroad Bearings
14. Diagnose Bearing Grease
15. Wheel Failure Research
16. LED Lights for Locomotives
17. Wheel Life Model
18. Emergency Notification Signs Information Video
19. Emergency Responders Extrication Video
20. Evaluation of Modern Locomotive Crashworthiness Performance. FEA Models for entire cars.
21. Wireless Digital Train Using 160MHz. Conventional frequencies in big cities are too busy.
22. NDE of Railroad Tank Cars. Disseminate POD data to tank car industry. Also, advanced NDE methods. $240,000. TTC.
23. Tank Car Impact Tests. $750,000. TTC, PHMSA, Volpe
24. Tank Car Impact FEA. Puncture resistance. Validate models.
25. Behavior of Tank Car Construction Materials. Matl testing. Fracture of tank car steels. Volpe. $175,000.
26. Grade Crossing Impact (truck) of LNG Tender (vessel). They want to use LNG as fuel. TTC. $875,000.
27. Tank Car Coupling Forces. Forces can exceed yield limits of mild steel and can fracture tanks.
28. Tank Car Steel Research. Materials testing. Tensile, fracture. Fabrication techniques. TC128 steel. Volpe. $150,000.
29. Full Scale Fire Test of UNT75 Portable Tank. SWRI
30. Pressure Relief Valves in tank Cars.
31. Passenger Train Structural Crashworthiness.
32. Locomotive Structural Crashworthiness. Full scale testing. Standards development. Volpe. $1.1 million
33. Interior Occupant Protection
34. Field Investigations. Study and identify info on passenger equipment safety. Volpe. $25,000
35. Improve Survivability for Locomotive Crews

36. Coupler Torsional Strength Research.
37. Wheel Measuring Device to confirm geometry is suitable.

Train Control and Communication

1. Automated Train Operations Specs and Safety
2. Automated Train Operations Sensors
3. There are several Automated Train Operations Projects. Many millions of dollars.
4. Onboard Broken Rail Detection R&D. Impedance. Coils $1.4 million.
5. Quasi Moving Block (QMB) Train Control. A type of novel, new train control. TTC. $2 million.
6. Positive Train Control (PTC)
7. Road Remote Control Locomotive
8. Unmanned Aircraft Systems. Lidar, photogrammetry, etc. Grade profiles. Volpe. $190,000
9. Rail Trespass Prevention Summits
10. Trespass Risk Methodology
11. AI for Trespassing
12. Waze Notifications Research (the Waze commuter app)
13. Trespass Close Call Data
14. Trespass Toolkit
15. Railroad AI Intruder Learning System
16. Grade Crossing Accident Reconstruction with Drones
17. Quasi-Quiet Zone Study. “Annoying” train horns in urban areas.
18. Drone Study. 3D measurement of humped grades
19. Drones for Trespass Detection

Human Factors

1. Automation, Operating Personnel Information Management and Control. Safety implications of new technology.
2. Railway Worker and Operator Performance. How to assess performance.
3. Motorist Behavior at Highway Rail Crossings. A virtual reality simulator is shown.
4. Railroad Trespass Prevention
5. Railroad Suicide Prevention. Signage image examples are shown, but the study is more extensive.

Appendix B

Forging Industry Association, “On the Issues”

Vol. 1

FORGING INDUSTRY ASSOCIATION

ON THE ISSUES

VOLUME ONE | JANUARY 2024

Photo Courtesy of Scot Forge

FORGING OUR FUTURE

The arsenal of democracy rests on North America's forging industry. Forges in 38 states, Canada and Mexico mold the metals and alloys for warships, planes, spacecraft, combat vehicles, missiles, rockets, bombs, ammunition, artillery pieces, and more.

CLEAN ENERGY'S FUTURE IN FORGING

They also forge heavy components for clean energy and power generation systems and supply vital components to a host of industries that are propelling the 21st century economy, from equipment to make semiconductors to electric vehicles components.

THE THREAT OF BARGAIN-HUNTERS

But unfair trade practices and customers who overlook North American producers in favor of lower prices have siphoned off billions of dollars' worth of work. That has left the nation and its armed forces at risk of losing the capacity to ramp up in a major crisis.

FORGING BUILDS A STRONG FUTURE

To better compete, companies are updating aging infrastructure, automating production processes, identifying new sources of raw materials, and nurturing the highly skilled work workforce that will be necessary to remain robust well into the future.

"Forging started 4,000 years ago. The reality is the longer something's been around, the odds are higher it will still be around in the future."

JOHN CAIN, CEO AND CHAIRMAN OF THE BOARD OF SCOT FORGE COMPANY

The Forging Industry Association asked three industry leaders to outline how their companies support national defense, energy independence, and to share their perspectives on the challenges and possible solutions for an industry at a crossroads.

Chelsea Lantto

Chelsea Lantto is president of Trenton Forging Company in Michigan, which specializes in stainless steel, carbon and alloy forgings, and is the Forging Industry Association's Chairperson, and member of the Public Policy, Women in Forging, Safety, and Workforce Development committees.

Mike Morgus

Mike Morgus is president of Ellwood Quality Steels in Pennsylvania, a leading supplier of high-quality carbon, nickel and copper-based alloys and stainless-steel ingots, and a FIA board member.

John Cain

John Cain is CEO and chairman of the board of Scot Forge Company, a leading producer of forged products for a range of defense and power generation systems, with facilities in Illinois and Wisconsin.

Q & A

WITH THE HEADWINDS FACING THE FORGING INDUSTRY, WHAT'S AT STAKE FOR NATIONAL SECURITY?

JC: Things atrophy and then we become vulnerable, and then we've got to reinvest in a hurry—inefficiently and almost desperately—to get us back to where we now look like we're more of a deterrent. Because none of us want to fight, right?

CL: If the commercial forging industry is not strong, the capacity and the capability is not going to be there in a time that the military is really going to need us. What we're talking about is being commercially competitive enough to make sure that we are viable into the future so that we are available when the military needs us.

WHAT ARE SOME OF THE MISSION-CRITICAL PRODUCTS THE FORGING INDUSTRY SUPPLIES FOR NATIONAL DEFENSE AND ENERGY INDEPENDENCE?

CL: We forge components that go into the M-240 machine gun. We also produce various tie-down rings for military cargo transport. Two years ago, we started making components that are critical for a quick assembly medical evacuation ramp.

MM: We produce a number of military applications: tracks for tanks; parts for mechanical drives; missile tube assemblies; structural components for subs; and the nuclear plant in the submarines. We also support NASA and the Artemis moon project.

JC: We do a lot of work with clean energy–mineral extraction for electric vehicles, hydropower, solar, wind. We do a lot of projects with the Department of Energy's (DOE) national labs. We are a critical part of the ecosystem that it takes to do all these things, starting with exceptionally good raw materials.

We are helping a lot of the national goals we have with space exploration, energy security, decarbonization—a lot of the things that make modern civilization work.

MM: We're not just supporting our military and the Army and Navy but energy independence and all of the other national goals.

WHAT ELSE COULD NORTH AMERICAN FORGERS PRODUCE, BUT HAVE LOST TO OFFSHORE SUPPLIERS?

JC: Huge stainless-steel valves and valve gates for hydroelectric power systems. Just like Hoover Dam. There was a 'Buy America' call out in a contract. The prime contractor said they can't be bought in this country anymore. And we've made those things for 40 years. When somebody says something can't be made here, or the capacity or the capability doesn't exist, we clearly can show them that it does.

The DOE comes here, and they say, 'we had no idea this could still be done in the country.' We just want to put out the welcome mat, open the doors so they can come and see. There's a lot more here in this country domestically that we want them to understand so their decision quality can improve.

DO YOU THINK THE MESSAGE IS GETTING THROUGH?

CL: The Department of Defense (DOD) and DOE came to a forger and asked, 'do you have excess capacity to meet our needs?' The response was 'absolutely, without a doubt.' And their response was, 'are you sure? We don't really believe you.' It speaks exactly to what we're up against.

Challenges in the Global Economy

WHY HAS DEMAND FOR NORTH AMERICAN FORGING DECREASED?

CL: If you think about the situation that happened with the microchips—where the Original Equipment Manufacturers (OEM) sent all of that capacity and capability offshore because they were searching for the lowest price—it drove all of that capability elsewhere. All of a sudden, everybody was up in arms because we couldn't get the chips we needed, but we couldn't make them stateside.

The same thing is going to happen to the forging industry. If OEMs continue to push all of that capability and capacity offshore in search of the lowest price. And that's exactly what is happening and why forging companies are being closed and consolidated.

WHERE IS THE BIGGEST THREAT TO OUR FORGING INDUSTRY COMING FROM?

CL: We did a snapshot of one year and we calculated lost opportunities just to China. We calculated $386 million dollars in lifetime revenue lost to China. It is a small snapshot of the actual reality. We stopped counting because we got so sick to our stomachs.

So that's little Trenton Forgings' lost opportunities. Can you imagine what the full picture of that would look like?

JC: It is not cheap labor. It's China's subsidization, manufacturing policy and their trade policies that they have been effectively convincing other countries to live with, because of the price.

> *"We don't need handouts. We just need to be able to compete fairly and continue doing what we've always done exceptionally well—which is to produce high quality forgings for a wide variety of industries."*
>
> CHELSEA LANTTO, PRESIDENT OF TRENTON FORGING COMPANY

Bringing Forging Back

THE FORGING INDUSTRY ISN'T WAITING FOR OUTSIDE HELP. HOW ARE YOU FIGHTING BACK?

CL: The forging industry, as old as we are, and as rooted in history as we are, we're very good at adapting and embracing new technologies that are available to us. It's all still rooted in traditional blacksmithing; the metallurgy is the same.

We're just building upon and improving the processes and the equipment and the tooling that we're using to get to that final product to meet the customer's needs. We are planning to spend $14 million in three phases to greatly expand our capacity and our ability to compete for the higher-volume of jobs.

DOES THE GOVERNMENT HAVE A ROLE TO PLAY?

MM: What we're saying is, 'help us level the playing field so we can compete, so we can show that we're competitive and we can win that business.' And if that happens, we'll be creative, we'll use ingenuity, we'll develop the middle-class workforce and we'll have strong manufacturing.

JC: The encouraging part is you hear our elected officials and the DOE and DOD more and more recognizing that trade policy is at the root of many of the problems they're trying to solve today.

MM: I think we can solve a lot of our own problems if we are given the opportunity to compete fairly on a global basis. So, when—and if—the government does need additional flex, it'll be there because we're winning on the commercial side. There's newer technologies and better solutions out there. The more the government can be receptive to that, the more that we can help them help themselves and be more competitive.

CL: We don't need handouts. We just need to be able to compete fairly and continue doing what we've always done exceptionally well.

WHAT WOULD BE THE BEST APPROACH?

JC: Kicking the lowest price addiction. It's real and it's as tough as any other addiction to break. The honorable mention of 'Buy America' is wonderful and it's a start, but there's really no way to enforce it.

CL: OEMs are the biggest part of the problem when only considering the lowest price. Of course, we don't want all of that to end up being passed to the consumer, right? So, you have to look at the full picture so that we're not just flipping the cost burden to the consumer.

It's strengthening the American sector so that we can really balance out what we're able to produce stateside. If we don't start to unravel that knot, we're never going to get out of it.

I would pull the trigger on the next two phases of my automated line investments tomorrow if the commercial demand was there. But I am still fighting tooth and nail and scratching to bring all of that offshore work back. And if that work came back, I could do probably two and a half brand new Trenton Forging-size facilities from the ground up.

Forging for the 21st Century

THERE'S A GLOBAL PUSH FOR CLEANER, MORE MODERN TECHNOLOGY IN EVERY SECTOR. HOW IS THE FORGING INDUSTRY ADAPTING?

MM: Electric Arc Furnaces (EAFs), by definition, are much cleaner from a CO2 standpoint. Those tools also help us lower our emissions because our furnaces run hotter, they run faster. Therefore, they run cleaner. Electric units that we use to heat up our raw material that go into either the drop hammers or the press for the forging process are the most energy efficient and commercially efficient way to heat steel for the size range that we forge. We're able to heat up that material in a couple of seconds. So those of us who have been able to make that switch, we absolutely invested in that technology, not only for the commercial benefit, but also because it is the most efficient way to do that process.

JC: Those are things that were done as private investments for global competitiveness—and for being good community partners for the planet. If one of our companies lost to a foreign competitor, it wasn't to a company that innovated better. They lost it to a dirtier, slower, lower quality, less efficient company.

> *"We're learning to change with the times to be more effective communicators so that these are the places people want to come to work and we're also more effective keeping those people."*
>
> MIKE MORGUS, PRESIDENT OF ELLWOOD QUALITY STEELS

Forging's New Workforce

IS THE WORKFORCE KEEPING PACE WITH THE INDUSTRY'S NEEDS?

MM: We just haven't done a good enough or effective enough job communicating to them who we are and what we are, what we can offer. I think that we've recognized as a group of companies that we need to do a better job communicating in our communities, reaching out to the high schools, reaching out to trade schools.

We have a lot more work to do, but I think we're learning to change with the times to be more effective communicators so that these are the places people want to come to work and we're also more effective keeping those people.

CL: There is a gap in the number of available people who not only want to work or are interested in working in manufacturing, but also have the skills that need to go with that. We're competing against air-conditioned facilities, with retail. Why would you want to work in a hot, loud, and dirty environment?

We've always had an electrician gap here. Same with machinists, same with maintenance mechanics that have actual hydraulics experience that they can hit the ground running. And now that we're all moving into automation, the education sector has not caught up yet when it comes to controls engineers, the robotic and automation technicians.

I think we still have our work cut out for us when it comes to the public relations side of manufacturing—and showcasing that it is a viable, high paying, fulfilling career path.

IS AUTOMATION HELPING?

CL: It gives us a lot of flexibility. It also does double duty in alleviating any manpower issues that we might be facing. So we have not replaced anybody by implementing a robotic line; we're just expanding our capabilities. We'll be able to run a second shift because even though we have some noise ordinance restrictions in our area, it's a lot quieter than our drop hammers.

> *"We are helping a lot of the national goals we have with space exploration, energy security, decarbonization; a lot of the things that make modern civilization work."*
>
> JOHN CAIN, CEO AND CHAIRMAN OF THE BOARD OF SCOT FORGE COMPANY

FORGING INDUSTRY ASSOCIATION

Photo Courtesy of Scot Forge

FORGING.ORG
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Appendix C

Testimony Before the Office of U.S. Trade Representative

Testimony of Angela Gibian
Deputy Chief Executive
Forging Industry Association
Before the Office of U.S. Trade Representative
Promoting Supply Chain Resilience
Public Hearing Virtual Panel
Thursday, May 23, 2024

Thank you for the opportunity to speak today. My name is Angela Gibian, Deputy Chief Executive of the Forging Industry Association based in Independence, OH.

FIA has 230 member companies, of which - 106 are producers. Forging is a metalworking process where metal is manipulated by “die plates” which act as large hammers, pressing, pounding, or squeezing the material into a final or near net shape.

Most forging plants are small businesses, with 55 percent of FIA members reporting sales below $30 million and only 12 percent reporting sales over $120 million.

Many aircraft have over 1,000 forgings. A typical passenger vehicle or truck can contain 250 forgings. These products are a critical part of U.S. national and economic security with roughly twenty metric tons of forgings on a typical large wind turbine - and 550 forgings on a heavy tank.

The Defense Department identifies forgings as being of national security significance. In a February 2022 report, the Pentagon said that forged parts “are critical to the development, procurement, and sustainment of all major defense systems.” In 2020, the Defense Logistics Agency identified 30,061 out of 32,597 specialized items that contain casting and forged parts.

While USTR recently increased the tariff rate on a select group of products, FIA believes that USTR should also increase the tariff on items identified as of national security and economic significance. Imports of products in this special category should face a higher tariff rate, including forgings.

While the tariff rate of 25 percent continues to make U.S. forgings more competitive, FIA members report that forged imports from China remain 40 to 80 percent cheaper. A special category with a higher tariff rate will help protect our manufacturers and the supply chain.

Over the past two decades, U.S. manufacturers watched in real time as China increased exports, leaving China in control of 46 percent of the global forging market. Trade laws should work in real time to prevent this type of market concentration, so the “next China” does not undermine domestic supply chains.

A prime example of this is the rise in competition from India - as production shifts from one country to another following the Section 301 tariff action. Imports of iron or steel forgings, not further worked, from India increased from $7.2 million in 2019 to over $13 million last year. Steel forgings for vehicle gearboxes also jumped from $13.4 million in 2017 to $31 million in 2022.

In the time it takes to initiate a trade investigation and impose tariffs - or duties - to protect U.S. industry, the imports shift to a different company within China -- or to a new country altogether.

Goods now coming in from that new source, are often transshipped, receive transnational subsidies, or both. Aluminum forgings from Vietnam increased from $152,000 in 2017 prior to imposition of the tariffs on China, to $3.1 million worth of imports in 2022. These actions undermine the effectiveness of the 25 percent tariff imposed under the Section 301 tariff action on imported Chinese forgings.

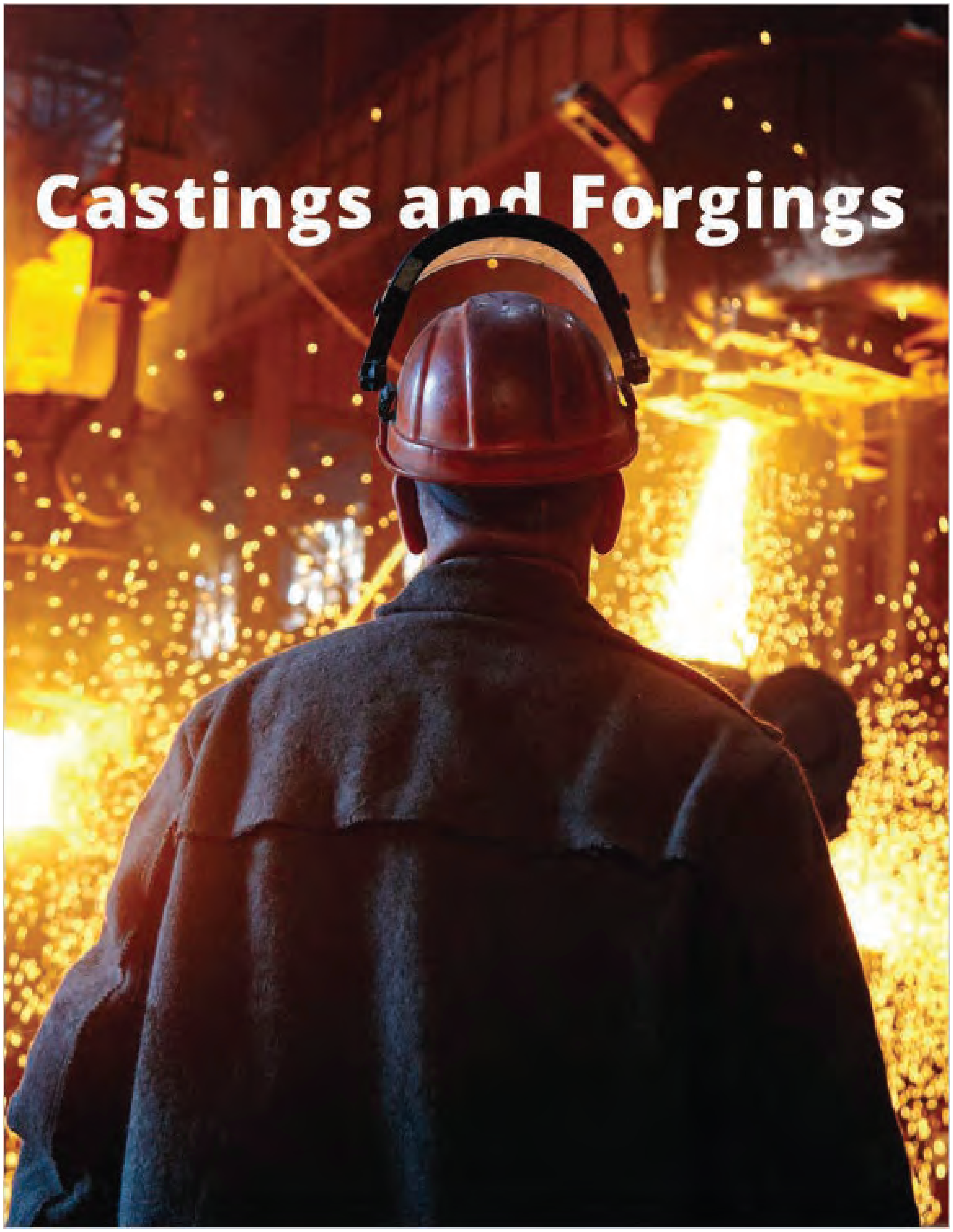
As the U.S. begins its review of USMCA - we ask USTR to pay particular attention to the surge in imports of forgings from Mexico. According to import data, Mexico shipped $2,081 worth of aluminum forgings into the U.S. in 2017. Following entry into the USMCA and imposition of tariffs on China, those imports totaled $22.4 million in 2022.

The U.S. needs to update its antiquated system of trade laws to adapt to today's global strategy of evading tariff actions through tactics including transshipment and transnational subsidies. USTR should investigate and track the country of origin if it is suspected that the "substantial transformation" is in fact, minimal, and simply used to change the country on a shipping label to evade tariffs.

Thank you for allowing me to speak today and I look forward to answering your questions.

Appendix D

Securing Defense–Critical Supply Chains
Pages 24-30, Castings and Forgings


Castings and Forgings

Castings and Forgings

National Security Significance

> **Organic Defense Industrial Base (OIB)**
> The OIB includes government-owned government-operated (GOGO) and government-owned contractor -operated (GOCO) facilities that provide specific goods and services for the DoD.

Cast and forged (C&F) parts are critical to the development, procurement, and sustainment of all major defense systems by the DIB, including, where applicable, the organic industrial base (OIB). They are used in almost all platforms (e.g., ships, submarines, aircraft, ground combat vehicles, spacecraft, etc.), kinetic weapons and weapon systems (e.g., guns, missiles and rockets, bombs, ammunition, artillery pieces, etc.), and many supporting systems (e.g., vehicles, powered support equipment, etc.). In 2020, the Defense Logistics Agency (DLA) identified 30,061 out of 32,597 specialized end items that contain C&F maintenance, repair, and operations (MRO) parts. Many of these parts are high importance/low-volume and minimal demand items[18] that support "critical go-to-war weapon systems and platforms that affect military readiness."[19] C&F products are essential components of the machine tools and other equipment used to produce and sustain fielded systems and forgings are found in 20 percent of the products representing the gross domestic product of the United States.[20]

> **Casting and Forging**
> **Casting** is the process used to create geometrically complex parts by pouring molten or high-temperature metal or composites into a mold.
>
> *"About Metalcasting,"* American Foundry Society
>
> **Forging** is the process used to develop metal parts by pounding, pressing, or squeezing metals under great pressure; the metals are often preheated before working but are never melted.
>
> *"Forging Facts: What is Forging?"* Forging Industry Association

Manufacturers use C&F capabilities to provide specific material properties in intermediate products[21] and end items that cannot be produced by other manufacturing processes. Production of C&F parts often includes

18. United States, Defense Logistics Agency Industrial Capability Program, "*2019 Castings Summit & Industry Review*," February 26, 2020.
19. *Ibid.*
20. Forging Industry Association, Vision of the Future, https://www.forging.org/producers-and-suppliers/technology/vision-of-the-future, accessed December 8, 2021.
21. *Ibid.* The vision says, "*The industry is a key link between critical manufacturing segments--metal suppliers (both ferrous and nonferrous) and end user industries. Forgings are intermediate products used widely by original equipment manufacturers in the production of durable goods. They range in size from less than an ounce to more than 150 tons and are found in the machines, vehicles and equipment used to generate our industrial economy.*"

heat treatment to ensure specific material properties and machining to produce precise shapes and finishes. The resulting products are long-lived, rugged, and can withstand high temperatures, pressures, and stresses. Although people have produced cast and forged products for thousands of years, the relevant processes, equipment, and technologies continue to evolve and improve.

Dependence on foreign sources for key materials and production capabilities can introduce FOCI threats and presents a strategic vulnerability that increases the time and cost to deliver new systems and maintain current capabilities, especially if global transportation channels are backlogged or threatened. The United States needs a robust and secure C&F industry and supply chain to provide reliable, timely delivery of the parts used in DoD's operational systems and to produce and sustain new systems.

Sector Challenges

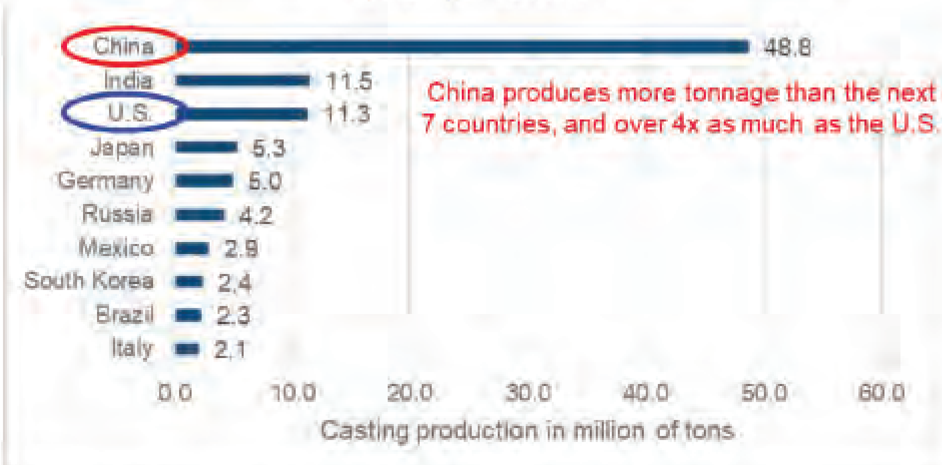
The U.S. C&F industry faces challenges related to capability and capacity, workforce, and U.S. Government policies. Like all businesses, domestic producers need predictable demand, costs, and returns to compete successfully for global market share. In some cases, DoD product needs involve specialized, often low-density requirements that can only be addressed by a small portion of the casting and forging market. Furthermore, the variability of DoD funding (timing and amount) creates challenges for businesses trying to satisfy DoD needs. Industry currently prefers to pursue commercial work. Obstacles to expanding DoD's sources of supply in this area lie in the complex Federal contracting process, the need for improved technical data requirements, and the requirement to modify plant capabilities to support the manufacturing of products that meet military specifications.

Capability and Capacity

The Military Services have experienced casting and forging capability and capacity challenges that can be attributed in part to the impacts of offshoring and waves of industry consolidation since the mid-20th century. For example, the United States has only one foundry that can produce the large titanium castings required for some key systems. The Army has also identified shortfalls in production and heat treatment of specialty alloys that are mission critical.[22] The Navy has documented C&F capacity and quality issues affecting many facets of shipbuilding.[23] The Air Force has identified needs for the ability to cast single crystal turbine blades and large thin-wall titanium components, an additional source for an extrusion press used for powder nickel super alloy billets, and downstream post-processing capacities and capabilities—including heat treating, coating, hole drilling, machining, and hot isostatic pressing to help eliminate unwanted voids and provide increased strength in cast products.[24] Although some suppliers have updated equipment over time in an attempt to meet the Services' needs, many commercial and OIB C&F plants have aging equipment or are limited by existing facilities, infrastructure, and, for commercial firms, state and federal operating permits.[25]

22. Army inputs to September 2021 Deputies Management Action Group briefing. The closure of key West Coast heat treatment facilities has significantly lengthened schedules and added costs due to the need to repeatedly ship parts to suitable heat treatment facilities in other places during the manufacturing process.
23. A government-only 2021 analysis for the Navy reported the need for reliable production of extremely large C&F parts is such a high concern to DoD that the Navy added an NTIB firm to produce large cast shapes for shipbuilding due to domestic suppliers' capacity and quality issues.
24. Air Force Research Laboratory, *USAF View of Military Supply Chain Concerns (Castings and Forgings)*, 25 October 2021.
25. For example, the Army recently invested over $68M to upgrade a critical rotary forge at Watervliet Arsenal, NY.

Figure 4. Statista Research Department, Volume of the Global Casting Production in 2019, by Country, 23 March 2021.[26]



U.S. supply chains currently involve significant materials and products from foreign manufacturers. Multiple U.S. sources report that China and other foreign suppliers can often deliver a completed item for the same cost that a U.S. forge will pay for the raw materials needed to produce the parts of an item. As shown above in Figure 4, China is the world's leading producer of cast products by a wide margin. DoD counts on foreign countries, including China, for very large cast and forged products used in the production of some defense systems and many machine tools and manufacturing systems in which the DoD is reliant.[27]

As domestic capacity and overall market share erode, fewer U.S. and allied firms can afford improvements to equipment and processes. Limited access to capital for America's small and medium size producers has hindered their ability to invest in the necessary technologies. This includes the adoption of innovative processes and complementary technologies such as additive manufacturing, robotic automation, and digital engineering to support reverse engineering of aging parts.

Acquisition and Program Protection Policy

Low-volume work driven by U.S. Government and DoD procurement practices incurs high startup costs and produces limited profits. Many small and medium sized manufacturers find it challenging to create sustainable businesses or production lines in this space. Although many trade policy actions are conducted pursuant to specific authorities and designed to remedy injury to domestic industry and respond to unfair or unreasonable foreign trade practices, participants in DoD industry listening sessions reported that tariffs on raw materials used in U.S.-made C&F parts made U.S. products significantly more expensive than parts made in China, driving U.S. suppliers out of business.[28] Other challenges included traditional concerns about non-standard technical data packages, complex contracting process, burdensome accounting system requirements, small and unreliable demand, and a slow Government sales cycle.[29]

26. Figure 4 Source: https://www.statista.com/statistics/237526/casting-production-worldwide-by-country/
27. The Navy uses an English firm to supplement domestic suppliers of large parts required for shipbuilding.
28. DoD Castings & Forgings Industry Listening Session, op cit.
29. United States, Defense Logistics Agency Industrial Capability Program, *2019 Castings Summit & Industry Review, February 26, 2020*

Technical Data Policy

Vendor control of detailed technical data for C&F parts can constrain DoD's ability to acquire affordable replacement parts, especially for long-lived systems. This is especially true if the original vendor no longer has the capability or desire to manufacture the part. It also makes it difficult for DoD to enable new manufacturers to produce replacement parts using specific geometries, materials, and manufacturing methods that can be constrained by lack of technical data or data rights.

In some such cases, DoD could create and use detailed, Government-developed technical data (i.e., product specifications including manufacturing equipment specifications and a detailed manufacturing "recipe") to address such issues. Experience at Oak Ridge National Lab's Manufacturing Demonstration Facility indicates that detailed Government-owned tech data can provide the following:

- Expand the supplier base ("democratize manufacturing") by licensing on a non-exclusive basis to as many manufacturers as needed that could afford to compete for defense work, reducing prices and pricing practices (i.e., opening non-commercial pricing).
- Increase speed and reduce the cost of first-part certification and acceptance (requires the IP to include a sufficiently complete manufacturing "recipe", which manufacturers must follow scrupulously). This reduces cost-based barriers to entry for new suppliers, increasing the size of the supplier base (including smaller businesses) that could afford to compete for defense work, thereby reducing prices and vendor lock.
- Contribute to development of a creative, competent workforce able to deliver next-generation solutions efficiently, as further discussed in the Workforce strategic enabler section.

Recommendations

Internal

Recommendation C1.1: Develop a C&F strategy. DoD is developing a cross-service C&F strategy to inform policy and investment decisions over the coming the years. The strategy will leverage market research evaluating DoD's casting and forging demand and the commercial sector's ability to meet DoD's requirements. Current plans call for publication no later than the end of the second quarter of FY 2023. The strategy will make recommendations concerning the following:

- Establishing C&F centers of excellence.
- Identifying other specific measures to improve the OIB's capabilities.
- Prioritizing DoD research into:
  - New C&F processes.
  - Alternatives to C&F, such as new subtractive and hybrid methods.
  - Expanding use of additive manufacturing and digital production capabilities as a tool to enhance traditional methods, such as 3D printing sand cores, and for direct manufacturing.
  - Identify specific opportunities requiring the development of Government-owned technical data.

Recommendation C1.2: Invest in the C&F industrial base. Based on the strategy developed in Recommendation C1.1, DoD should create and support a persistent C&F working group to guide execution of the investment plan and research activities, which will address sub-tier supplier and workforce development, competition that enables affordable production, and designs and procurements that optimize synergies within the DIB.

Interagency

Recommendation C2.1: Expand government and industry partnerships. Guided by the strategy, DoD should continue to expand its current partnership, America's Cutting Edge (ACE), with DOE's Oak Ridge National Laboratory to refine ways to supplement C&F capabilities, including additive and hybrid manufacturing processes and metrology.[30] DoD should also leverage and build on the activities and capabilities of organizations like the American Metalcasting Consortium[31] and Forging Defense Manufacturing Consortium[32], among others, to share information, identify and fulfill research and development opportunities, and identify new sources of supply to support DoD's need for cost-effective, high-quality cast and forged parts. DoD should progressively expand its network of relationships to include other interagency partners.

International

Recommendation C3.1: Identify and develop allied and partner C&F capabilities. Guided by the investment strategy developed as part of the cross-service study from Recommendation C1.1, DoD should coordinate with its international partners to scope, develop, and implement plans to develop and coordinate C&F capabilities, including key aspects of the supply chain such as critical minerals and materials (and therefore in alignment with those recommendations and initiatives outlined in the 100-day review responding to E.O. 14017). Where appropriate, DoD should support the development of international agreements to develop and protect key technologies related to C&F (and suitable alternatives), machine tools, and industrial controls.

Additional international recommendations are captured in the Cross-Cutting Recommendations section.

Industry

Recommendation C4.1: Engage industry to develop domestic capacity. In developing its C&F strategy, DoD will engage the National Institute of Science and Technology's Manufacturing Extension Partnership to develop its understanding of industry's perspectives on building commercially viable domestic capacity.

Table 3 (next page) maps the recommendations against the three challenge areas for castings and forgings.

30. ACE is a national initiative for machine tool technology development and advancement. It has developed a computer numerical control (CNC) machining training program in collaboration with IACMI — The Composites Institute and Oak Ridge National Laboratory.
31. https://amc.ati.org/cast-it/
32. https://www.ati.org/collaboration/fdmc/

Table 3. **Challenges and Recommendations for Castings and Forgings.**

		Capability and Capacity	Acquisition and Program Protection Policy	Technical Data
Internal	Rec C1.1: Develop a C&F strategy	✓	✓	✓
	Rec C1.2: Invest in the C&F industrial base	✓		✓
Interagency	Rec C2.1: Expand government and industry partnerships	✓	✓	✓
International	Rec C3.1: Identify and develop allied and partner C&F capabilities	✓		
Industry	Rec C4.1: Engage industry to develop domestic capacity	✓		

Appendix E

Results of Initial Assessment for RAPLSS Topics

Table E-1. Offshore Wind/Maritime Initial Gap Suggestion Items

Category	**Item**
Design Methodologies and Models/Digital Thread and Twins	Heavy thick section design methodologies
	Mooring systems – novel elastomers / spring dampeners / anchors for floating platforms (≥100 ft of water)
	Scan to Plan / Lights-out manufacturing systems
	DFX (design for manufacturing, inspection, maintenance, etc.)
Fabrication Technologies	Field erection challenges
	Serial production and high production rates of large steel components
	In-situ NDE and auto flaw recognition
	Large section precision forming and joining
Integrity – Condition Monitoring and Service Life Optimization	Real-time health monitoring
	Field robotics and drones – autonomous
	Implementation of AI/ML technology
	Long life corrosion life resistance (50-100 years)
	Abrasion and ablation resistance of blades
Advanced Materials and Performance	New design allowables for fracture and fatigue
	New polymers for mega-blades (600-ft long)
Supply Chain	Availability of large installation vessels
	Lack of coastal fabrication facilities
Workforce Development	Training facilities for unique production processes
	Need for automation to augment shortages
CAPEX Costs	Establishment of coastal fabrication facilities
	Shipbuilding/offshore installation vessels (Jones Act) and support ships
	Point of need manufacturing of fiber reinforced polymer structures
	Finish machining of large components (3+ tons)
Standards – Codes	Development of new guides for design, advanced materials and production
	Material and procedure qualification requirements

Table E-2. Hydrogen/CCUs/Petro-chemical/Refining

Category	Item
Design Methodologies and Models/Digital Threads and Twins	Understanding pipeline performance – embrittlement for H_2, corrosion and fracture resistance for CO_2
	Opportunity for smaller refineries?
	Understanding specific microstructure-hydrogen interaction and adsorption kinetics due to steel surface condition; difference with sour service grades
	Welding procedure development for H_2 and CO_2, especially for high strength steel grades
	Blended H_2 gas transport – consideration for flow separation in pipeline design
	Running ductile fracture for CO_2
	Brittle fracture for CO_2 (during decompression due to JT effect, especially in the presence of impurities)
	Decompression modeling for CCUS
	Next gen facilities for sorting biproducts
	Design for supercritical CO_2
	AI for integrity management of pipelines (incorporating NDE and material property inputs and operating conditions)
	Improved process monitoring, sensing – intelligent infrastructure life prediction
Fabrication Technologies	New pipe materials and welding consumables tailored to H_2 and CO_2 service
	Coatings/chemical inhibitors/reactions to prevent H2 dissociation/uptake or protect corrosion for CO_2
	Advanced NDE for flaw detection during pipe manufacturing
	Advanced CP design for pipeline – H_2 and CO_2 to a lesser extent
Integrity – Condition Monitoring and Service Life Optimization	Intelligent pigging
	High-temperature in-situ NDE, monitoring at temperature
	Understanding new damage mechanisms and monitoring of accelerated damage rates
	NDE/inspection through coatings
	Implementation of AI/ML technology for component failure prediction – predictive analytics
	Advanced UAV/robotic inspection methods
	Multi-process in-situ repair
	Life extension – continued operation of aging infrastructure
	Types of and accumulation rates of damage – new testing methods
Advanced Materials and Performance	New design allowables for fracture and fatigue
	Advanced corrosion resistant materials
	Multi-purpose pipeline – natural gas, H_2, CO2. Developing steel composition and processing methods for H2 and CO_2 service.
	Advanced coatings

Category	Item
	High strength-high toughness line pipe – HE resistant, superior resistance to CO2 corrosion and high toughness to prevent ductile running fracture and brittle fracture during decompression
	Non-metallic process piping
	Corrosion for CCUS; chemical inhibitors
	Non-metallic pipe materials
	Novel coatings for corrosion resistance
	Polymers, gaskets, compressor materials, valves, fittings (e.g., elbows, bends)
	Polymers, gaskets, compressor materials
Supply Chain	Lack of existing infrastructure for production and transport of H_2 and CO_2
	Lack of new refineries (lack of permitting, etc.)
	Lack of high strength HE resistant line pipe grades
	More efficient plant turn-around/retrofits
	Lack of HE resistant casing/connections
	Lack of accessory components such as compressors, valves, fittings – both for H_2 and CO_2 pipelines
	Lack of accessory components such as compressors, valves, fittings – both for H_2 and CO_2 pipelines
	Lack of steel production capabilities for the anticipated demand
	Lack of efficient separation technologies (for blended condition)
	Lack of CO_2 drying/cleaning technology
	Lack of high strength, high toughness corrosion-resistant line pipe grades
Workforce Development	Aging workforce in all areas
	Lack of expertise/trained professionals, training of trainers
	Insufficient replacement of workforce
	limited university and government lab resources/capabilities/infrastructure
	Insufficient replacement of workforce
CAPEX Costs	Lack of H_2 and CO_2 production and transmission infrastructure – distribution and storage to a lesser extent
	Implementation of CCUS at point of production/emission
	Retrofitting existing NG transmission infrastructure
	Developing processes to develop marketable products from CO_2
	New ILI, leak detection and other integrity management tools/technology development and implementation
Standards – Codes	Accelerated ASME code cases / overhaul of ASME B31.12 (H_2) and B31.08 (CO_2)
	Lab scale testing standard for ductile running fracture
	New standards for flaw tolerances

Table E-3. Nuclear

Category	Item
Design Methodologies and Models/Digital Thread and Twins	Move towards SMRs or new approaches for LWRs
	Design allowables for new materials
	Improved process monitoring, sensing – intelligent infrastructure life prediction
Fabrication Technologies	Near-net shaped component production – MegaHIP facility
	Flexible production of limited quantities of unique shapes
	In-situ additive manufacturing of features on large structures
	Lights-out robotic conformal cladding
	Field robotics
Integrity – Condition Monitoring and Service Life Optimization	Tele-manufacturing – remote repair and replacement
	In-process monitoring to inform NDE
Advanced Materials and Performance	Higher temperature materials
Supply Chain	Reduced lead times
	Availability of large forgings and castings
Workforce Development	Aging workforce in all areas
	Insufficient replacement of workforce
CAPEX Costs	Reduced cost of plants
	MegaHIP facility – rebuild forging/casting infrastructure
Standards – Codes	Accelerated ASME code cases
	New process additions (AM) to standards

Table E-4. Mining/Primary Metals

Category	Item
Design Methodologies and Models/Digital Threads and Twins	Design for all applications needs to integrate process modeling with performance modeling and NDT to use fitness for purpose designs and life cycle management.
	The process and performance models should be coupled with the service.
Fabrication Technologies	Agile repair – convergent manufacturing for equipment overhaul
	Processes need to be able to be modeled to determine performance capability so hybrid approaches can be used to optimize
	Enhanced weld processes and/or consumables to resist weld fatigue and wear
	High productivity weld processes to reduce equipment/CAPEX costs
Integrity – Condition Monitoring and Service Life Optimization	Health monitoring of equipment
	Implementation of AI/ML technology
	With fitness for purpose design, monitoring of critical features can be instrumented or inspected. Condition monitoring will also validate the design
	Integrating smart sensors into critical welds and components for predictive maintenance
	Design methodologies need to use fatigue and fracture to determine service loads and quantitative NDT levels
	integrating smart sensors into critical welds and components for predictive maintenance
Advanced Materials and Performance	Developing capabilities to enable large scale green production of new materials
	Targeting new material performance and investing in commercially useful alloys also needs code or requirement paths to validate their safety and reliability
Supply Chain	Re-shoring facilities
	Public policy has for decades discouraged U.S. ownership of capital intensive businesses. Tax, trade, and regulatory reform is needed.
Workforce Development	Aging workforce in all areas
	Insufficient replacement of workforce
	The low fertility rate means that artisan like automation is required.
CAPEX Costs	Low carbon footprint infrastructure – sustainability mandates
	Increased domestic supply – cost-effective expansion
	The public policy preference for services and the structure of our economy is a significant barrier to CAPEX needed. Modernization, automation, and innovation are all limited by the lack of profitable investment.
Standards – Codes	Modernizing requirements to allow innovative hybrid processes like AM + forging or AM + casting is needed.

Table E-5. Mega Buildings and Bridges

Category	Item
Design Methodologies and Models/Digital Threads and Twins	Corrosion engineering and prevention
	Design methodologies for seismic activity
	Dfx – design for inspection, repair, maintenance, etc.
	Climate change – design for extreme weather events
	Implementation of digital manufacturing for next generation bridges/structures
Fabrication Technologies	Cold spray for structural repair of corrosion damage
	Remote robotics for field erection
	Improved fabrication methods for structural beams
	Lattice/honeycomb deck structures for lightweight bridges
	Adaptive welding for erection joints
Integrity – Condition Monitoring and Service Life Optimization	Next generation health monitoring technologies
	NDE/inspection through coatings
	Automated drone/robot/crawler inspection
	Smart structures
	Implementation of AI/ML technology for predictive maintenance and failure avoidance
	Field automation for in-situ inspection and repair
	Tele-robotics for human supervised adaptive inspection and repair
Advanced Materials and Performance	Affordable low cost corrosion resistant steels
Workforce Development	Aging workforce in all areas
	Insufficient replacement of workforce
Standards – Codes	New codes and standards for weather and climate change

Table E-6. Rail and Mass Transportation

Category	Item
Design Methodologies and Models/Digital Threads and Twins	Lightweight designs and better crash
	Multi-material freight car structures
	Next generation tanker design for H2 transportation
	Design for recyclability
	Implementation of digital thread for fleet maintenance
Fabrication Technologies	Joining technology for multi-material structures
	High productivity joining methods
	Convergent manufacturing systems for overhaul and repair
Integrity – Condition Monitoring and Service Life Optimization	Next gen positive train control
	Implementation of AI/ML technology
	Rail inspection at high speeds
	Recycling of electrified vehicle components
Advanced Materials and Performance	Better rail welding and repair methods
Supply Chain	Availability of castings and forgings
	Development of precision rail component suppliers for high-speed passenger rail
	Batteries/supercapacitors for electrified rail vehicles
Workforce Development	Aging workforce in all areas
	Insufficient replacement of workforce
CAPEX Costs	Distributed power – electric train systems

Appendix F

OSU Data from Second Focus Group

OSU Data from Second Focus Group

Three areas were chosen for assessment at Focus Group 2 held in Miami, Florida, associated with the Ma2JIC meeting: fabrication technology, conventional and advanced materials, and workforce development. The item lists and voting from that session are shown in Tables C-1 to C-3.

Table C-1. Fabrication Voting from Focus Group 2

Theme Description	Total Points	Overall Rank	People Voting
Standards	113	1	33
Large Fab Processes	112	2	33
HUBS – Modeling, Process Parameter, Optimization, Software Tools, Data Structure	63	3	18
Wire DED productivity	54	4	14
Supply Chain	43	5	12
Scale Up	41	6	13
Adv Testing/Extreme Environments	41	6	14
Mobile Robotics + Automation and Controls	36	7	16
Circular Economy/Recycling	34	8	10
Alloy Development	20	9	8
NDE/Monitoring	20	9	8
Advanced Joining	19	10	12
Modular Tooling	14	11	6
Coatings	11	12	6
Polymer/Composite AM	9	13	4

Comments were provided on the top four items. Standards were noted as crucial to implementation of new processes or materials. Large fabrication processes were noted as different for different industries (tens of tons for nuclear, smaller for shipbuilding, and smaller still for wind energy, although the volume goes up as the size goes down). The largest forging and casting equipment is missing in the Unites States. Desired weld and additive manufacturing of large structures must be considered in ways that standards allow. HUBS modeling needs a centralized but open database to support modeling and process development. Wire DED productivity user base expansion has been limited by lack of knowledge. The application of high productivity for very large-scale wire DED will benefit from further research and development.

Table C-2: Materials Items from Focus Group 2

Theme Description	Total Points	Overall Rank	People Voting
Sustainability + Recycling Alloys	85	1	28
Property Database	70	2	17
Feedstock Material Design	63	3	21
Lightweight + Advanced Alloys	59	4	19
Alloy Design DFX	51	5	14
Refractories + Extreme Environment Materials	51	5	16
Cladding and Coatings and Graded Materials	41	6	16
Material Supply Chain	39	7	13
Material Selection Methods + Material to Designers	28	8	11
Small Scale Production	27	9	9
Steel	23	10	8
New Testing Methods	18	11	8
Property-Material Relationships	17	12	6
Non-Metallic Structural Materials	13	13	8
HUBS/Education/Qual/Cert/Standards	11	14	6

The sustainability and recycling of alloys item was noted as reducing energy use, reusing materials that may be rare, improving recycled materials performance, and limiting mineral extraction damage. The property database described an open database for base/weld and additive material properties in extreme environments to support alloy and end-use design. The feedstock material design item covered weldability, productivity, custom use applications, and the mass production of custom feedstock. The lightweight and advanced alloys item covered weldability, the need for greater performance of joints, and lowered structural weight.

Table C-3. Workforce Items from Focus Group 2

Theme Description	Total Points	Overall Rank	People Voting
Tech/Trade Programs	107	1	30
Culture/Mindset	78	2	19
Tailored Facilities – Advanced Technology + Modern Tech Training	73	3	25
Curriculum and Multimedia	41	4	12
Multi-Disciplinary, Cross-Cutting Experience	40	5	13
Education- HS	39	6	12
Internships, Apprenticeship, Co-ops	37	7	12
Digital Tools + Video Production Capabilities	32	8	14
Marketing and Promotion	28	9	10
Emerging Needs Research	25	10	10
Design understanding manufacturing process	25	10	10
Robotics and Automation	24	11	10
Safety	20	12	7
Presentation skills	18	13	8
Quality/importance of standards	16	14	9
AR/VR	6	15	2
Train the trainer	5	16	2

The explanations for items in the workforce development theme were provided for the first four items. For technical and trade programs, it was indicated that there is a massive lack of skilled trades workers such as welders, boiler makers, pipe fitters, and machinists. There is a lack of internships, especially for DED. For the culture and mindset item, needs were described to change the reputation of industry to good rather than taboo, to attract the next generation to this industry, and to build effective teams. The modern technical training item described the need to have available advanced technology at trade schools to ensure that the workforce is prepared for the realities of the rapidly advancing manufacturing world. The curriculum and multimedia item noted the need for a curriculum focused on industry needs.

The voting on importance at the meeting in Miami indicated strong support for the two top items on fabrication: standards development and expansion of large fabrication processes. The top two items for materials were not far ahead of several other items. They were sustainability and recycling of alloys, as well as improving materials property databases. The top three items of workforce development: technical and trade education programs, culture and mindset, and tailored facilities with advanced technology and modern technical training also saw stronger support than other items.

Appendix G

RAPLSS National Conference:

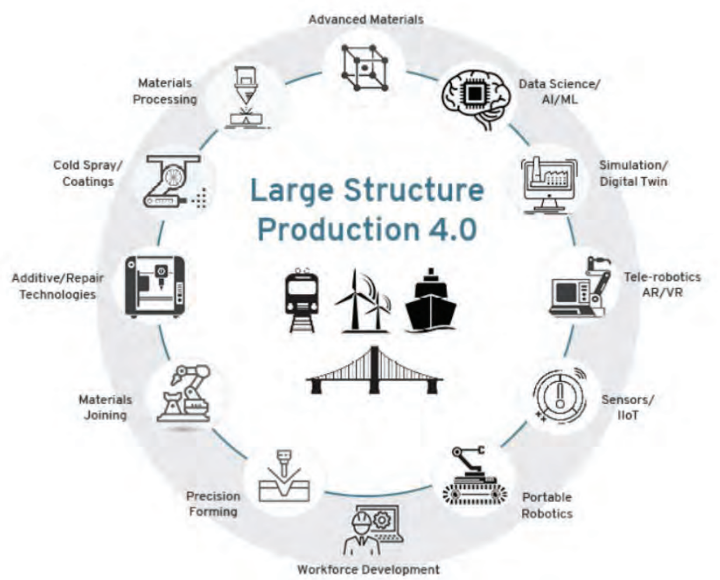
Conference Agenda
NIST Keynote
Offshore Wind
Nuclear Roadmap Priorities
Workforce Development Priorities
Challenges in Development, Adoption, and Scale-up of Robotics in Manufacturing
Cobots for Fabrication of Large Structures
Steel Casting Roadmap Priorities
Forgings Priorities
RAPLSS National Conference Slides

Conference Agenda

Roadmap for Accelerating Production of Large Structures and Systems (RAPLSS) Conference

March 19 – 20, 2024
EWI – Columbus, OH

EWI and OSU invite you to attend our "Roadmap for Accelerating Production of Large Structures and Systems (RAPLLS)" conference. The conference will discuss advanced manufacturing and fabrication technology roadmaps that are critical to American competitiveness for advanced energy, transportation, and supply chain infrastructure. Industry leaders will present key segment roadmaps and discuss priorities for technology and workforce development. The project was funded by NIST's Advanced Manufacturing Technology Roadmap (MfgTech) Grant Program (70NANB22H045).



Large structure and system industries are critical for American competitiveness. Industry, academic and government collaboration is critical to affordably develop this infrastructure, next generation industry capabilities, and large structure production 4.0 technologies. At this conference, industry experts for offshore wind, next gen nuclear, petro-chemical, shipbuilding, rail, mining, and defense, etc. will provide their perspective on research priorities, technology gaps and workforce needs. The conference will conclude with an integrated roadmap presentation on accelerated production of large structures and systems that was synthesized through a series of workshops, interviews and surveys. The conference will also provide opportunities to discuss collaboration strategies, network with industry experts and tour unique relevant research capabilities at EWI and OSU.

AGENDA

Day 1 - Tuesday, March 19th (Eastern Standard Time)

12:00-1:00 – Arrive / Check-In / Networking Lunch
1:00 – 1:15 – Introduction to NIST RAPLSS Conference
1:15 – 1:45 – **NIST keynote – NIST – Dr. Kelley Rogers**
1:45 – 2:15 – EWI NIST RAPLSS Program Overview
2:15 – 3:55 – **Advanced Energy**
- 2:15 – 2:40 - **Wind Roadmap Priorities – Doug Fairchild, Welding, Metallurgy, and Steel Consultancy, LLC**
- 2:40 – 3:05 – **Nuclear Roadmap Priorities – Dave Gandy, EPRI (Virtual)**
- 3:05 – 3:30 – BREAK
- 3:30 – 3:55 – **Carbon Capture and the Hydrogen Economy - Josh James, EWI**

3:55 – 4:20 – **Workforce Development Roadmap Priorities – Gardner Carrick, Manufacturing Institute (Virtual)**
4:20 – 4:30 - BREAK
4:30 – 5:15 – **Day 1 Subject Matter Expert Panel – Rogers, Fairchild, Gandy, Carrick**
5:15 – 7:00 – EWI Tours + Reception

Day 2 – Wednesday, March 20th (Eastern Standard Time)

8:00 – 8:30 – Arrive / Check-In
8:30 – 8:35 – Agenda Review
8:35 – 10:15 – **Large Structure Mfg. & Fab Supply Chains**
- 8:35 – 9:00 – **Challenges in the Development, Adoption, and Scale-up of Robotics in Manufacturing – Chuck Brandt, ARM Institute**
- 9:00 – 9:25 – **Cobots for Fabrication of Large Structures – Doug Rhoda / Drew Akey, Vectis Automation**
- 9:25 – 9:50 – **Castings Roadmap Priorities – Ray Monroe, SFSA**
- 9:50 – 10:15 – **Forgings Roadmap Priorities - Jim Warren / Dekland Barnum, FIA**

10:15 – 10:25 – BREAK
10:50 – 11:30 – **Day 2 Subject Matter Experts Panel – Brandt, Rhoda/Akey, Monroe, Warren/Dekland**
11:30 – 11:45 – BREAK
11:45 - 1:00 – **EWI Roadmap Results** (working lunch)
1:00 – Dismiss

Conference Agenda
NIST Keynote

Convening Ecosystems to Accelerate Innovations in U.S. Advanced Manufacturing

RAPLSS Launch Event

Roadmap for Accelerating Production of Large Structures and Systems

Edison Welding Institute, Inc.
March 19, 2024

NIST | OFFICE OF ADVANCED MANUFACTURING

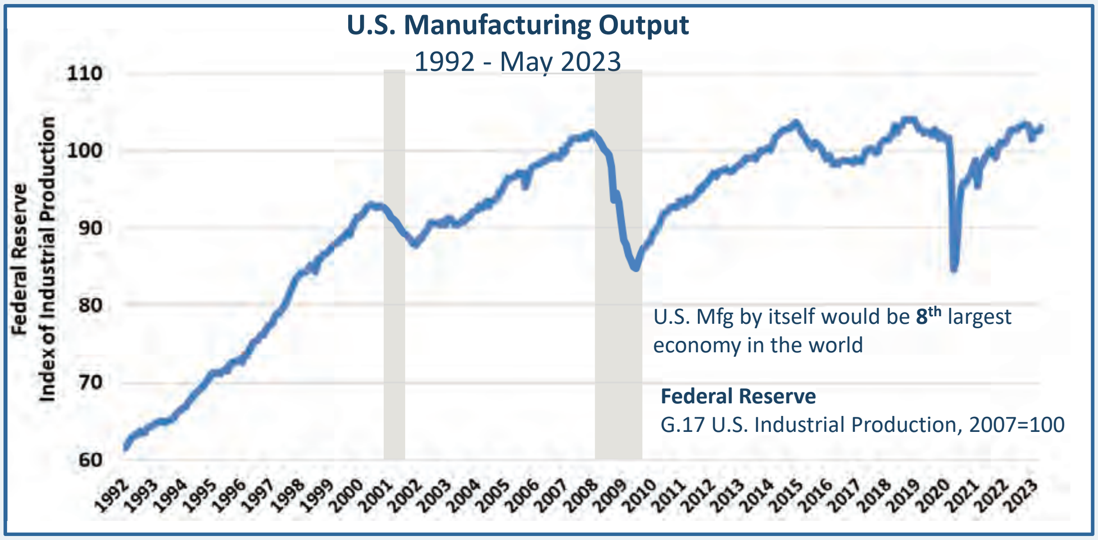
Kelley Rogers, Chief - Program Operations

Agenda

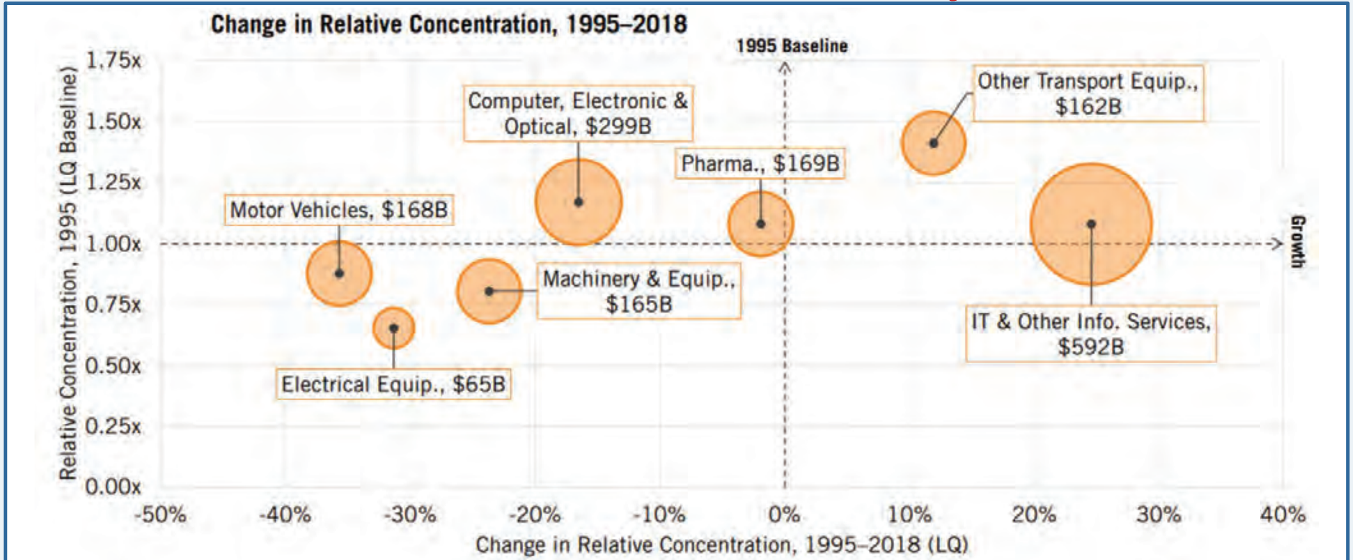
- Manufacturing in America
- NIST: Industry's National Lab
- Advanced Manufacturing Technology Roadmaps
- Manufacturing USA

MANUFACTURING IN AMERICA

Manufacturing Output is Growing but…



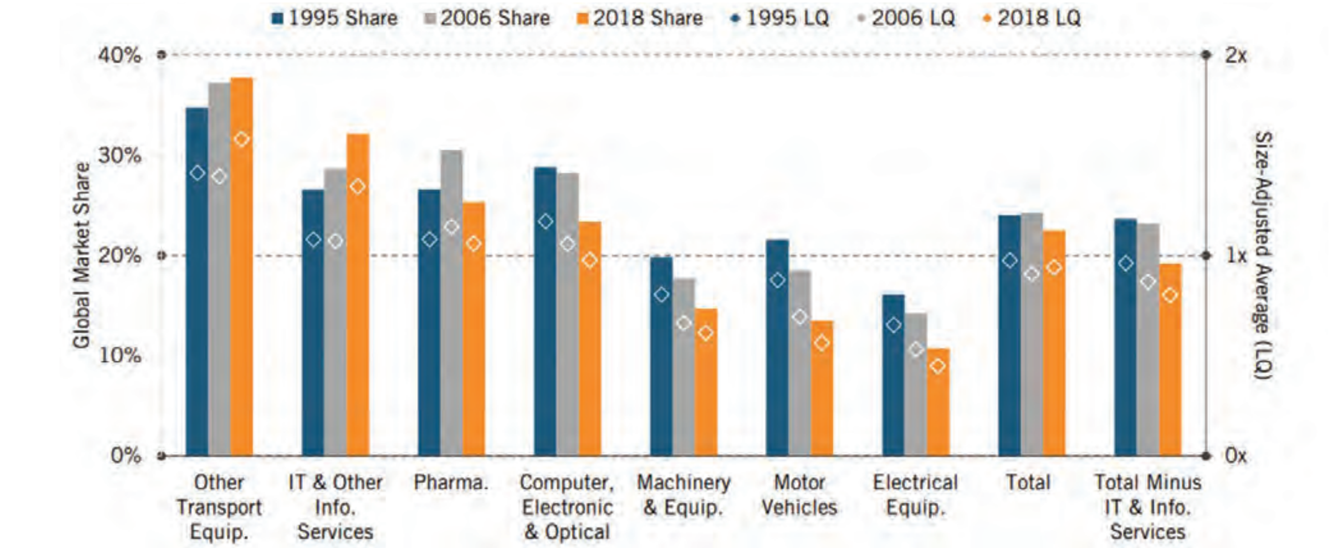
Advanced Technology Sectors are Not Growing As Fast as Other Parts of the Economy…



Source: Information Technology and Innovation Foundation, The Hamilton Index: Assessing National Performance in the Competition for Advanced Industries

ManufacturingUSA

U.S. Global Shares Have Fallen in Advanced Industries



Source: Information Technology and Innovation Foundation, The Hamilton Index: Assessing National Performance in the Competition for Advanced Industries

….which is important because..

Advanced Manufacturing Creates

ECONOMIC COMPETITIVENESS

INNOVATIVE PRODUCTS IN THE MARKETPLACE

NATIONAL SECURITY

AGILE, COST-EFFECTIVE MANUFACTURING PROCESSES

ENERGY SECURITY

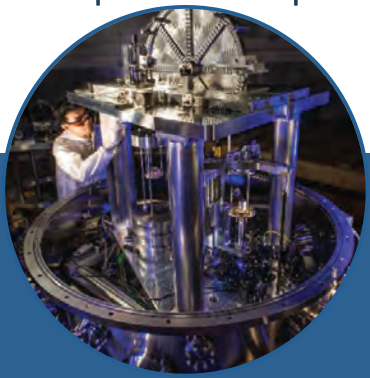
HIGH-WAGE JOBS FOR AMERICANS

ManufacturingUSA

NIST - INDUSTRY'S NATIONAL LAB

NIST Mission

To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life



World-Leading Scientific and Engineering Research

Advanced Manufacturing National Programs

Technology Transfer and U.S. Innovation

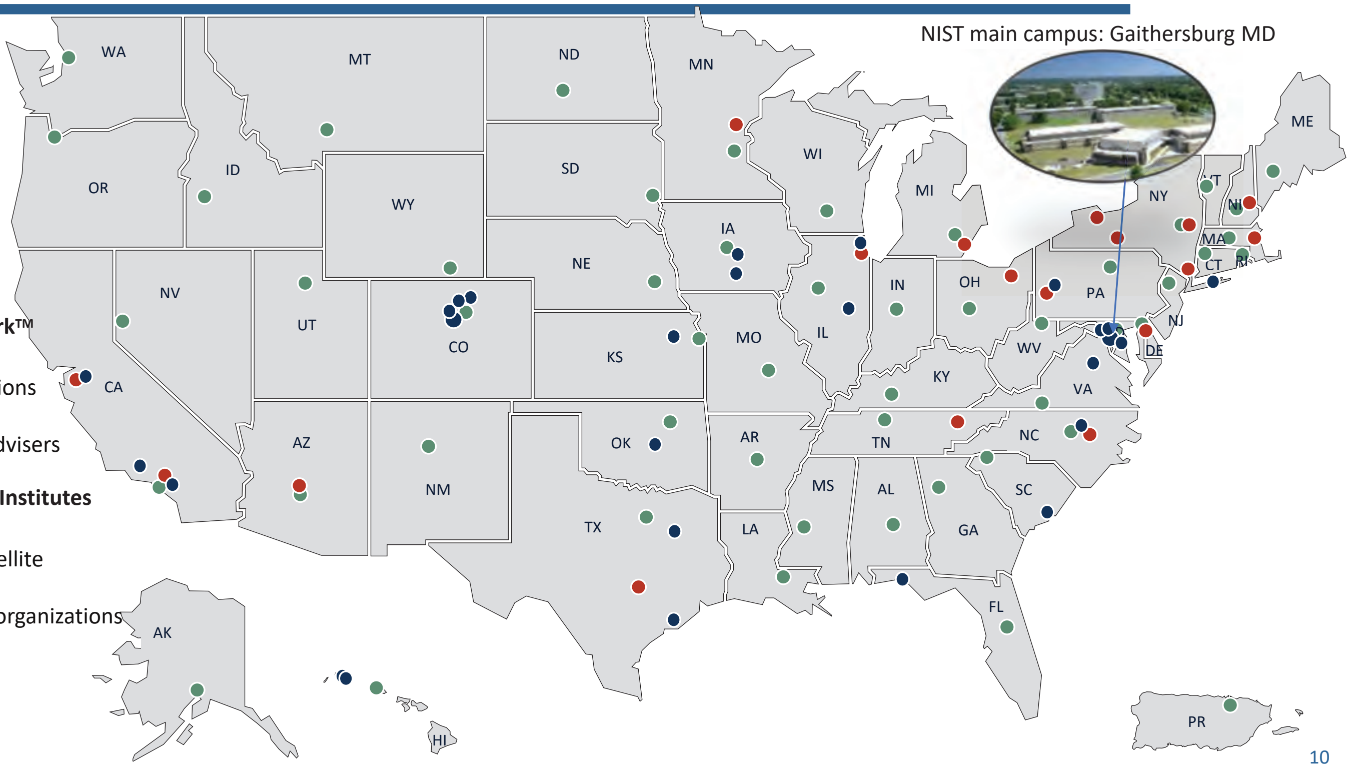
Credit: L to R: Robert Rathe, NIST/K.Dill, Shutterstock/SergeyKohl

NIST, MEP, and Manufacturing USA Presence

NIST
2 NIST campuses
- 8 joint institutes and centers
- 3 NIST centers of excellence
- 2 atomic clock signal stations

MEP National Network™
51 MEP Centers
- 430 service locations
- 2,200+ partners
- 1,450+ trusted advisers

Manufacturing USA® Institutes
17 Institutes
- 18 additional satellite locations
- 2,500+ member organizations



Priorities

To **promote U.S. innovation and industrial competitiveness** by advancing **measurement science, standards, and technology** in ways that enhance economic security and improve our quality of life

Critical & Emerging Technologies Leadership

Standards Leadership

Manufacturing Leadership

Mission Delivery Enhancement

NIST Community Building

Manufacturing Leadership

NIST is industry's one-stop shop for practical tools, services and measurement expertise to accelerate competitiveness and impact.

- Research programs and standards
- Manufacturing Extension Partnership extramural program
- Manufacturing USA extramural program

NIST: Resilience and Infrastructure

NIST supports the safety, interoperability, and resilience of the Nation's core infrastructure, including power, transportation, water, and telecommunications

- Develop new measurement techniques and disseminate reference materials and performance data
- Aid in deploying new technologies in the infrastructure sector
- Promote interoperability in infrastructure systems
- Assess impact of hazards on buildings and communities
- Provide technical basis for improved standards, codes, and practices used in infrastructure systems

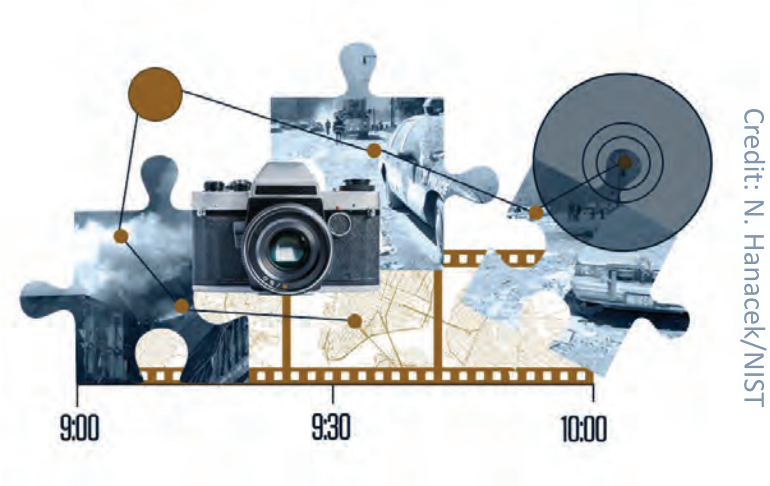
NIST Programs and Activities for Infrastructure

- NIST Framework and Roadmap for Smart Grid Interoperability Standards
- Additive Manufacturing with cement-based materials
- Standards development for interoperable public safety broadband network
- Standards and Measurements for smart grid and microgrid power conditioning systems
- National earthquake hazards reduction program office
- Engineered materials for resilient infrastructure
- Data and computational tools for advanced materials design
- Standard reference materials and data for assessing water infrastructure

NIST Infrastructure Research

Credit: NIST

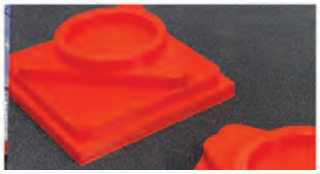
2011- Joplin Missouri Tornado



Credit: N. Hanacek/NIST

2001 – World Trade Center investigation




ROADMAPS TO ACCELERATE INNOVATION ECOSYSTEMS IN U.S.










Why Technology Roadmaps?

NIST

"If you don't know where you're going, you'll end up someplace else."
- Yogi Berra

Technology Roadmaps strengthen long-term U.S. leadership in advanced manufacturing technologies by pinpointing strategic areas of interest and guiding the direction to sustainable economic growth and job creation.

These roadmaps are used for:

- Identifying **technological barriers and related development steps** needed to innovate and manufacture new products, tools, and services
- Facilitating partnerships to align industry, academia, government, and other interested entities where **competitors can become collaborators**
- Catalyzing the development of **industry-driven**, **shared-vision** strategies towards addressing critical, high-priority R&D challenges

Roadmap Process

Planning and Preparation

Identify steering committee and develop a plan of action

Roadmap scoping

Industry surveys and identify high priority industry needs and barriers

Drafting and convene stakeholders

Convene stakeholders across government, non-profit, academia, and industry to develop content for roadmap

Feedback and Review

Develop preliminary roadmap and gather feedback (iterative cycle)

Develop and disseminate final roadmap

Synthesize information, develop short and long-term milestones; disseminate results

NIST Adv Mfg Technology (AMTech) Roadmaps

- **$21M** in federal funding
- **41** organizations
- **49** technology roadmaps

2023-24 NIST MFGTech Roadmaps

NIST

- Strengthen long-term U.S. leadership in advanced manufacturing technologies by accelerating innovative R&D.
- Identify industry-wide barriers that inhibit growth of advanced manufacturing for a specific technology area.

$4.2M funded multi-partner organizations in the development of **14 roadmaps** over an 18-month performance period

Diverse input from **300+ partners**, including large and small private sector participants, academia, and national labs, contributed to roadmap formation

4 topical areas represent foundational building blocks needed to address national priorities in manufacturing:

2023-24 NIST MFGTech Roadmaps

MICROELECTRONICS
5G/6G mmWave Materials and Electrical Test Technology

Artificial Intelligence for High Mix Production

Heterogeneous Integration and Electronics Packaging

Microelectronic and Advanced Packaging

SUPPLY CHAIN RESILIENCE
Freeze-Thaw and Aseptic Drying for Pharma/Biotech Manufacturing

Strengthen the U.S. Manufacturing Supply Chain via the Digital Thread

FUTURE INDUSTRIES
Advanced Space Manufacturing

Quantum Technology Manufacturing

Convergent-Manufacturing of Agriculture and Food Equity

Electric Machines and Systems for Clean Emissions

REVITALIZING TRADITIONAL INDUSTRIES
Digitalization of Construction Industry

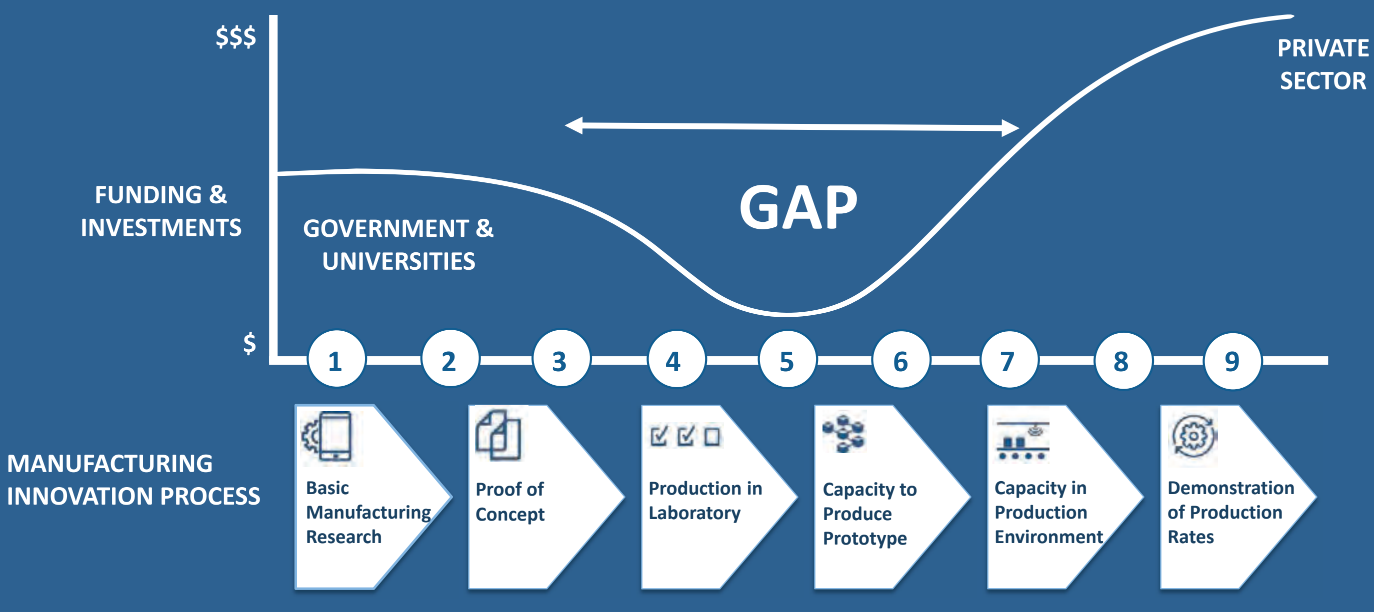
AI-Enhanced Multimodal Sensing of Materials and Process

Iron and Steel Sustainable Industrial Supply Chain

Production of Large Structures and Systems ←


MANUFACTURING USA

Manufacturing USA Purpose



About Manufacturing USA

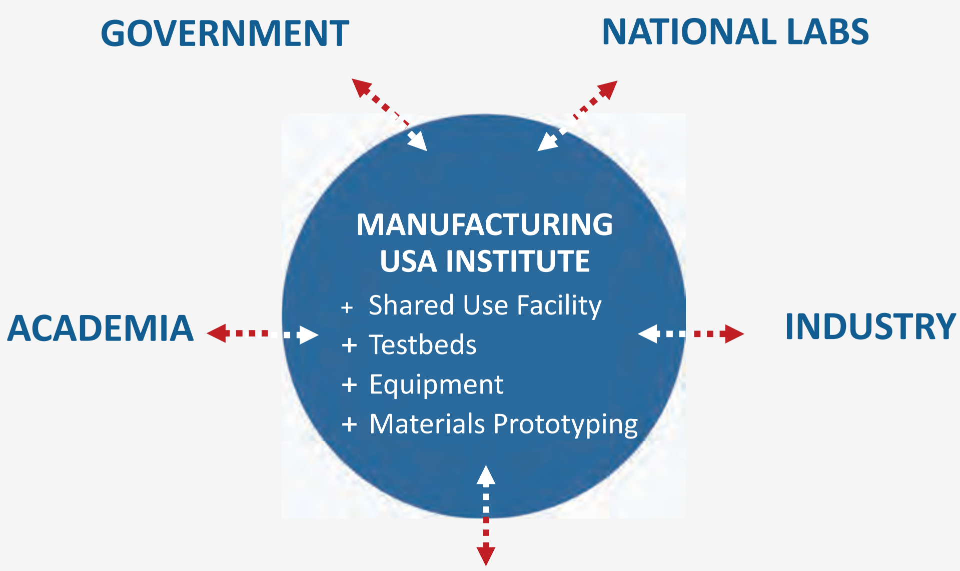
VISION: Securing U.S. Global Leadership in Advanced Manufacturing

MISSION: Connecting people, ideas, and technology to:

- solve industry-relevant advanced manufacturing challenges
- enhance industrial competitiveness and economic growth
- strengthen our national security

ManufacturingUSA

Institutes Enable Large-Scale Collaboration



ManufacturingUSA

Common Institute Functions:

+ Industry-led consortia
+ Neutral collaboration space
+ Technology development
+ Workforce development
+ Public-private partnership

ManufacturingUSA

Manufacturing USA Network Today

ELECTRONICS	Integrated Photonics *Albany, NY* *Rochester, NY*	Flexible Hybrid Electronics *San Jose, CA*	Wide Bandgap Semiconductors *Raleigh, NC*	
MATERIALS	Advanced Fibers and Textiles *Cambridge, MA*	Advanced Composites *Knoxville, TN* *Detroit, MI*	Lightweight Materials *Detroit, MI*	
ENERGY/ ENVIRONMENT	Modular Chemical Process Intensification *New York, NY*	Sustainable Manufacturing *Rochester, NY*	Smart Manufacturing *Los Angeles, CA*	Industrial Process Decarbonization *Phoenix, AZ*
DIGITAL/ AUTOMATION	Additive Manufacturing *Youngstown, OH* *El Paso, TX*	Advanced Robotics & AI *Pittsburgh, PA*	Digital Manufacturing & Cybersecurity *Chicago, IL*	Cybersecurity in Manufacturing *San Antonio, TX*
BIO-MANUFACTURING	Regenerative Manufacturing *Manchester, NH*	Biopharmaceutical Manufacturing *Newark, DE*	Bioindustrial Manufacturing *St. Paul, MN*	

New 2024 Commerce-Sponsored Manufacturing USA Institutes

Semiconductor Institute

- **Digital Twins**, aligned with overall CHIPS R&D Strategy
- Expanded institute model, integrated with National Semiconductor Technology Center
- **Minimum $200M** federal investment + co-investment

New Commerce Institute

- **Artificial Intelligence for Resilient Manufacturing**
- **$70M** federal investment over 5 years
- Requires equal non-federal co-investment

CHIPS Institute Competition — NOI Feb 1

AI Institute Competition — NOI Mar 13

ManufacturingUSA

Our Network @ Work

2022 Impacts

Work with Member
2,500+
organizations

Collaborate on
670+
major applied research and development projects

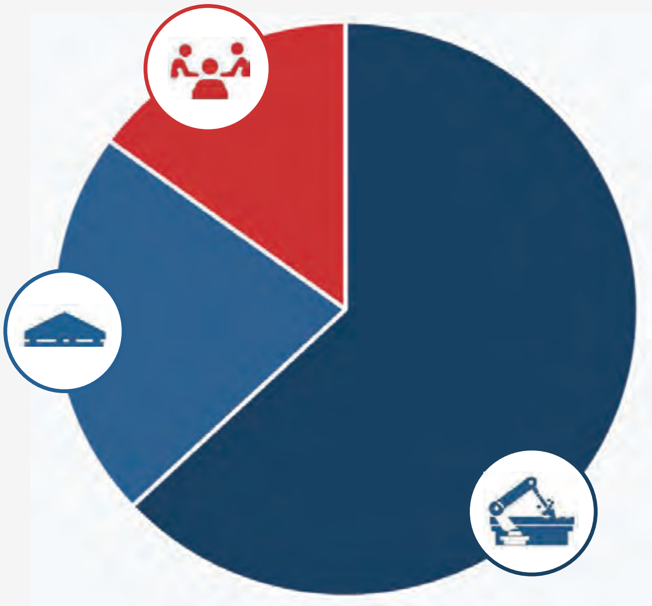
Engage
106,000+
people with workforce knowledge and skills in advanced manufacturing

Invest
$416M
in these activities from state, industry, and federal funds

Our efforts help ensure **what's invented here is made here by a skilled American workforce.**

ManufacturingUSA

Manufacturing USA Network: 2500+ Member Organizations



63% Manufacturing Firms

73% are small and medium-sized

22% Community Colleges, Major Research Universities

15% State and Local Economic Development Entities

Advancing Technology
ADVANCING TECHNOLOGY & INNOVATION
Building Resiliency into Critical National Supply Chains
Developing Technologies to De-Carbonize Manufacturing
Developing Technologies that Save Lives
Protecting and Securing the Nation's Manufacturing Enterprise
ManufacturingUSA
30

MFG USA Education & Workforce Development

EDUCATION & WORKFORCE DEVELOPMENT

Developing Programs that Promote
Diversity, Equity, Inclusion

Creating **Clean Economy Jobs**

Training the Next Generation Workforce for
Innovative, Smart, and Sustainable Manufacturing Jobs

ManufacturingUSA

Revitalizing Manufacturing and Communities

America Makes

biofabusa
Brought to you by ARMI

NIIMBL

ManufacturingUSA

Photos courtesy of the Library of Congress, University of Delaware, America Makes and BioFabUSA

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NIST MEP:	www.nist.gov/mep
CHIPS Act:	www.chips.gov

NIST National Institute of Standards and Technology U.S. Department of Commerce

Manufacturing USA

MEP · MANUFACTURING EXTENSION PARTNERSHIP

Offshore Wind

Offshore Wind

A new $100B⁺ industry in the U.S. that is entirely dependent on large structures

Doug Fairchild, PhD

March 19, 2024

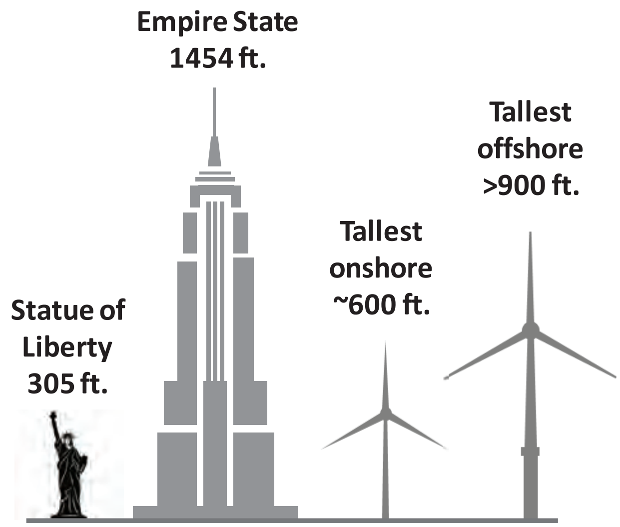
Welding, Metallurgy, and Steel Consultancy, LLC

40 Years in Oil & Gas Industry with ExxonMobil

Welding, Metallurgy, and Steel Consultancy, LLC

Offshore Wind

- Onshore wind: US ranks #2 in world with ~72,000 turbines
- Offshore wind turbine count:
  - Europe: > 5000
  - Asia: > 5000
  - United States: 2023 = **7**, March 2024 = **24**
- The US hit a tipping point for offshore wind in 2021
  - US announces 30 GW by 2030 (aka: 30-by-30)
  - 30 GW = ~2100 turbines (mostly on upper East Coast)
  - Estimated **$108 B CAPEX and 80,000 jobs by 2030**
- CAPEX is the vast majority of OW farm costs
  - Heavy fabrication (i.e., steel & welding) is ~32% of CAPEX
- Consider the size magnitude of 2100 turbines

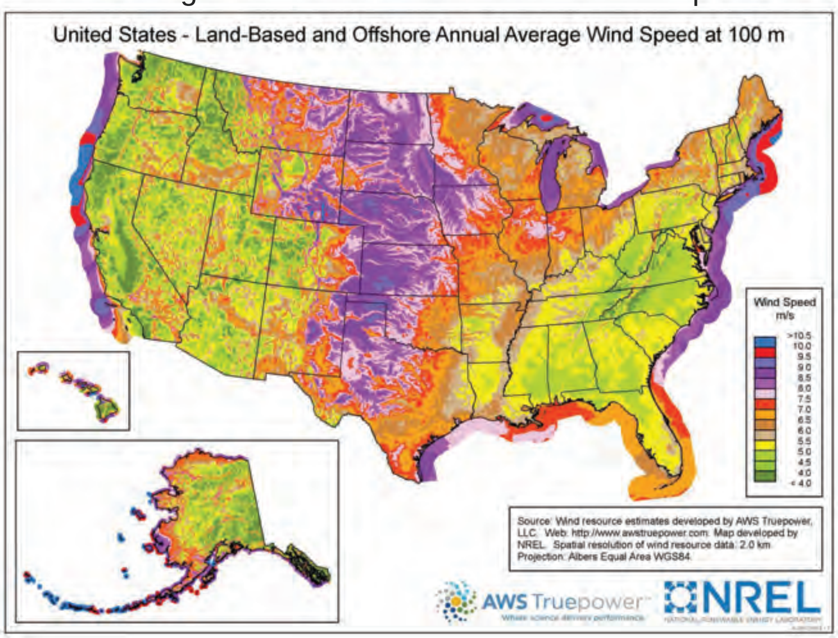


Adapted from:
https://www.nyserda.ny.gov/All-Programs/Programs/Offshore-Wind/About-Offshore-Wind/Offshore-Wind-101

Welding, Metallurgy, and Steel Consultancy, LLC

Substantial Energy from Offshore Wind

Wind strength in the U.S. has been studied and quantified

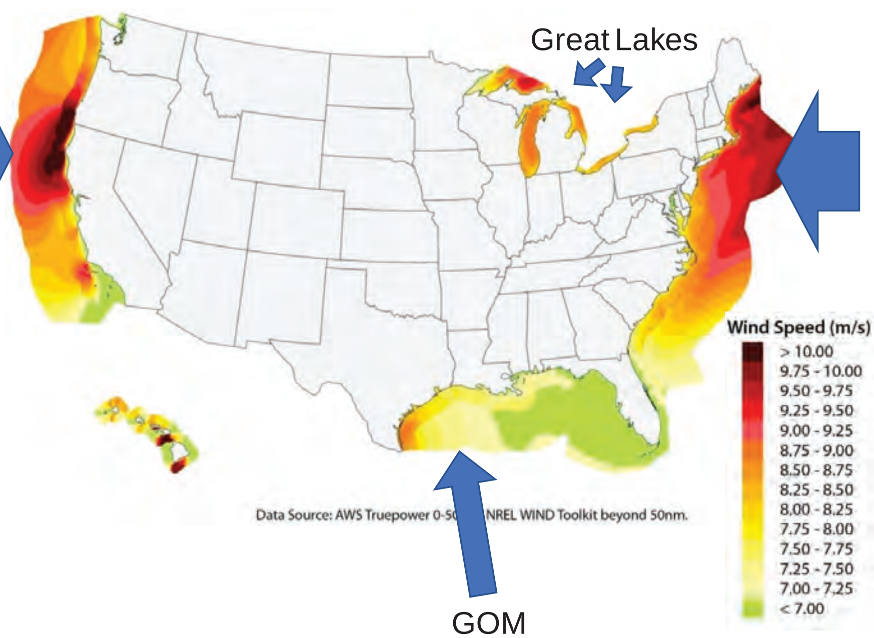


Picture from NREL: https://www.nrel.gov

Substantial Energy from Offshore Wind

Wind strength in the U.S. has been studied and quantified

West Coast winds are in deep water which require floating structures. Will lag East Coast by 5-10 years.



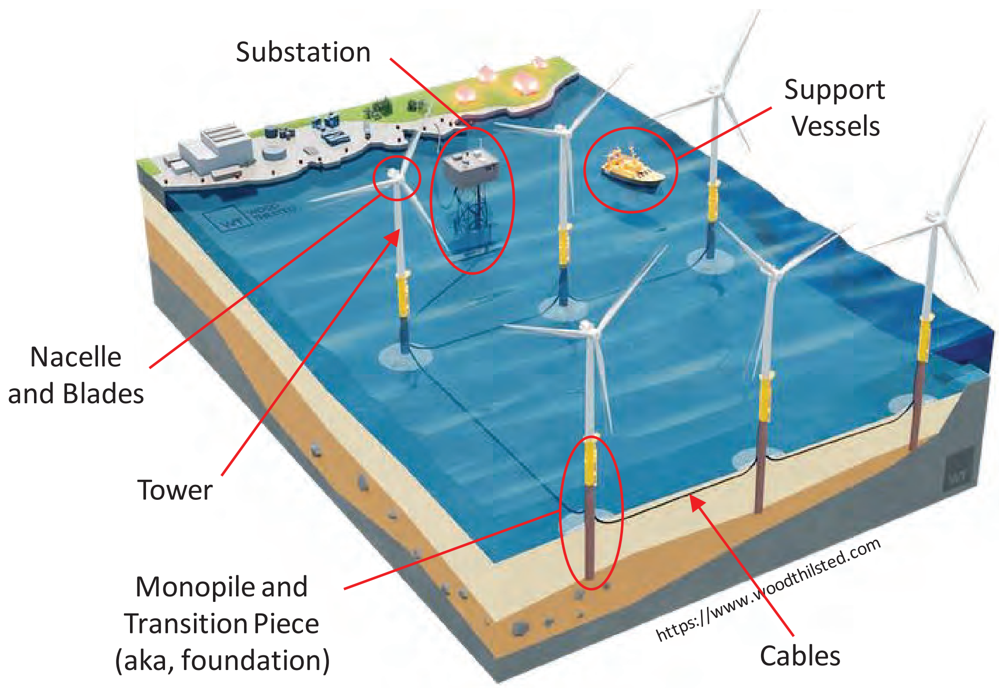
Strong wind, “shallow” water, large population centers. First region in the U.S. to adopt OW.

Components of an Offshore Wind Farm

- Nacelle (turbine & housing)
- Blades
- Tower
- Monopile & Transition Piece
- Cables
- Substation
- Marine Vessels

How many turbines per farm?

- Small: < 50
- Medium: 50 - 75
- Large: 75 – 200



Welding, Metallurgy, and Steel Consultancy, LLC

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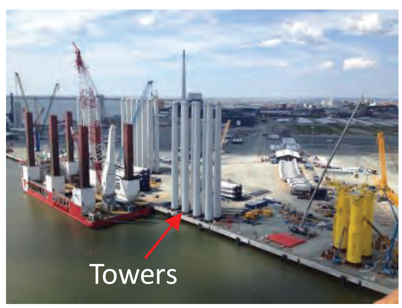

Welding, Metallurgy, and Steel Consultancy, LLC

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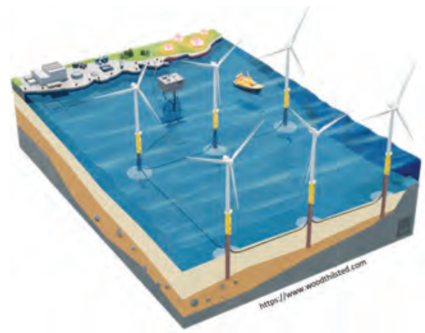


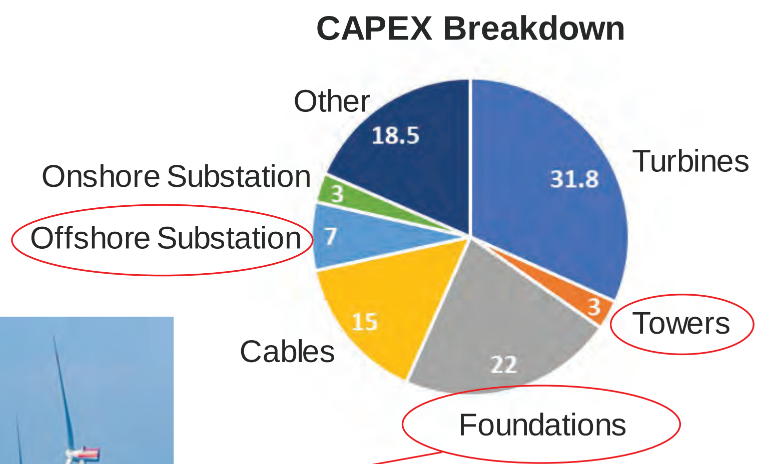
Marine Vessels

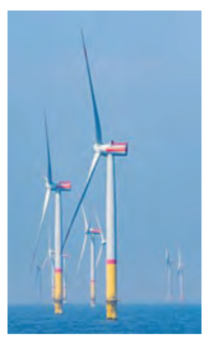
From BOEM: https://www.boem.g

From Van Oord: Used with permission

Offshore Wind Farm Costs; what portion is heavy fabrication?

- CAPEX is the vast majority of OW farm costs
- Heavy fabrication is a major CAPEX contributor
  - Foundations (monopile, jacket, etc)
  - Offshore substation
  - Towers
- Heavy fabrication is primarily:
  - Buying, cutting, forming steel
  - Welding and inspection
- Heavy fabrication: ~32% of CAPEX
- Average OW farm:
  - Heavy fabrication ~ $1 billion





Monopiles dominate the offshore wind industry

Welding, Metallurgy, and Steel Consultancy, LLC

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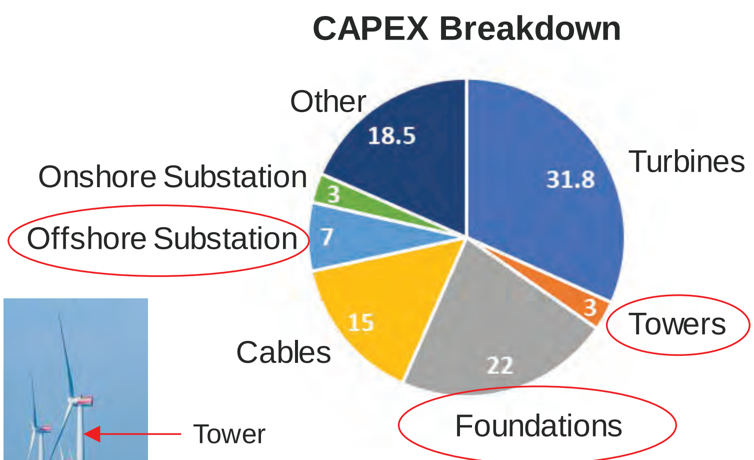
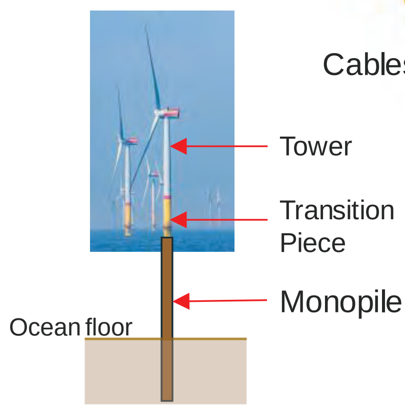




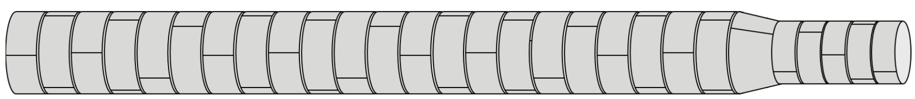
Welding, Metallurgy, and Steel Consultancy, LLC

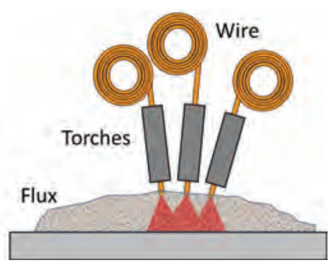
Monopile (MP) Costs: welding is the primary driver

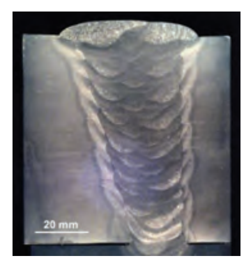
- MPs increasing in size (XXXL)
  - 10+ m diameter, ~100 m long
  - Steel thickness: ~100⁺ mm routine
- Welding is bulk of fabrication effort
- Multi-wire submerged arc welding is #1

- How much submerged arc welding (SAW)?
- 20 - 30 cans per MP
- Longitudinal welds: ~ 300 m
- Circumferential welds: ~ 800 m
- ~ 25 passes per weld
- 25 passes x 1100 m = **27,500 m per MP**
- U.S. 30-by-30 goal is ~2100 turbines
- **~58,000,000 m of SAW by 2030**

EEW SPC/Andreas Duerst, Studio 301







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For OW, the Numbers of Large Structures are Unprecedented

U.S. Targets

- 30 GW by 2030 (2100 turbines)
- 110 GW by 2050 (7700 turbines)
- New fabrication facilities are opening in the Northeast US. Shipyards/ports, too.

- For structures of this size, repetitive fabrication is not the norm, but it will be for OW.
- There is significant opportunity for companies that specialize in fabrication technologies.

EEW American Offshore Structures
$250 M Monopile Facility
Paulsboro, NJ

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Welding, Metallurgy, and Steel Consultancy, LLC

The Main Competitor to the Monopile is the Jacket Design

- Turbines keep growing. So do the MPs.
- Steel thicknesses are routinely ~100 mm and some designs are approaching 150 mm.
- Few steel mills can produce (only one in U.S.)
- Jackets are inherited from Oil & Gas
- Steels are thinner, but welding is more complex
- **Welding innovation could enable jackets for U.S. offshore wind**

Sing Da Marine Structure (Taiwan)

Welding, Metallurgy, and Steel Consultancy, LLC

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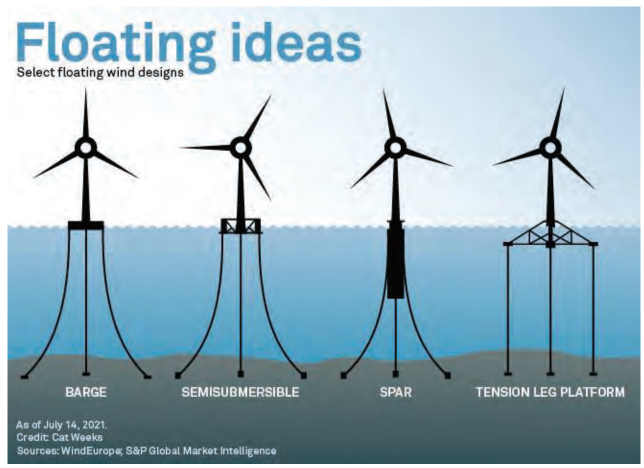
Wikinger Offshore Wind Farm (Germany)


Block Island Wind Farm (Rhode Island)

Welding, Metallurgy, and Steel Consultancy, LLC

Deep Waters Require Floating Structures

- Monopiles are limited to ~60 m water depth
- Deep water locations with strong wind:
  - West Coast (CA, OR, WA)
  - Maine
  - Further offshore East Coast
- Floating foundations are more expensive than monopiles and jackets
  - Requires flexible moorings
  - Requires flexible power cables



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Principle Power's Windfloat Design

The Jones Act and the Shipbuilding Boom in the U.S.

- The Jones Act: 1920s law requiring that marine vessels carrying "goods" in U.S. waters be U.S. built, owned, and crewed
- U.S. shipbuilding is taking place for vessels of all sizes
  - Crew transport vessels (CTVs)
  - Service operation vessels (SOVs)
  - Heavy lift transport vessels (HLTVs)
  - Wind turbine installation vessels (WTIVs)

From BOEM: https://www.boem.gov

From Jumbo: Used with permission

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Welding, Metallurgy, and Steel Consultancy, LLC

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Shipbuilder: St. Johns Ship Building
Location: Florida
6 Crew Transport Vessels
25m (83 ft)
2023/24 launch

Shipbuilder: Philly Shipyard
Location: Pennsylvania
Name: Acadia
Subsea Rock Installation Vessel
141m (461 ft)
Cost: $197M
2024 launch

Welding, Metallurgy, and Steel Consultancy, LLC

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  - Wind turbine installation vessels (WTIVs)

Shipbuilder: Edison Chouest
Location: LA, MS, FL
Name: ECO Edison
Service Operation Vessel
80m (262 ft)
2024 launch

Shipbuilder: Keppel
Location: Texas
Name: Charybdis
Wind Turbine Installation Vessel
144m (462 ft)
$500M
2024 launch

Welding, Metallurgy, and Steel Consultancy, LLC

Is it smooth sailing for offshore wind? Ans: no.

Cost Pressures

- Supply chain
- War in Ukraine
- Inflation
- Interest rates

The Positive Spin

The offshore wind industry is 100% dependent on large structures.

Cost pressures are an opportunity for advanced fabrication technologies.

HEATMAP July 21, 2023

Why Offshore Wind Is Suddenly in Trouble

Is the East Coast's most abundant source of renewable energy too expensive?

THE NEW BEDFORD LIGHT FREE · NONPROFIT · NEWS

Oct. 2022

Major Massachusetts offshore wind project no longer viable

"... global commodity price increases, in part due to ongoing war in Ukraine, sharp and sudden increases in interest rates, prolonged supply chain constraints, and persistent inflation have significantly increased the expected cost of constructing the project. ..."

THE WALL STREET JOURNAL.

Sept. 2021

Cost Inflation Is Blowing Through the Wind Turbine Industry

Covid delays and expensive shipping will likely hurt more than higher prices for steel and other raw materials

BARRON'S July 2023

America's Bet on Wind Power Is Running Into a Big Problem

Higher costs and serious delays are plaguing offshore wind projects. Here's who will pay the price.

Welding, Metallurgy, and Steel Consultancy, LLC

Offshore Wind's Economic & Innovation Conundrum

- The U.S. Offshore Wind industry has begun, however, global economic and geopolitical conditions are difficult
- Offshore Wind economics are challenged
- Technology advances are needed
- Chicken-and-egg situation for innovation
  - Projects and fabricators reluctant to pursue innovation due to uncertainty (i.e., risk)

U.S. offshore wind circa ~~2022~~ ~~2023~~ 2024

Nuclear Roadmap Priorities

EPRI Nuclear Manufacturing Priorities & Roadmap

David W. Gandy
Principal Technical Executive, EPRI Nuclear Materials
davgandy@epri.com

NIST Roadmap for Accelerating Production of Large Structures and Systems
RAPLESS Conference, Columbus Ohio
March 19-20, 2024

Overview

- Many-Many-Many Nuclear New Builds on Horizon!
- Manufacturing for SMRs and ARs?
- How Do We Change the Paradigm?
  - Rebuilding the US Infrastructure, Differently
- Supply Chain Requirements
- EPRI/NEI Roadmap
- Summary

Graphic Source: Georgia Power Vogtle Website

EPRI

Many New Builds on Horizon…

Nuclear Reactors	Operational, Proposed, or Under Construction
~60	Under construction worldwide across 17 countries.
110	Planned (~ 110GWe). Most are in Asia.
~300	Proposed worldwide.
440	Operating units, with combined capacity of 390GWe. Represents 10% of world electrical capacity.

https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx

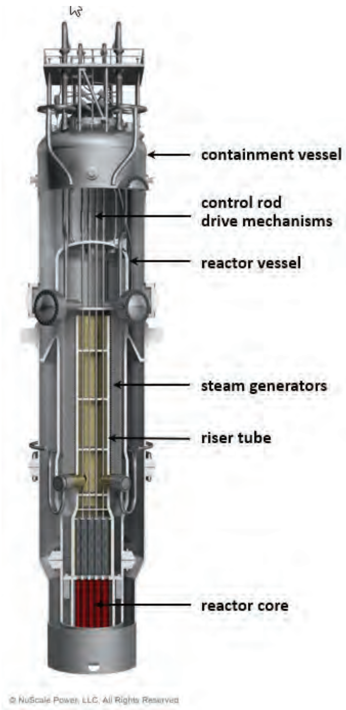
Advanced Reactor Deployment Plans--Grid-Scale Reactors

Developer	Utility / User	Location	Size	Target Online
NuScale	Standard Power	PA and OH, USA	12 @ 77 MWe (2 plants)	2029
	KGHM Polska Miedz	Poland	6 @ 77 MWe	2029
	Nuclearelectrica	Romania	6 @ 77 MWe	2028
GEH BWR X-300	OPG	ON, Canada	4 @ 300 MWe	2028
	TVA	TN, USA	4 @ 300 MWe	2032
	Synthos & Orlen	Poland	300 MWe (>10 plants)	Early 2030s
	SaskPower	Sask., Canada	~300 MWe (4 plants)	2032 to 2042
Holtec SMR-160	TBD	NJ, USA	160 MWe	2030
	TBD	MI, USA	2 x 160 MWe	2032
	Entergy	Gulf Coast, USA	160 MWe	Early 2030s
X-energy	Dow	Texas, USA	4 @ 80MWe	2030
	Energy Northwest	Washington, USA	80 MWe (up to 12)	2030
TerraPower	Pacific Corp.	Wyoming, USA	345 – 500 MWe	2030
ARC	NB Power	NB, Canada	100 MWe	2030
Moltex	NB Power	NB, Canada	300 MWe	2032
TBD	Duke Energy	NC, USA	TBD	2034
TBD	Purdue/Duke Energy	Indiana, USA	TBD	TBD

Updated 12/19/2023

Where Is US Industry Today In Terms of Manufacturing for ARs and SMRs?

- 1st wave of major reactor contracts (X-Energy & NuScale) for Manufacturing and Fabrication have gone overseas.
- US was not cost competitive, and in several instances did not have ASME N-Stamp certification to build large components.
- Since we haven't really built nuclear units (other than Vogtle 3&4) in the past 3 decades, **much of the sourcing for large nuclear components lies overseas.**
  - **Absolutely will require Government Investment to re-shore capabilities.******
- We must re-shore some of this capability if we plan to be competitive in "large scale manufacturing and fabrication."



How Do We Change the Paradigm?

Rebuild the USA Manufacturing Infrastructure, Differently!

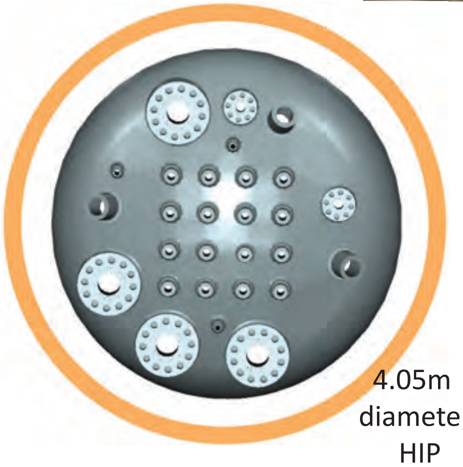
Four Key Technologies:

- ATLAS – A Big Enabler
- Directed Energy Deposition-AM (wire)
- Heavy Forging & Melting Capabilities
- Electron Beam Welding

Courtesy of North American Forge

Rebuild the Infrastructure, Differently…
--Large Hot Isostatic Pressing (HIP) Capabilities

Need/Gap
- The largest HIP vessel in the:
  - USA is 1.6m diameter X 2.5m in length.
  - World is in Japan. It is 2.06m diameter.
- To produce larger components for AES applications (reactor heads, nozzles, pump housings, valve bodies, etc.), a much larger HIP is required.
- Could also be used for post-processing of DED-AM components.



Call To Action
- USA group is working to design/secure at 4.05m HIP (called ATLAS)
- UK group is also looking toward a larger HIP, >4.0m (called Titan)
- Both units would enable industry to produce more complex, NNS components

Rebuild the Infrastructure, Differently… -- Directed Energy Deposition-AM

Need/Gap

- Near-term potential to supplement availability and quality needs for valve bodies/pump housings. EPRI is working with ASME/Industry to accept both wire-arc and electron beam DED-AM manufacturing.
- Research is required to understand acceptance criteria, including how to manufacture for inspectability.
- Also, research is required to address performance in time-independent regime to build industry confidence.

Call to Action

- Once "over the finish line", DED-AM will provide an alternative/supplement to existing forging/casting capabilities.
- The degree of adoption will dictate the overall need for investment by industry.
- The processes will rely on robotics and welding technologies that can be easily, and cost effectively scaled.

1,600-lb 316-L stainless steel valve body printed using DED-AM (Lincoln Electric)

Rebuild the Infrastructure, Differently…
--Heavy Forging & Melting Capabilities

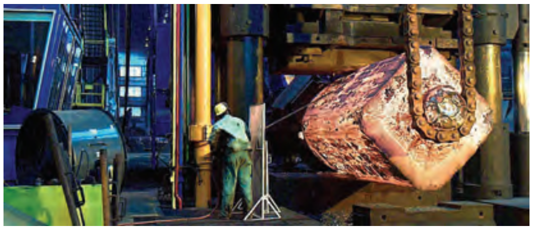


Image supplied by Lehigh Heavy Forge Corp.

Need/Gap

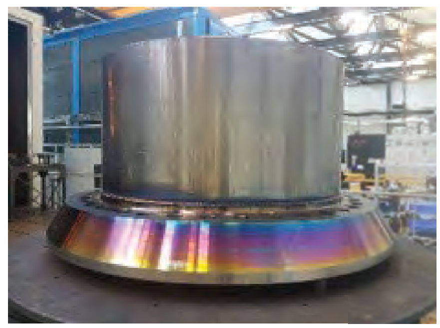
- In US alone, NEI identified ~40 units slated for production by 2032. Worldwide we are looking at >300 units as stated earlier.
- Clearly **there is not sufficient USA manufacturing capacity to support** these numbers by 2030 or 2050.
- Could make most forged products today, but limit on ingot size capabilities (***only up to 50 tons***).
- Almost all large forging has moved to Korea, Japan, India, China.

Call To Action

- Multiple forgers called for need to work directly with AES manufacturers now, not to wait to 2030-35 to place orders.
- 3 key activities to address this gap:
  - Need to improve ingot size—install large capabilities.
  - Demonstrate large forgings (reactor heads, pressurizers, SGs, etc.)
  - Joint qualification of new materials to foster engagement with forging houses in the interim period, before larger-scale deployment

4.9 m diam. X 1.2 m thick at ~91,000 kg forging. Image sup by North American Forgemasters/Scot Forge

Rebuild the Infrastructure, Differently…
--Electron Beam Welding



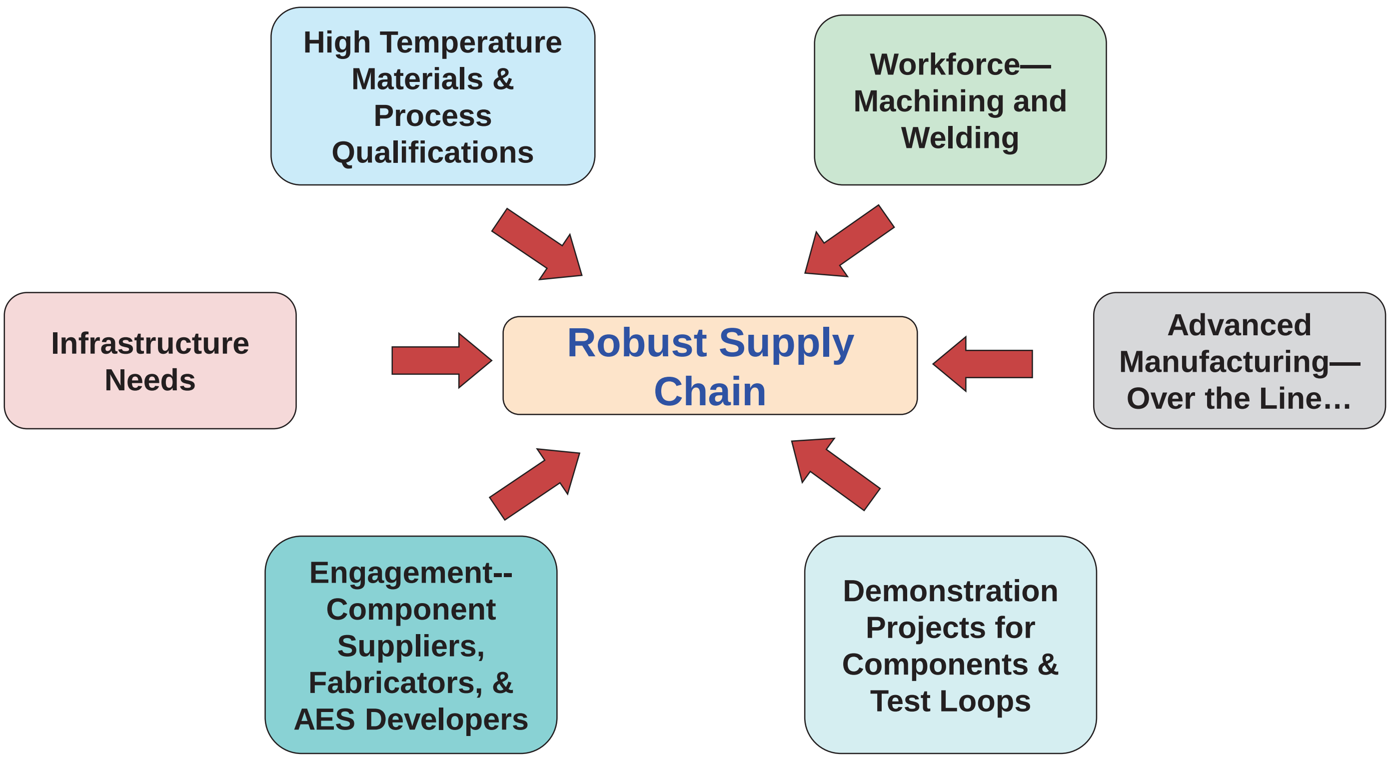
Need/Gap

- Establish large EBW capability in USA. EPRI, BWXT, PTR are currently working to install a large modular in-chamber EBW system in Barberton OH.
- Also, assess local vacuum capability.

Call To Action

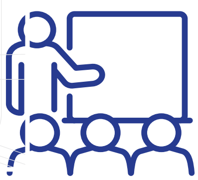
- Work with industry to transfer technology relative to Deployment of EBW. EPRI is currently leading a global initiative on Deployment.

Supply Chain Requirements – Key Themes…



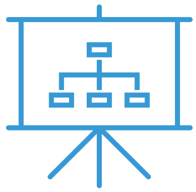
Advanced Reactor Roadmap

A shared strategy to ensure success at scale



Serving government, academic, industrial, and public **stakeholders**

Almost 100 GWe of **new nuclear** will be needed by 2050. This means around **300 ARs** in the next **30 years**



7 Enablers and **46 key actions** chart our path towards a **net-zero future**

Convening the industry for **strategic action**

Industry's roadmap to the future fleet

Purpose and Audiences

01 For potential customers of advanced reactors

02 For policy-makers and regulators

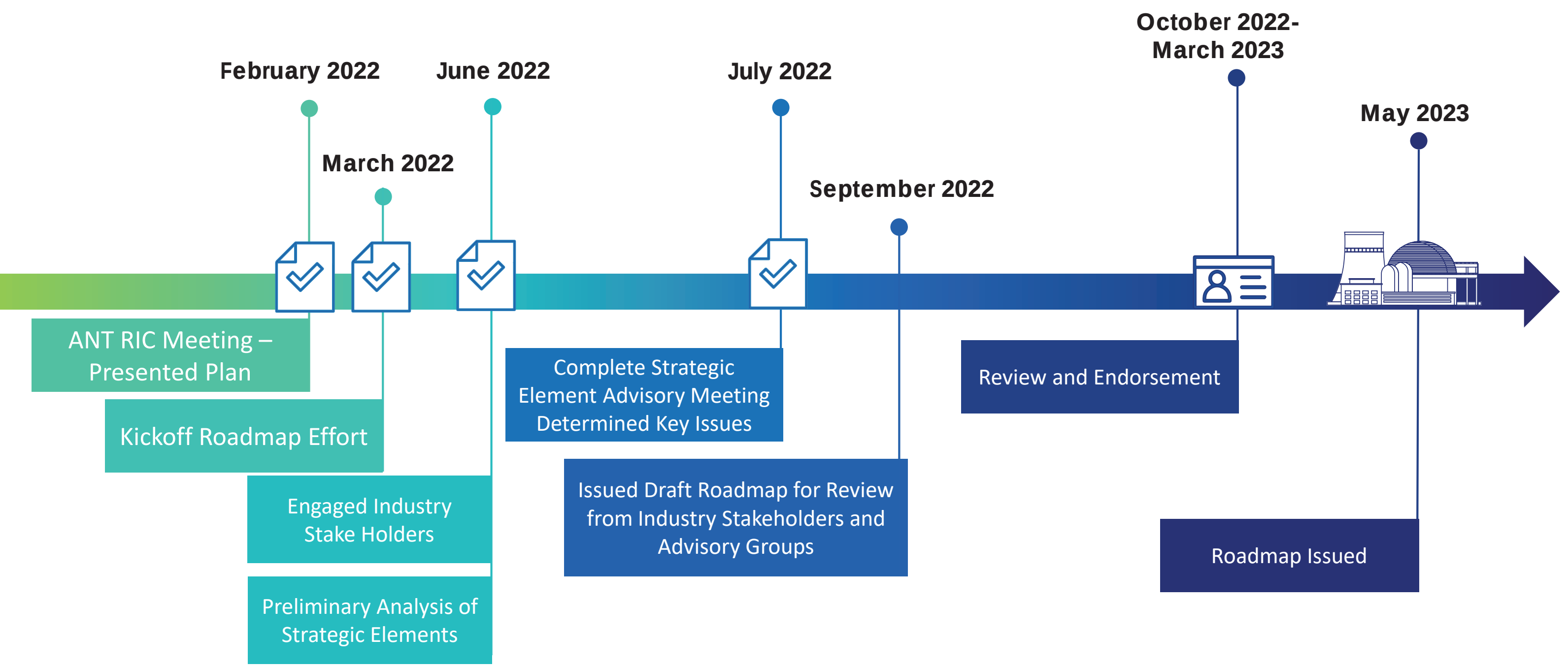
03 For financial institutions

04 For public stakeholders, including local and Indigenous communities

05 For industry stakeholders

Provides an achievable path forward to support the successful commercialization of advanced reactors

Roadmap Development Timeline



Just the Beginning – Roadmap is a Living Document

Enablers

01 First Mover Success

02 Fast Followers

03 Regulatory Efficiency

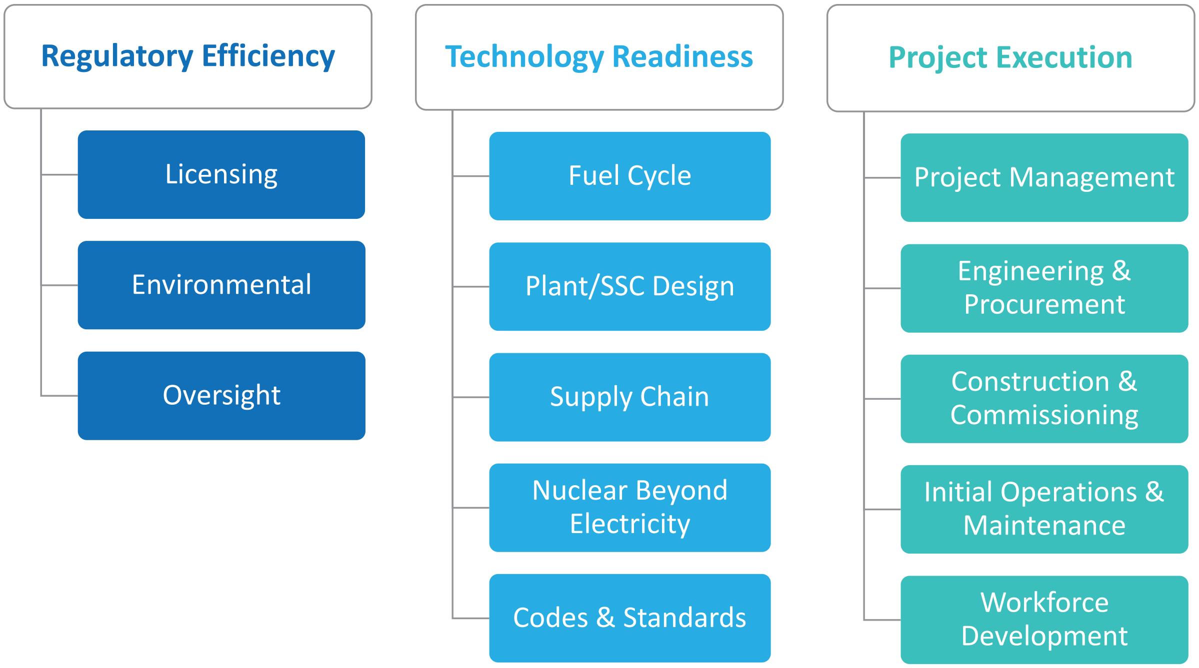
04 Siting Availability

05 Public Engagement

06 Supply Chain Ramp-up

07 Workforce Development

Strategic Elements and Key Issues



Technology Readiness Key Issues

Fuel Cycle	Plant/SSC Design	Supply Chain	Nuclear Beyond Electricity	Codes & Stds
• Qualifying fuel • AR fuel storage • Enrichment	• Material data • Legacy designs • Analytical tools	• Nuclear grade components • Small forging • Advance manufacturing • Module fabrication	• Demonstrations • Business models • Nuclear facility decoupling	• Risk-Informed/ performance-based approach standard • C&S Gaps

Project Execution Key Issues

Project Management	Engineering & Procurement	Construction & Commissioning	Initial Ops & Maintenance	Workforce Development
• PM execution • Contracting Strategies	• Mindset change • Design completion	• Mindset change • New construction technologies • Sharing lessons learned	• Reducing costs similar to other thermal plants	• Attraction • Retention • Training

EPRI

Summary (1/2)

- Enormous amount of nuclear reactor construction planned or proposed worldwide!!! Projected: ~**800GWe by 2050**.
  - Even if half this value >>> *Fantastic opportunity for the US in manufacturing!!!*

Questions:

1. Does the USA want to be a part of the upcoming generation of nuclear units? or
2. Are we simply okay with exporting the advanced AR & SMR technologies for others to Manufacture & Fabricate?

If the answer is #1, we must have government investment in infrastructure to make this happen!

Summary (2/2)

Rebuild the USA Manufacturing Infrastructure, Differently!

- ATLAS – A Big Enabler
- Directed Energy Deposition-AM (wire)
- Heavy Forging & Melting Capabilities
- Electron Beam Welding

EPRI/NEI Advanced Reactor Roadmap – Please join us to facilitate ARs.

EPRI Supply Chain Workshop for Structural Components in Advanced Energy Systems - April 10-11, 2024

Home - EPRI Supply Chain Workshop for Structural Components in Advanced Energy Systems - April 10-11, 2024 (cvent.com)

TOGETHER...SHAPING THE FUTURE OF ENERGY®

www.epri.com

Workforce Development Priorities

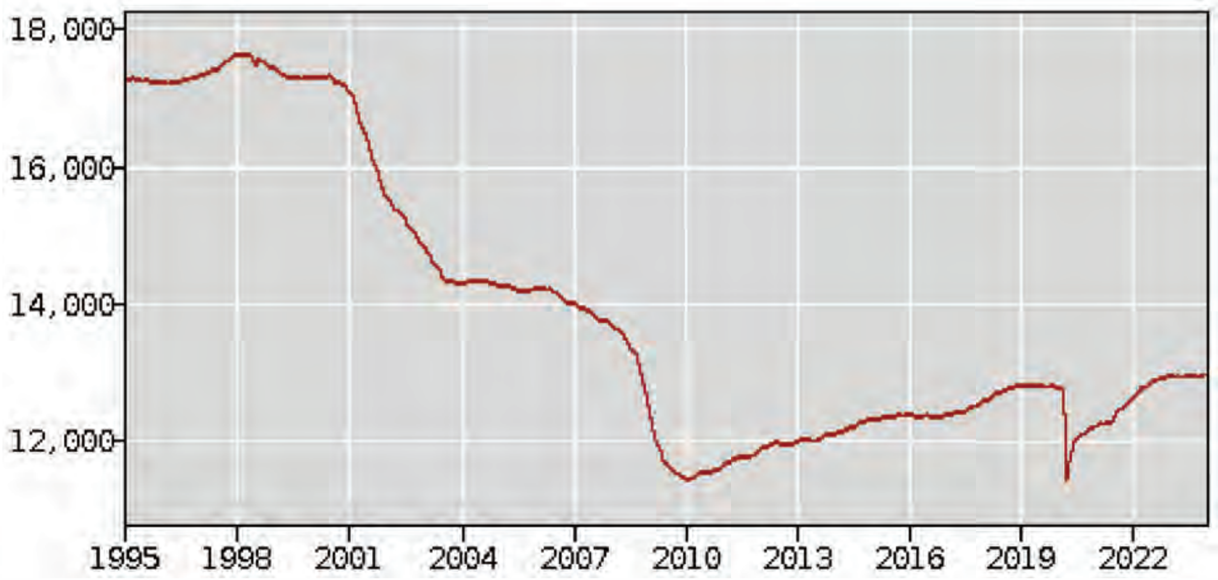
MANUFACTURING
Institute

NIST RAPLSS Conference

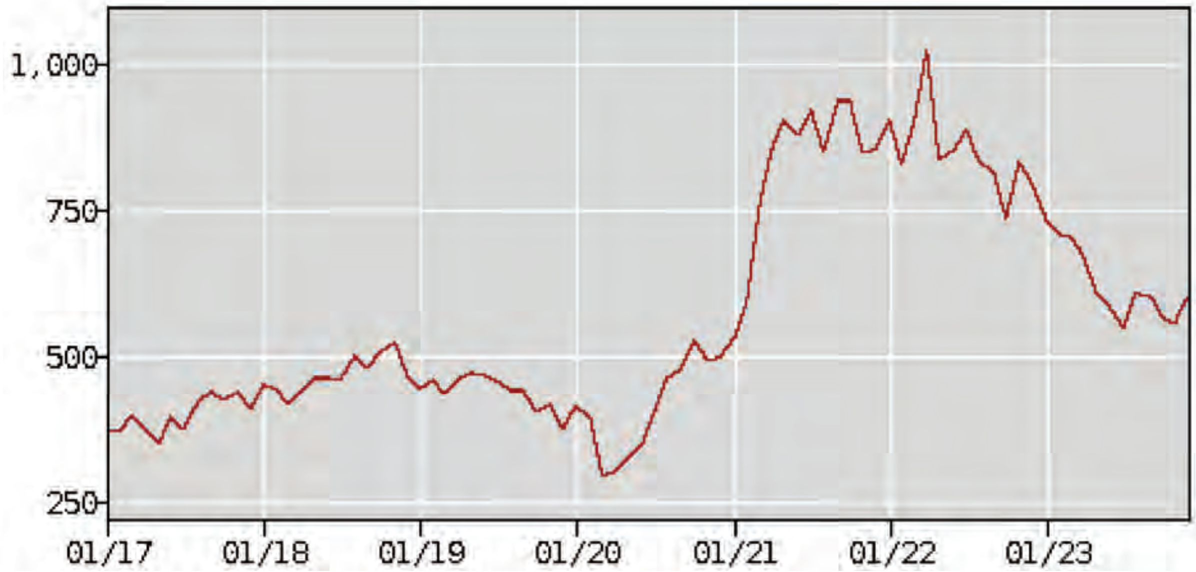
March 19, 2024

MANUFACTURING Institute

U.S. Manufacturing Jobs (000s)

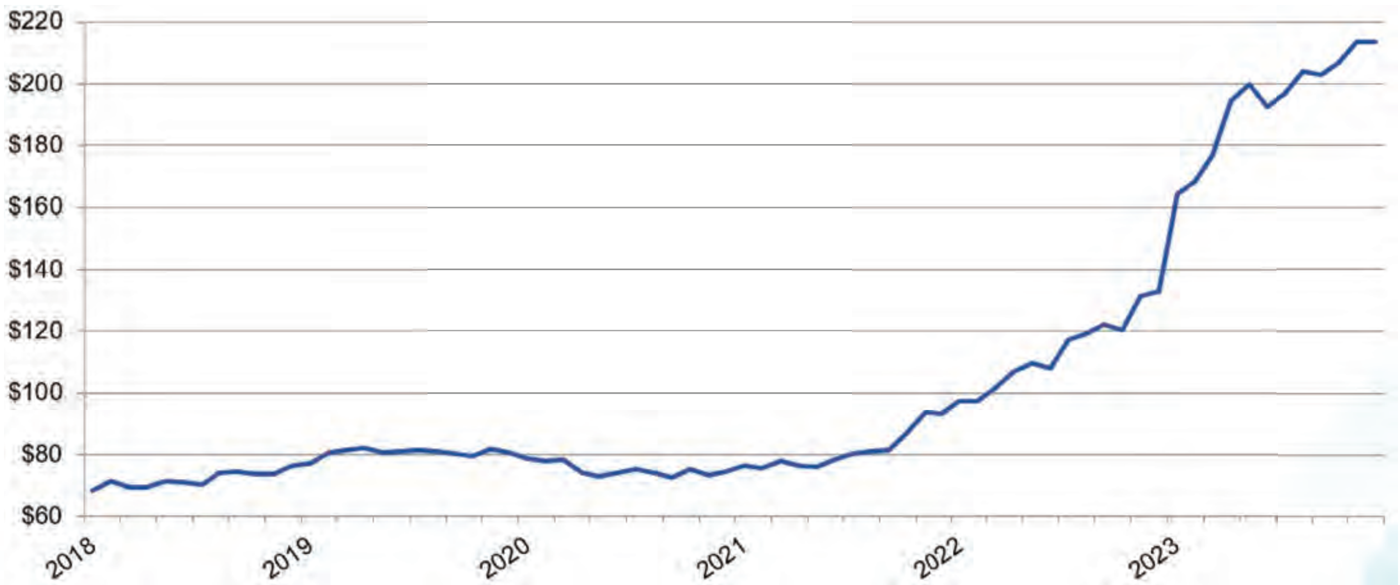


Open Jobs in Manufacturing (000s)



MANUFACTURING Institute

Manufacturing Construction Spending ($B)



MANUFACTURING Institute

NAM Members' Primary Business Challenges (23Q4)

Manufacturing Institute

Workforce Assumptions

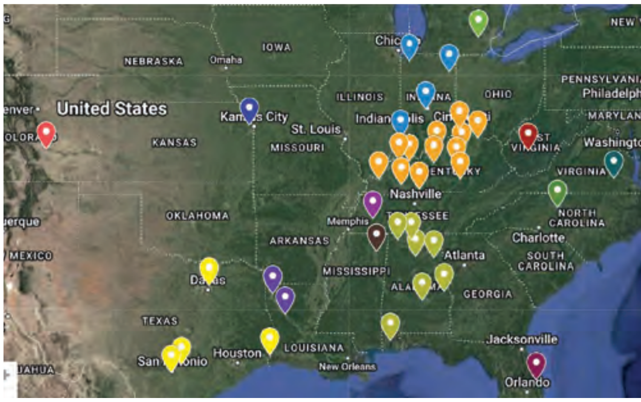
- All solutions are implemented locally
- Three distinct but overlapping challenges
  - Attract – Perception of manufacturing, awareness of jobs & careers
  - Train – Develop necessary skills to qualify for positions
  - Retain – Job satisfaction, career pathways,
- Employers lead but need engaged partners
- Multi-employer solutions are the most resilient, particularly for training

Important Workforce Organizations

- Companies – Single company or supply chain
- Employer Associations – Chambers of Commerce, Economic Development Organizations
- Education – High Schools, Community Colleges
- Recruiting & Support – Community Based Organizations
- Population Specific – Veterans, Minorities, etc.

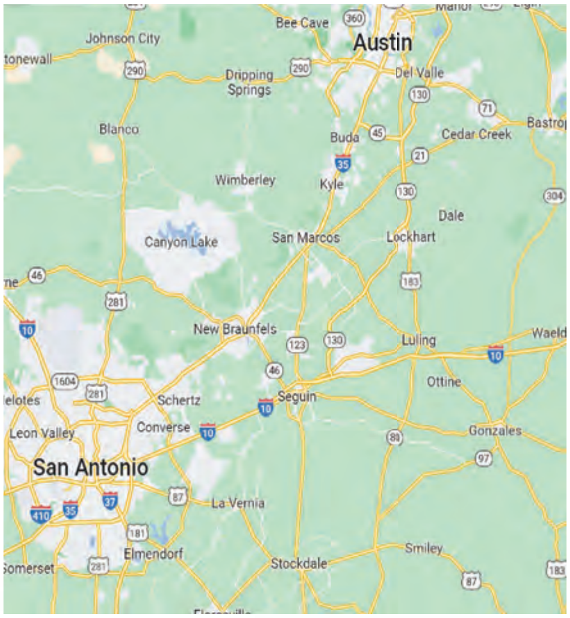
MI Solution In Action - FAME

- Nearly 40 locations training maintenance and process technicians in a 5-semester apprenticeship model
- Embeds comprehensive professional behavior training and lean manufacturing culture into technical education
- Multi-employer approach with 6-20 companies participating per location
- MI manages the FAME network, provides quality assurance for existing chapters, and trains new chapters to run the program



Case Study – Seguin, TX

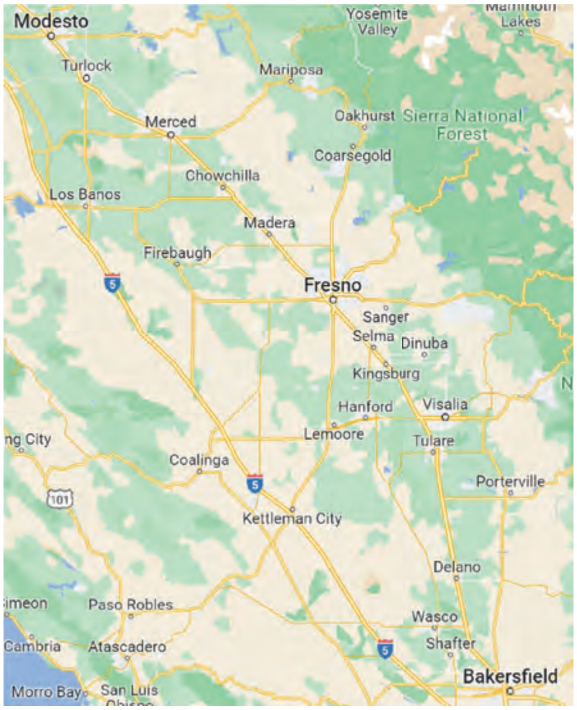
- Single company begins effort to start FAME
- Economic development corporation (EDC) joins and coordinates
- Other companies join and take leadership
- Allies in state capital pass critical legislation
- New training provider enters area
- EDC & companies fund new facility & state government funds new campus



Manufacturing Institute

Case Study – Fresno, CA

- Committed but small group of employers
- EDC and manufacturing association prioritize workforce & win grant
- Building broader employer support
- Changing relationship with local colleges
- Building better recruiting pipeline



MI Solutions Center

- Career Awareness
  - Manufacturing Day, Creators Wanted
- Military-to-Manufacturing
  - Training programs for transitioning military personnel
- Women in Manufacturing
  - National recognition awards plus recruitment campaign
- Create new programs, solutions, and events to test models and provide direct support to companies on important topics

2024 Federal Policy Priorities

- Workforce does not have a policy solution but can be assisted by better policies
- Workforce Innovation and Opportunity Act (WIOA)
  - Skill Development Fund
  - Alignment of training with employer need
  - Flexibility in funding successful industry-driven workforce programs
- Apprenticeship
  - Earn-and-learn models should be prioritized in all workforce legislation and should allow for expenses to be deducted that support business participation and student success
- State policy can be more important for workforce development

MANUFACTURING Institute

Challenges in Development, Adoption, and Scale-up of Robotics in Manufacturing

EWI®

We Manufacture Innovation

Project No. 59560GTH

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ARM Institute | RAPLSS Conference at EWI March 19-20 2024

Challenges in the Development, Adoption, and Scale-up of Robotics in Manufacturing

Chuck Brandt, PhD
Chief Technology Officer

About The Advanced Robotics for Manufacturing (ARM) Institute

- Established **2017** by Carnegie Mellon University
- Headquartered in **Pittsburgh**
- **One of 17** national Manufacturing USA Institutes
  - 1 of 9 funded by the US Department of Defense
- A **Public-Private** Partnership: **>400 members** across industry, academia and government representing the entire robotics ecosystem
- **>150 projects** funded to date in both technology and workforce development
- **Managed >$100 Million** to date of US Government Investments to date, matched > 1:1 by cost share investments from other sources

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The ARM Institute Mission

The ARM Institute **accelerates the development and adoption of innovative robotics technologies** that are the foundation of every advanced manufacturing activity today and in the future.

We **leverage** a unique, robust and diverse ecosystem of partners across industry, academia and government to:

- Make robotics, autonomy and artificial intelligence more accessible to U.S. manufacturers large and small
- Train and empower the manufacturing workforce
- Strengthen our economy and global competitiveness
- Elevate our national security and resilience

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Scale-up & Adoption Challenges

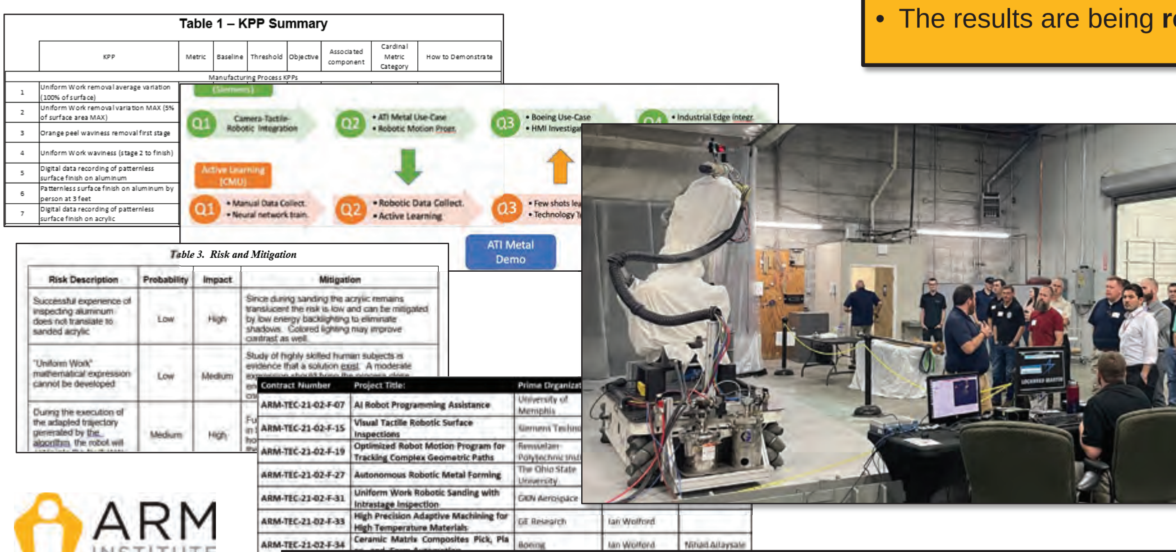
- Technology
- Money
- Business/Risk
- Workforce

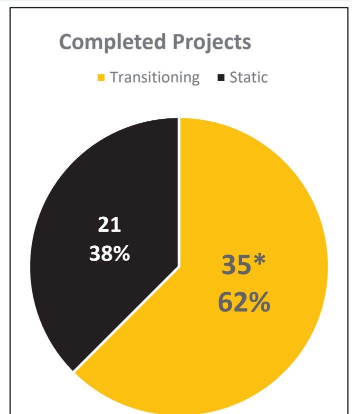
Plan for Success, Manage the Risk, & Maximize Impact

Transition plan/demo in all proposals & project plans → Collect data during/after project execution → Evaluate Transition Plan and Technology Value → Influence greater number of projects to transition

In the context of TRL4-7, transitioning means…

- The tech is on a **clear path to** commercial operation, DoD operation, or Production/product
- The project team received **additional funding** to continue the development towards transition
- The results are being **re-used** in another project





***Includes 21 projects reusing CDIP-SW.**

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Project technology is transitioning and providing manufacturing impact

SUCCESS STORIES IN THE MAKING:

TEAMS: Siemens, Sewbo, Blue Water Defense, Henderson Sewing, RPI, Hickey-Freeman, Levi Strauss, Yaskawa, UCBerkeley, DAP America, Interface Technologies, ISAIC, Pvilion, USC, Black Swan Textiles

Robotic Garment Assembly

- **Problem**: **ARM has funded a variety of projects that have significantly advanced the state of the art in robotic sewing, which was previously nonexistent**. Our early work integrated sewing machines with collaborative robot systems and designed an end effector capable of lifting and controlling a single large ply of fabric. Recent projects have focused on more advanced operations like hemming, pocket setting, and curved stitches. Companies like Levi's and sewing machine technology providers are very interested in integrating this capability into their processes and products.
- **Benefit:**
  - **The robotic technologies developed in these projects extends beyond the apparel industry to other companies that handle thin sheets (such as metal and plastic sheets, composites).**

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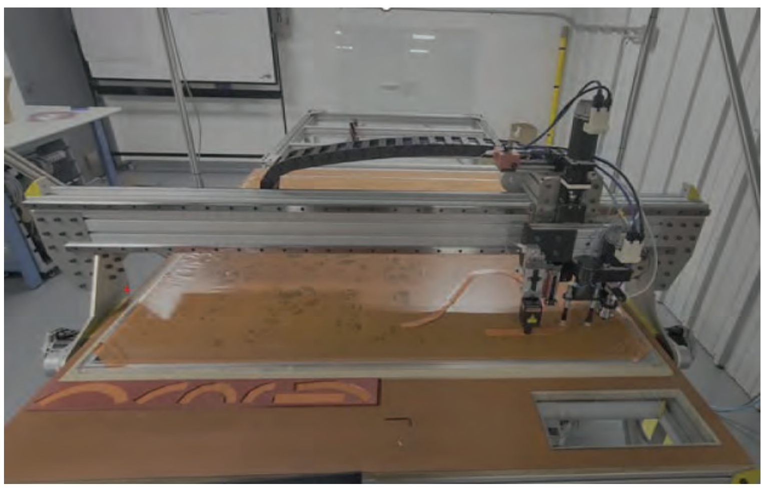
Project RAPID*: Automate the production of emergency life preservers



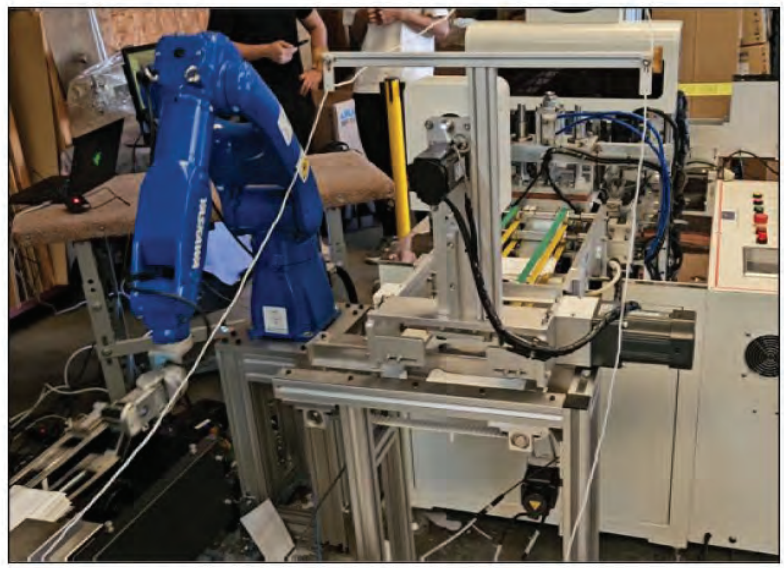
*Refined Automated Production of Inflatable Devices

MASCEI* – Where Are We At?

Pose Estimation

Case Packing

Disposable Mask Line



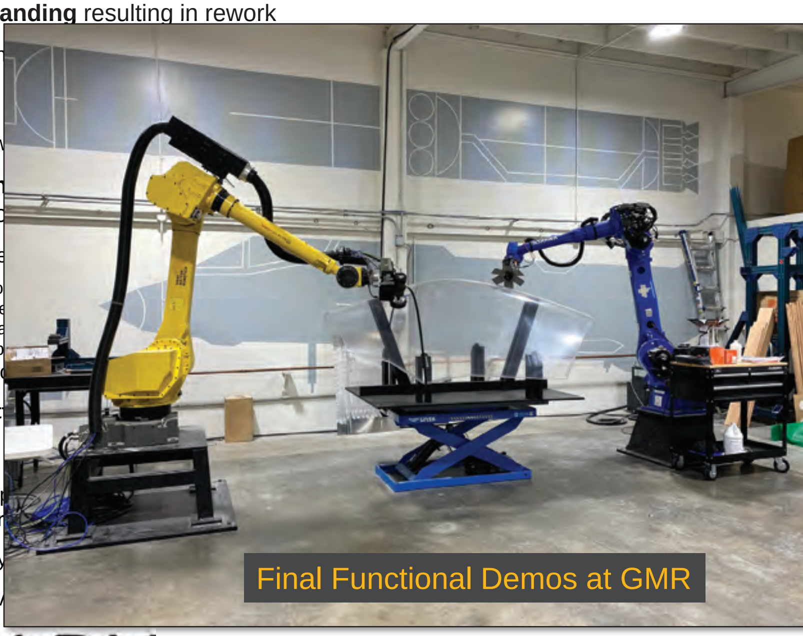
Container 1 Mask Assembly & Bagging

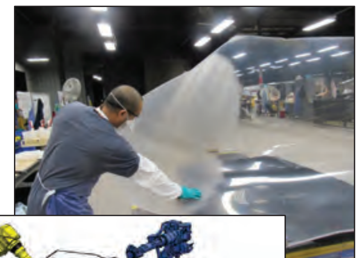
Success Story In The Making:

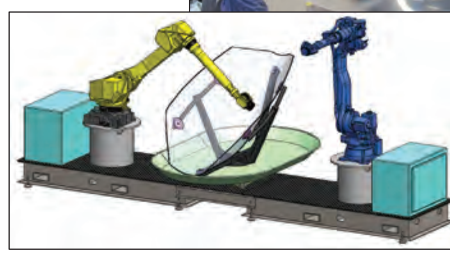
TEAM: **GKN Aerospace (Prime)**; GrayMatter Robotics, NIAR(WSU), UWash, Edison Welding Inst.

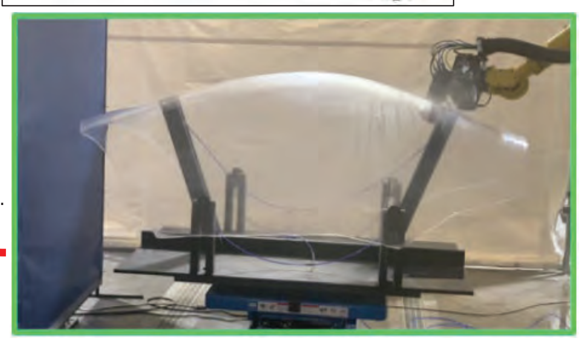
Uniform Work Robotic Sanding with Intrastage Inspection

- **Problem**: Optical requirements for modern combat aircraft canopies challenge **conventional manual sanding** resulting in rework
  - Path plan ... **es, and material**
  - "Uniform ... duce rework, w...
- **Approach** ... arency Systems c...
  - **NIAR**: De...
    - Ro...
    - Pre...
    - Tra...
    - Op...
  - **UW**: ML ...
  - **GrayMat**...
- **Benefits**: ...
  - Process ... **n acceptan**...
  - Efficiency ... work
  - Productiv ... **by 50%**.









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SUCCESS STORY:

Robotic Sanding and Finishing

TEAM: **Lockheed Martin Corporation (Prime)**, University of Southern California, Texas A&M University

- **Problem**: **Manual finishing processes** to remove surface irregularities and prepare for additional coating applications, create the following issues:
  - **Ergonomic**: repetitive motion and vibratory tool use
  - **Health**: dust exposure
  - **Quality**: inconsistencies in surface preparation
  - **Cycle time**: differences in the human element.
- **Approach:**
  - **Phase 1**: developed a prototype low cost and flexible RSF system for sanding segments of helicopter blades.
  - Provided sensing of the work item, path planning for both low- and high-resolution scanning, defect detection and cueing to the human as to where to apply filler material, and automated sanding and QC checking.
  - Modular Robot Operating System (ROS) nodes.
  - **Phase 2**: improve the Phase 1 system for products with complex geometries, larger dimensions and a variety of materials for sanding.
- **Benefits:**
  - **Demonstrate** on parts used on helicopters, missiles and spacecraft.
  - Reduce risk of repetitive motion injury to the human operator and increase production throughput of large surface area, contoured parts.

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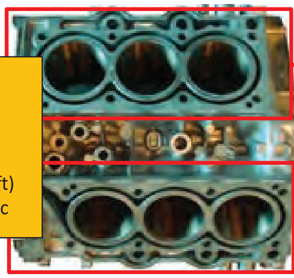
TEAM: Stellantis/FCA (Prime); Aris Technology, SwRI, FANUC, Yaskawa

SUCCESS STORY:
Human-Robot Collaboration in Quality Inspection

15 blue laser crosshatch pattern

Accuracy 0.025 mm
Part size range 0.2-6 m (0.7-20 ft)
Measurement Freq 1.8M per sec

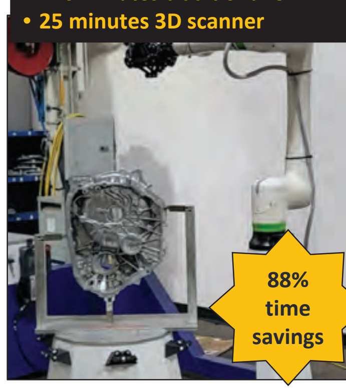


- **30 CMM measurement points** between both bank faces in 3 minutes
- **216 million laser measurement points** between both bank faces in 2 minutes

Gain full surface measurement data vs. limited CMM data

WL Cross Member full sample
- 55 minutes traditional CMM
- **10 minutes 3D scanner**

9 speed bell full sample
- 210 minutes traditional CMM
- **25 minutes 3D scanner**



Higher Productivity
Savings: time, labor, & SRR

TEAM: **Siemens Corporate Technology (Prime)**; Siemens Energy, GA Tech, rpGatta

Success Story in the Making:

Autonomous Multi-Tool Head Robotic Solution for On-Site Surface Prep

- **Problem**: Precise "in-the-field" tasks such as milling, grinding and polishing are cumbersome, time consuming and expensive.
  - Typical: up to 77 Metric Tons (170,000 Lbs.), 30 m long; - 40 C to 40 C.
- **Approach:**
  - A multi-tool head robot for on-site automated surface preparation (milling, polishing, grinding)
  - Optimization based real time trajectory planning; adaptation to local curvature
  - Realtime machining force controlled robotic milling capability
  - Rugged commercial 6-axis force/torque sensor mounted on the end effector
  - Dimensional accuracy to ≤ 0.25 mm using autonomous machining control and chatter suppression
- **Benefits**:
  - Use-case agnostic methodology and tool set
  - Ship and field mount robots to 100-micron level of machining accuracy
  - Adaptable for corrosion repair, weld prep, repetitive grinding and polishing
  - In the field operations or in a factory setting
  - **~$600K in savings per engine; up to $1M/day in lost revenue**

ARM INSTITUTE JROBOT JOINT ROBOTICS ORGANIZATION FOR BUILDING ORGANIC TECHNOLOGIES

Success Story: ASIIMOV

TEAM:Siemens (Prime); Siemens Energy, Allem Business Ventures

Autonomous Swarm Inspection & Interactive 3D Modelling with Orchestrated Visualization

- **Problem**:
  - **Inspection of large structures is a manual process: time, cost, safety concerns**
  - Emerging UAV-based methods need extensive preparation, skilled pilot control and data processing; need days to complete a full task
  - Need "software stack" that can be used for advanced service capabilities and inspection for: Shipyard operations, Hangar operations, Energy infrastructure, and Large field machines.
- **Approach:**
  - An inspection kit for agile deployment in remote / complex environment
  - Autonomous swarm **allow operator to focus on inspection** instead of UAV piloting
  - Mixed reality & HMI provide instant feedback to ensure the quality of work
  - **Automated process for repeatable results to improve productivity and performance**
  - Interoperable open SW/HW design allow fast adaptation and adoption.
- **Benefits**: Fully autonomous, fast operation, agile deployment inspection kit using drones and mixed reality-based human-in-the-loop to significantly advance the inspection technology for large structures / DOD sustainment goals.

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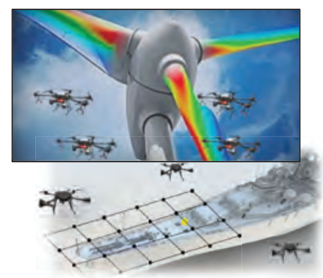
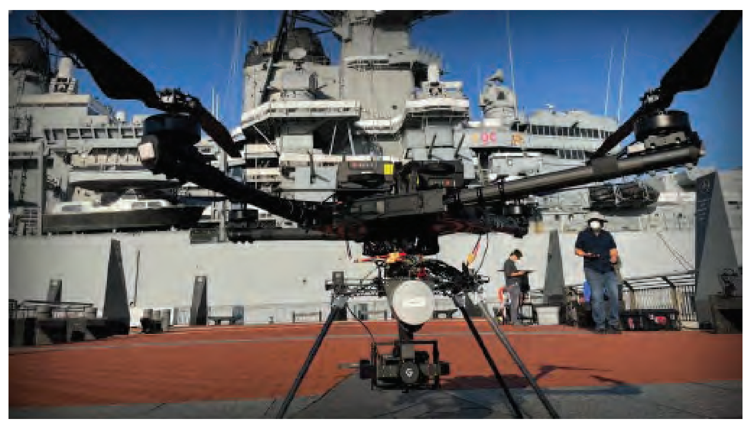
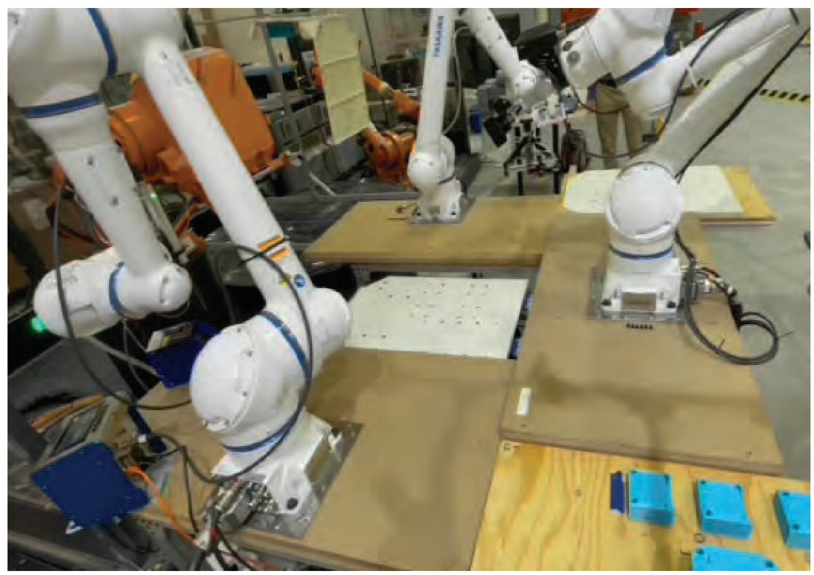
JROBOT JOINT ROBOTICS ORGANIZATION FOR BUILDING ORGANIC TECHNOLOGIES





Fixtureless Robotic Assembly and Manufacturing Environment (FRAME)

- **FRAME:** Configurable robotic system for fixtureless and dynamic high mix/low volume (HMLV) manufacturing that identifies and inspects assembly parts, autonomously plans assembly tasks and motions, and optimizes human collaboration with the robotic manufacturing cell.
- **Challenge:** HMLV manufacturing is costly, slow, and operator intensive as it requires new fixtures to facilitate assembly, changing machines, and pre-programmed motion plans for the robotic system(s).
- **Key technical challenges** to achieve fixtureless assembly:
  1) High fidelity sensing
  2) Dexterous grasp planning and control for multiple arms
  3) Real-time adaptive and dynamic work cell environment
  4) Human touchpoints optimization



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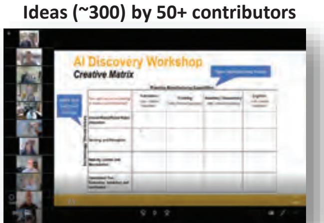
LOCKHEED MARTIN CapSen ROBOTICS USC Carnegie Mellon University

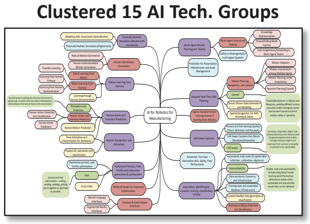
ARTIFICIAL INTELLIGENCE (AI) DISCOVERY WORKSHOP

- **Approach**:
  - Strategic alignment with DoD Modernization Priorities
  - Refine the ARM technology strategy for **AI in Robotics for Manufacturing**
  - **> 20 AI SMEs (OEMs, Integrators, Start-Ups, DoD, Academia, FFRDCs, NIST, and NIOSH)**
- **Results / Benefit:**
  - **Developed** ecosystem-informed technology strategy for AI
  - **Identified, Prioritized, & Roadmapped 8 AI Technologies**
  - Prioritized focus on Data (enabler) needs to develop and adopt AI solutions Robotics for Manufacturing
  - **Initiated a member driven Data for AI Working Group (Robotics & Manufacturing)**

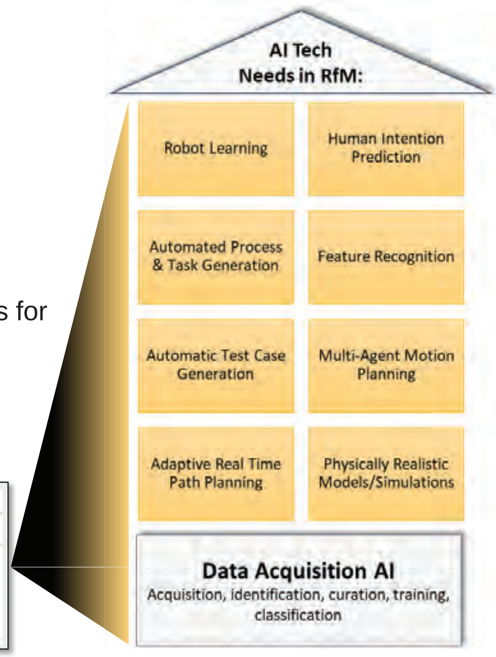
Ideas (~300) by 50+ contributors



Clustered 15 AI Tech. Groups



Prioritized



Casting & Forging Roadmap Generation+

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Scale-up & Adoption Challenges
• Technology
• Money
• Business/Risk
• Workforce


ARM INSTITUTE
Thanks!
chuck.brandt@arminstitute.org

Cobots for Fabrication of Large Structures

VECTIS AUTOMATION | LET'S FAB TOGETHER

Cobot Fabrication Tools

Cobots for Fabrication of Large Structures

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Outline

1. Vectis Introduction
2. Comparison of Collaborative Robots and Traditional Robots
3. Vectis Product Evolution
4. Remote Deployment Methods
5. Future of Cobot Fabrication

"Vec·tis"/ˈvek(t)əs / Latin: **A Lever, Leverage**

- **Who:** Team of engineers with 200+ years combined experience in the robotic fab industry. First to do cobot welding/cutting in U.S.
- **Where:** HQ in Loveland, CO. *Systems & partners all across North America*
- **What:** Cobot Welding & Cutting Tools to boost productivity
  - Easy-to-use, portable, versatile, quick delivery, cost-effective, low-risk
- **Why:**
  - Estimated shortage of 360,000 welders in U.S. by 2027
  - Man + Machine will fill the gap

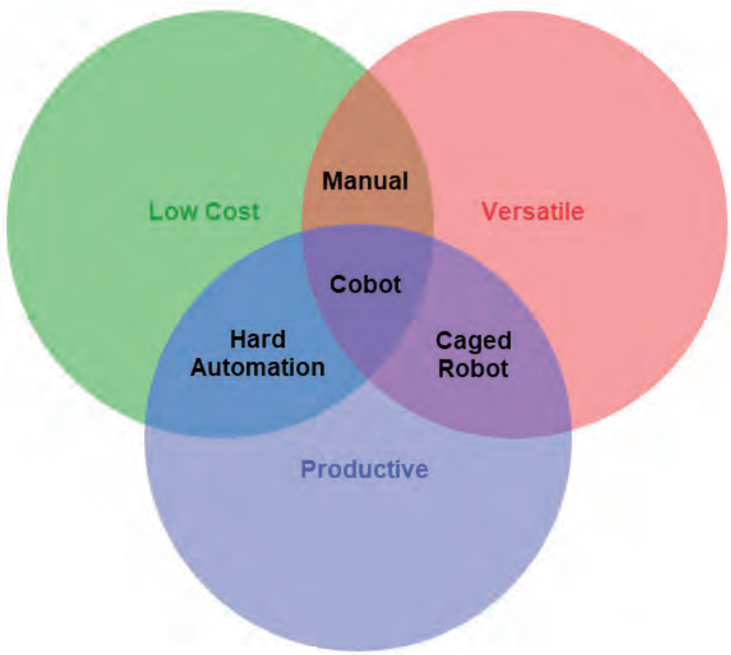
Robot Comparison: **Collaborative vs. Traditional**

https://www.youtube.com/watch?v=KloqHslvhdM

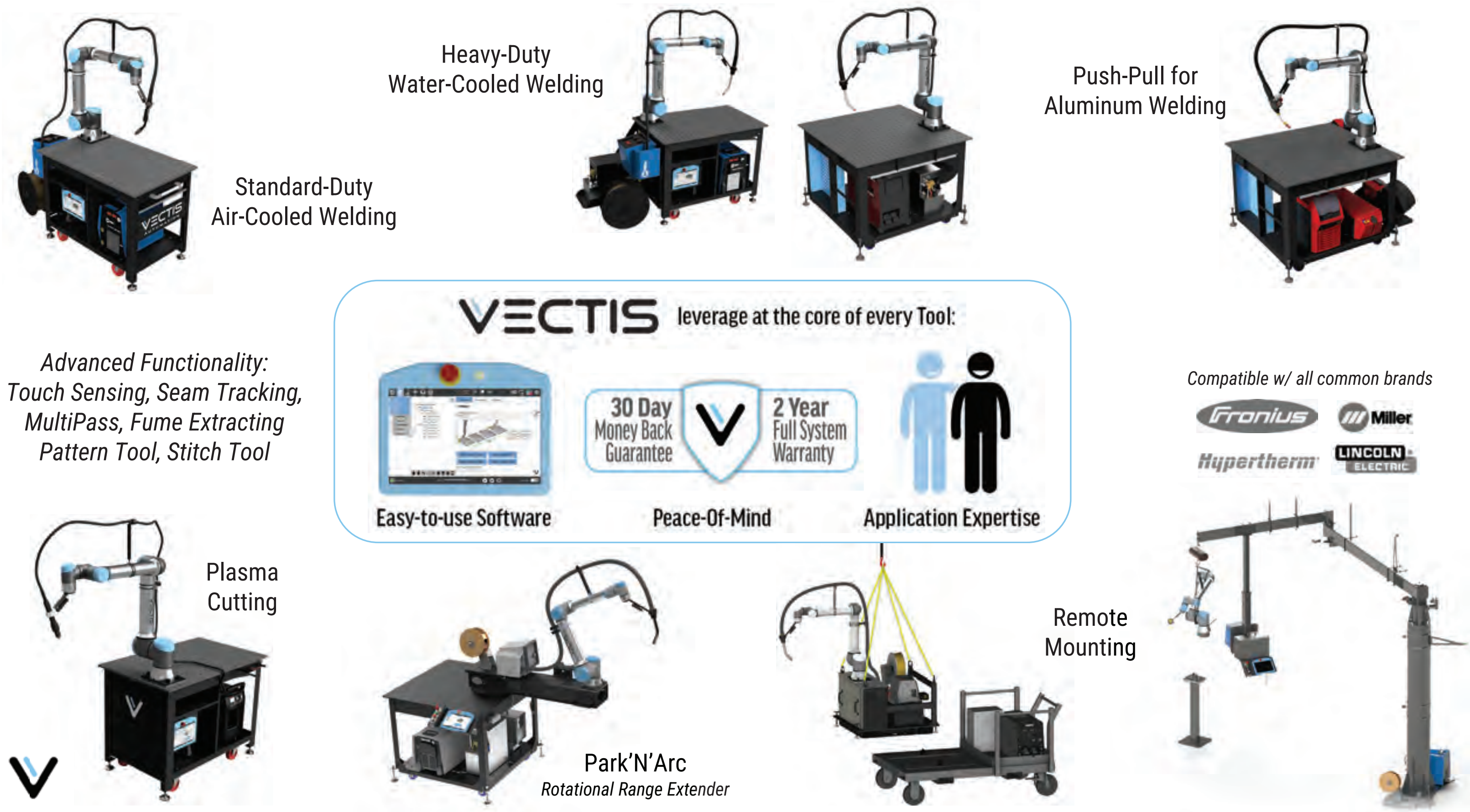
Collaborative Robot (Cobot) Systems
- Improved Safety
- Quick and Intuitive Programming
- Easily Setup and Redeployed within Hours
- Less Infrastructure Necessary

Traditional Robot Systems
- Safeguarded with Fencing & Safety Devices
- Weeks of Programming Training
- Purpose Built Machines with Months to Deploy
- Large Foundations & High Power Required

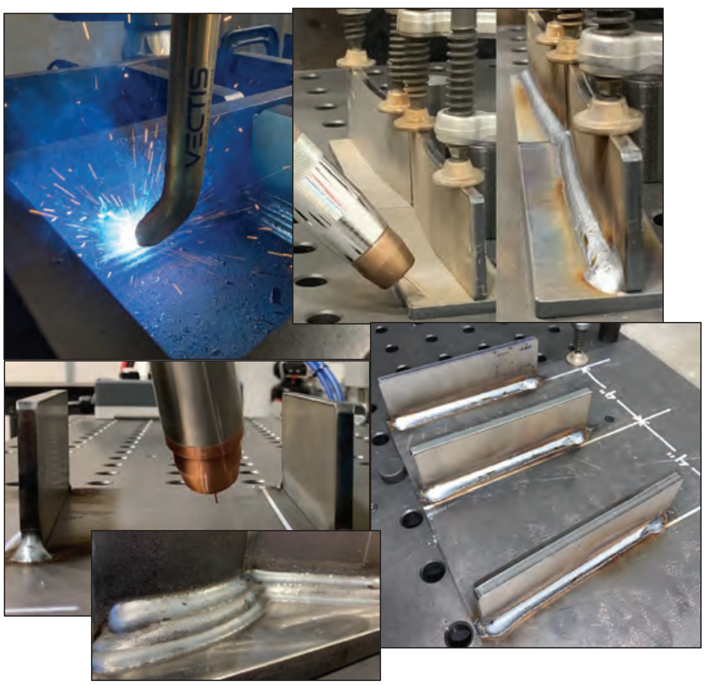
Comparison: **Hard Automation vs. Traditional vs. Manual**



**Typically*, may vary on the system and application.


Heavy-Duty
Water-Cooled Welding
Push-Pull for
Aluminum Welding
Standard-Duty
Air-Cooled Welding
VECTIS leverage at the core of every Tool:
30 Day
Money Back
Guarantee
2 Year
Full System
Warranty
Easy-to-use Software
Peace-Of-Mind
Application Expertise
Advanced Functionality:
Touch Sensing, Seam Tracking,
MultiPass, Fume Extracting
Pattern Tool, Stitch Tool
Compatible w/ all common brands
Plasma
Cutting
Remote
Mounting
Park'N'Arc
Rotational Range Extender

Software: **Touch Sensing, Multi-Pass, & Arc Seam Tracking**



- **Touch Sensing**
  - Enables the system to adapt for production tolerances from part to part
  - Forced based for safety of operators
- **Multi-Pass**
  - Similar to weld parameter recipes. Once a set of multipass offsets is defined, they can be used for other welds in the future
  - Enables the "bring the cobot to the work and teach one-off paths" use case
- **Arc Seam Tracking**
  - Manage part-to-part variations while live-welding
  - Monitors electrical properties of the arc to "steer" the cobot to the center of the joint
- **More In The Works**

Workforce Development: **Online Training Academy**

- Vectis' Online Training Academy provides a permanent and reviewable medium of learning the system
- Lifetime access
- Provides a DIY option for low cost & flexible schedules

Deployment Method Highlight: ***Cobot-to-Part***

Park'N'Arc
- Rotational Range Extender
- 44" Radial Extension
- Pinned locations every 45°

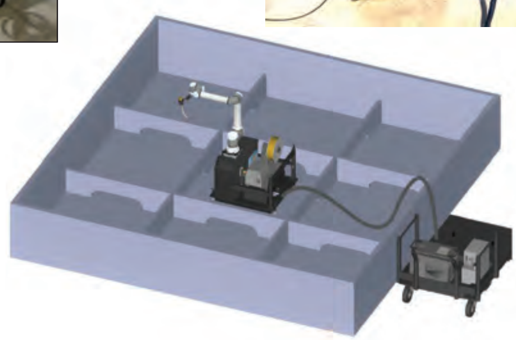
Rover
- Remote Fabrication System
- Detachable Skid
- Mobile Base

Boom

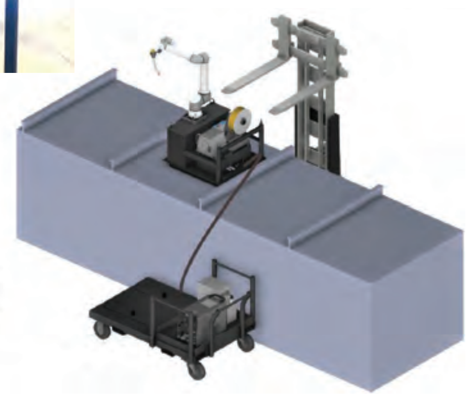
Boom
- Manual Docking Stations
- Ergonomic Lift Assist
- Cable Management

Deployment Method Highlight: **Park'N'Arc**

Deployment Method Highlight: **Rover**

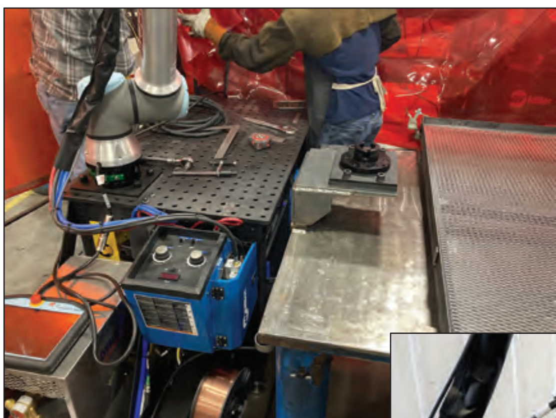


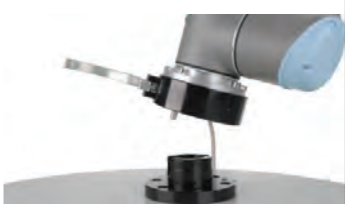
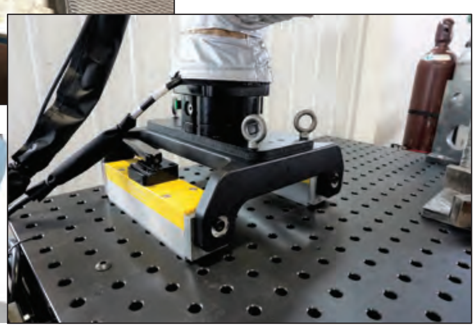
Craned into Position on Large Parts



Forklifted into Position on Large/Tall Parts

Future of Cobots: **Placing Cobots on the Part**



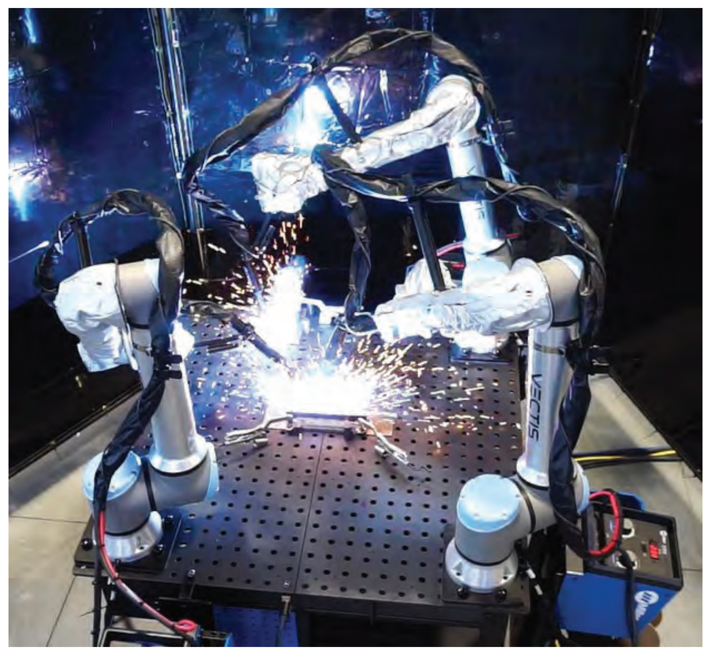
- **Magnetic Base**
  - Pairs with quick-docks to allow fully-flexible welding on magnetic surfaces
- **Quick-Dock Base Connector**
  - Primary dock attached to base of cobot arm; secondary docks attached to various fixtures or Mag Base
  - Manual cam lever enables precision locating & ease of operation
- **Applicable Segments**
  - Energy, Heavy Equipment, Rail Transportation, Shipyards, & Structural

Future of Cobots: **Upstream Material Prep**

- **Plasma Cutting**
  - Improved safety
  - Fills the gap between major equipment and manual cutting
  - Capable of cutting thicker materials (2-3" range)
  - Pairs well with welding systems to boost quality by reducing grinding/fitting and over welding
- **Applicable Segments**
  - Energy, Food and Beverage, Heavy Equipment, Rail Transportation, Shipyards, & Structural

Future of Cobots: **Swarming with Multiple Cobots**

- **Capital Cost Incentives**
  - Higher density of arcs per part
  - Lower capital cost per arc
- **Productivity Benefits**
  - Easier to adapt to new part models
  - Redundancy with multiple cobot systems
  - Each system is isolated from the other instead of one large integrated system
- **Applicable Segments**
  - Energy, Heavy Equipment, Rail Transportation, & Shipyards




Questions?

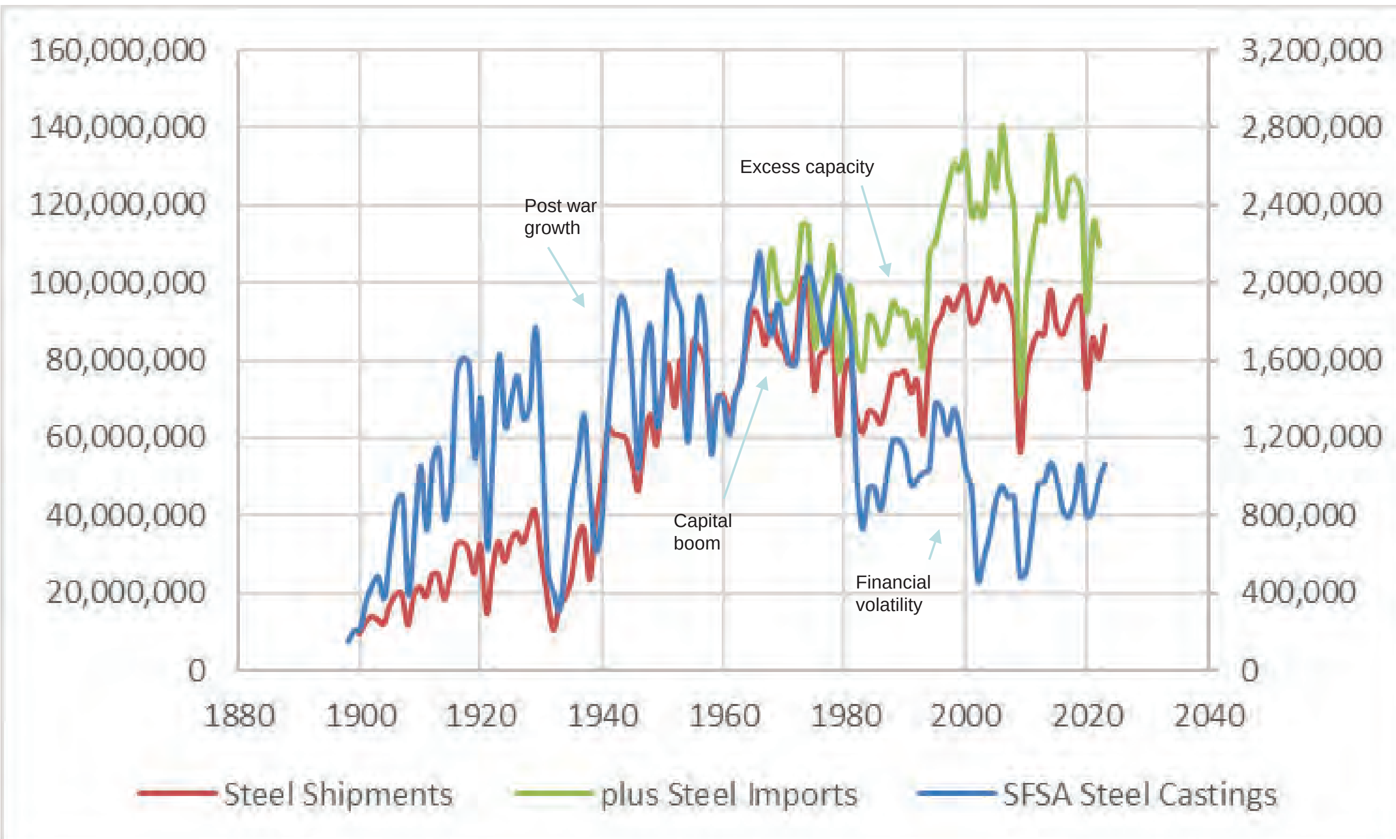
Steel Casting Roadmap Priorities

Casting Roadmap Priorities

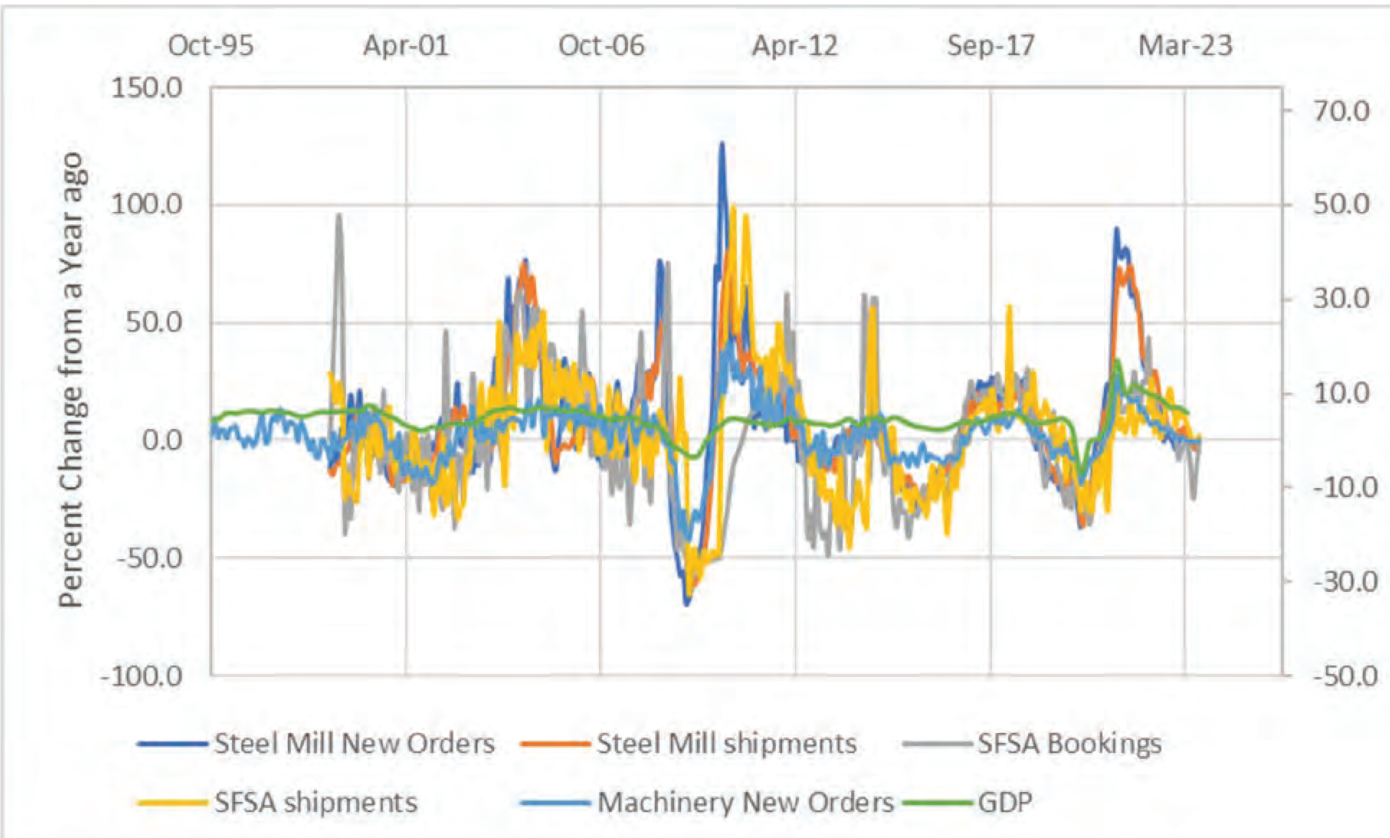
March 20, 2024

Raymond Monroe
Executive Vice President
Steel Founders' Society of America
T: (815) 263-8240
Monroe@sfsa.org

Steel Mill and Casting Production in U.S. tons

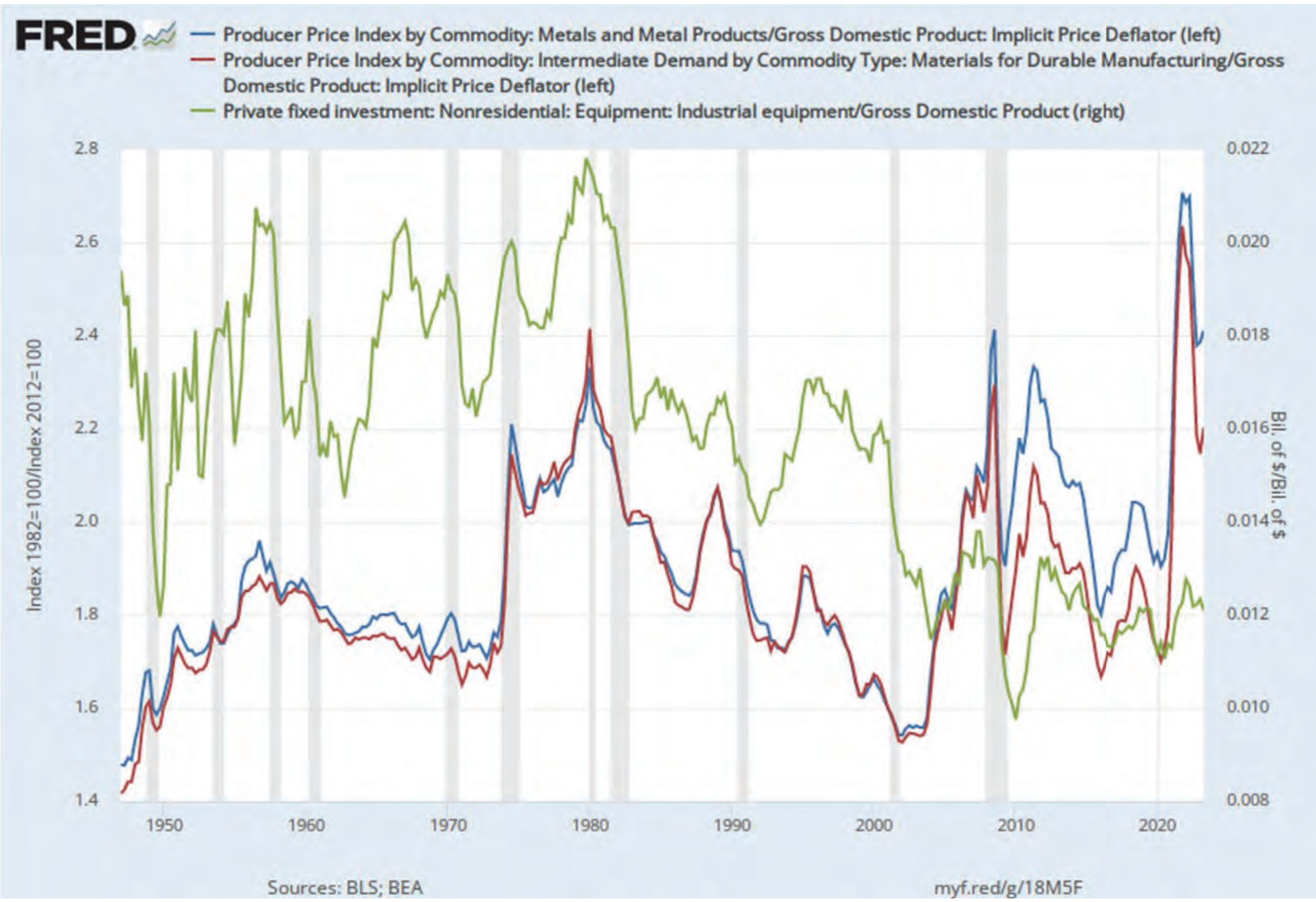


Steel Casting Market volatility for 30 years



Public policy managing the budget, the financial system and the currency have not controlled the volatility or made investment in industry attractive. Foreign Direct Investment shows that these plants have value, and that the U.S. policy makes domestic investors reluctant to own them.

We have been successfully de-industrializing!



We globalized instead of re-capitalized capital-intensive industry from 2004 until 2022.

Capital Equipment investments can be evaluated as a multiple of the sales.

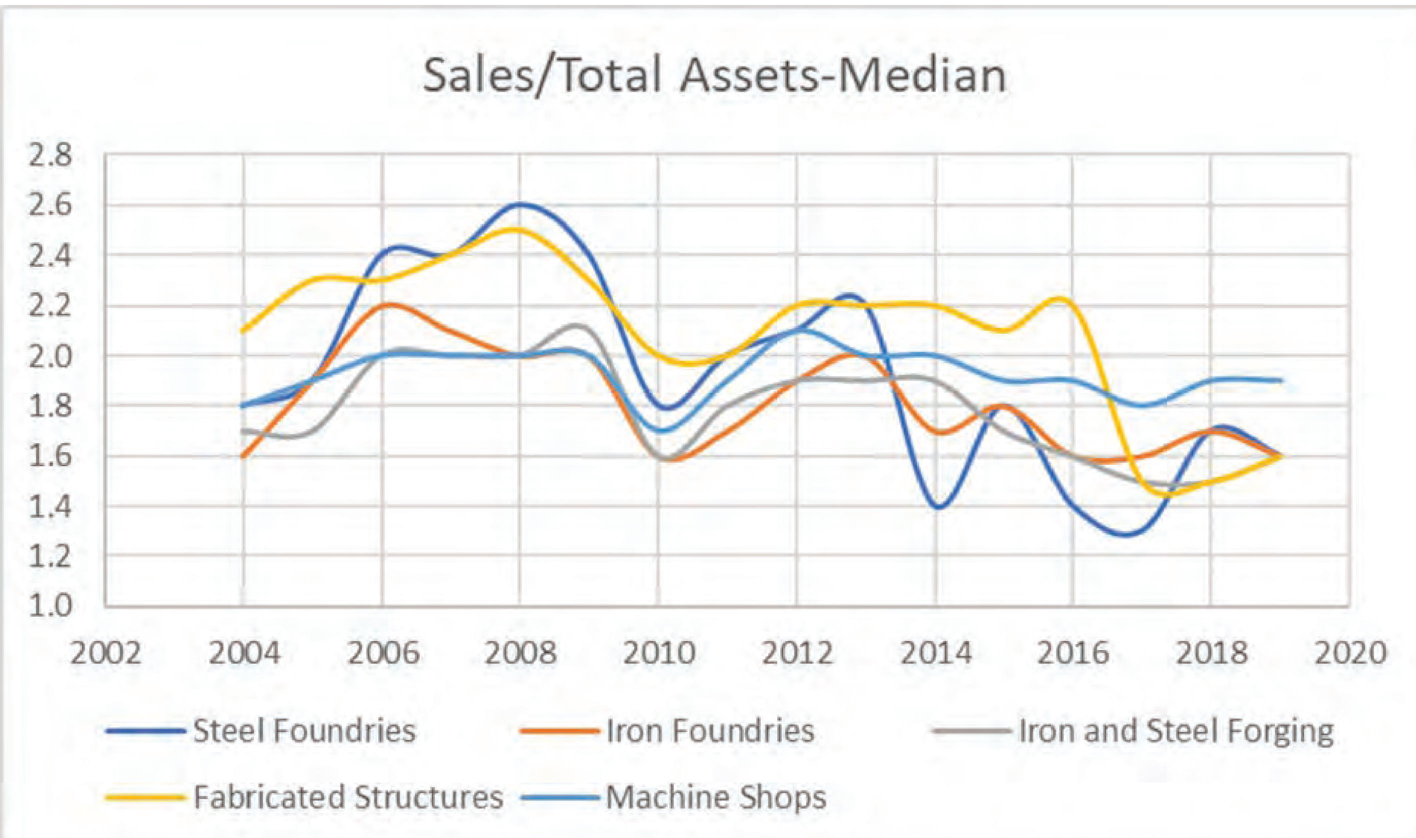
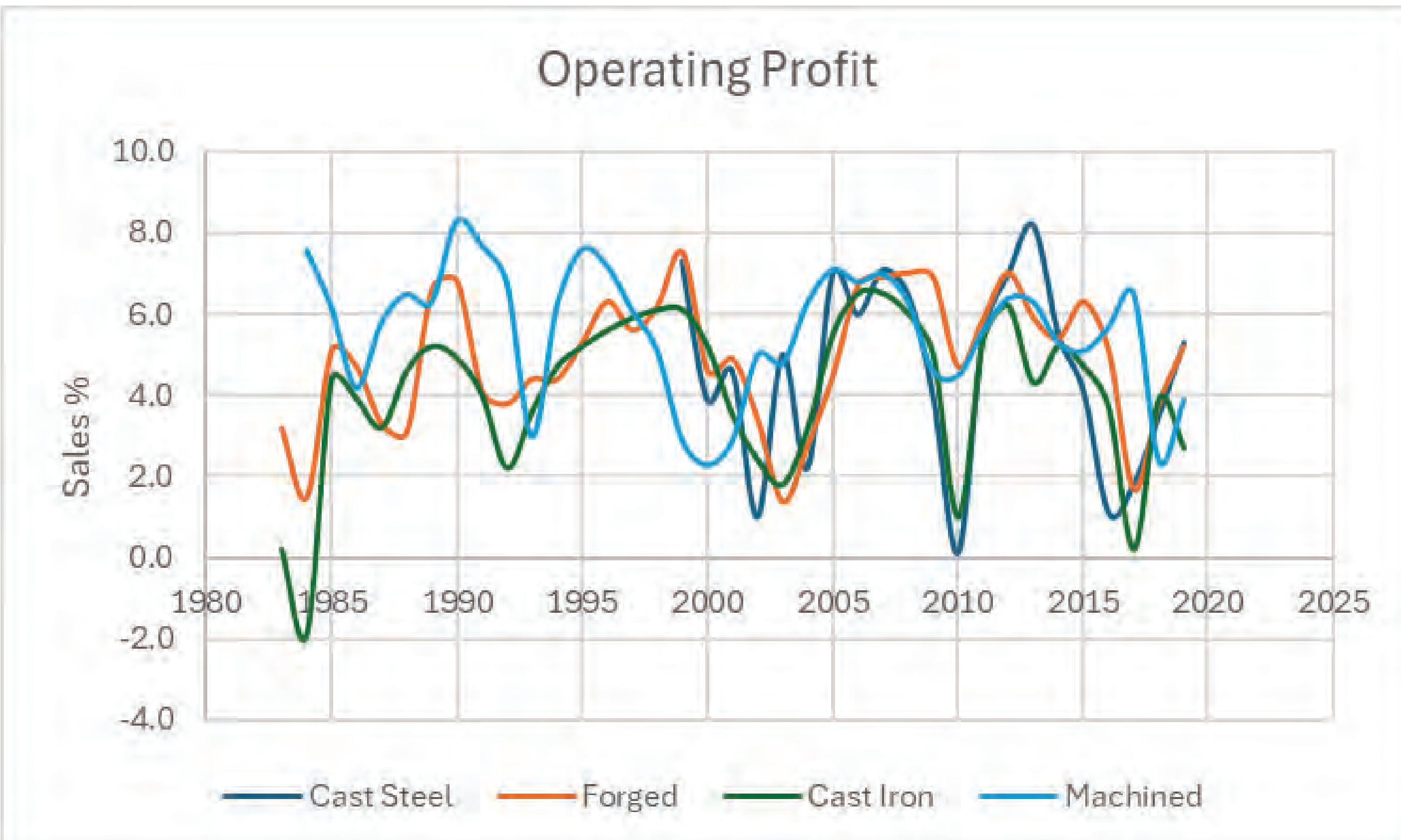
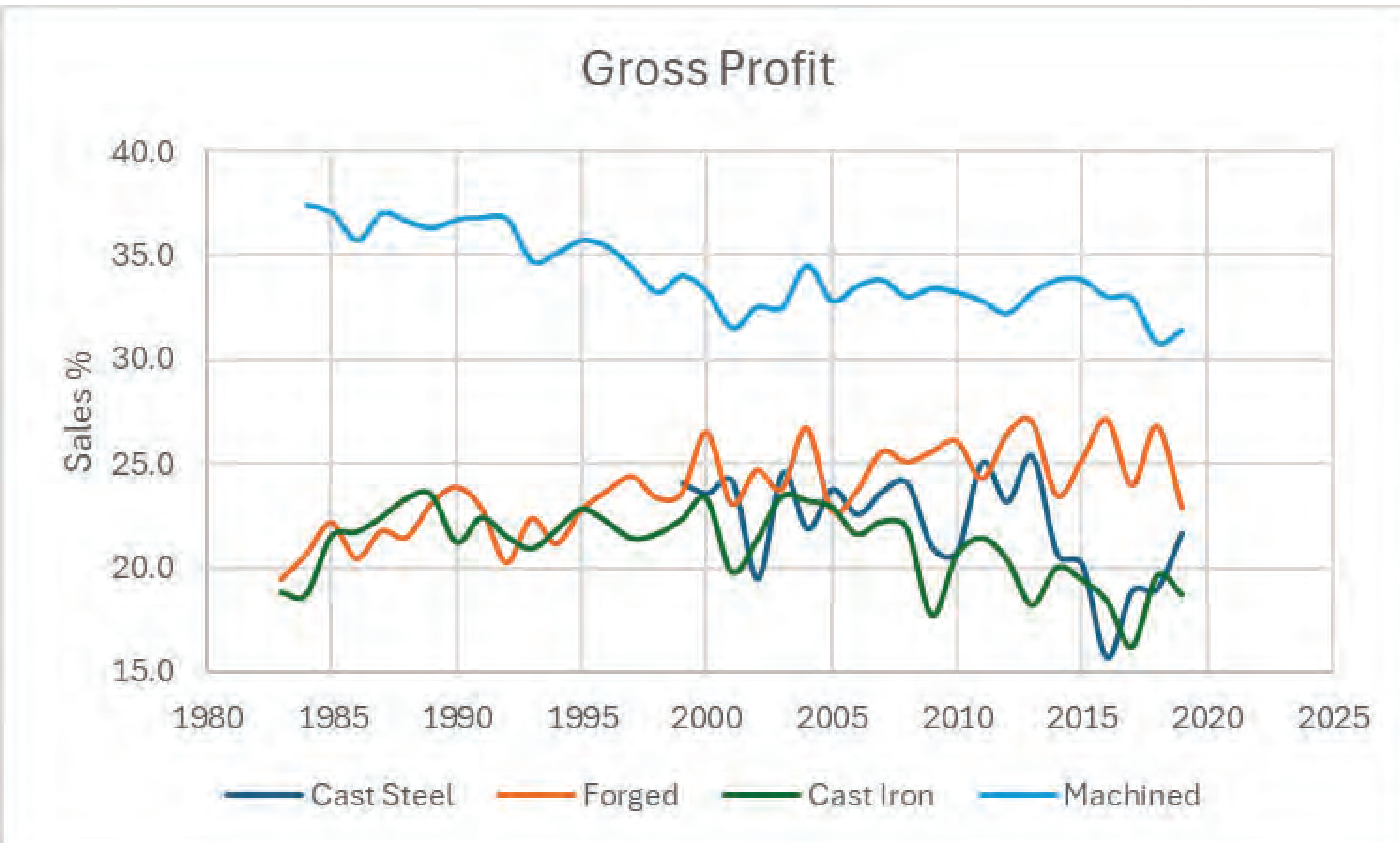


Figure 1 Sales of Steel and Iron Castings, Forgings, Fabrications and Machine Shop Products divided by the Total Assets



Operating Profit
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
Sales %
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Cast Steel
Forged
Cast Iron
Machined

Capital Equipment payback periods should be compared with Gross Profit.



Major Problem is lack of profitability to support new investment and technology to improve quality and lower costs.

	Sales	Payroll	Benefits	Materials purchased	Capital Investment	Value Added
	Per ton					
Mills	1195.98	89.57	34.51	850.10	30.97	374.49
Foundries	3394.79	676.59	240.95	1720.34	132.55	1948.11
Forge shops	3745.59	492.45	163.03	2080.39	193.04	1658.41
	Per Employee					
Mills	1,044,367	78,212	30,138	742,333	27,043	327,019
Foundries	250,086	49,843	17,750	126,734	9,764	143,513
Forge shops	431,343	56,710	18,775	239,578	22,231	190,982
	Per hour					
Mills	584.98	43.81	16.88	415.80	15.15	183.17
Foundries	146.27	29.15	10.38	74.12	5.71	83.94
Forge shops	263.33	34.62	11.46	146.26	13.57	116.59

DoD Action Plan to respond to E.O. 14017

National Security Significance

Cast and forged (C&F) parts are critical to the development, procurement, and sustainment of all major defense systems by the DIB, including, where applicable, the organic industrial base (OIB). They are used in almost all platforms (e.g., ships, submarines, aircraft, ground combat vehicles, spacecraft, etc.), kinetic weapons and weapon systems (e.g., guns, missiles and rockets, bombs, ammunition, artillery pieces, etc.), and many supporting systems (e.g., vehicles, powered support equipment, etc.). In 2020, the Defense Logistics Agency (DLA) identified 30,061 out of 32,597 specialized end items that contain C&F maintenance, repair, and operations (MRO) parts. Many of these parts are high importance/low-volume and minimal demand items[18] that support "critical go-to-war weapon systems and platforms that affect military readiness."[19] C&F products are essential components of the machine tools and other equipment used to produce and sustain fielded systems and forgings are found in 20 percent of the products representing the gross domestic product of the United States.[20]

Manufacturers use C&F capabilities to provide specific material properties in intermediate products[21] and end items that cannot be produced by other manufacturing processes. Production of C&F parts often includes

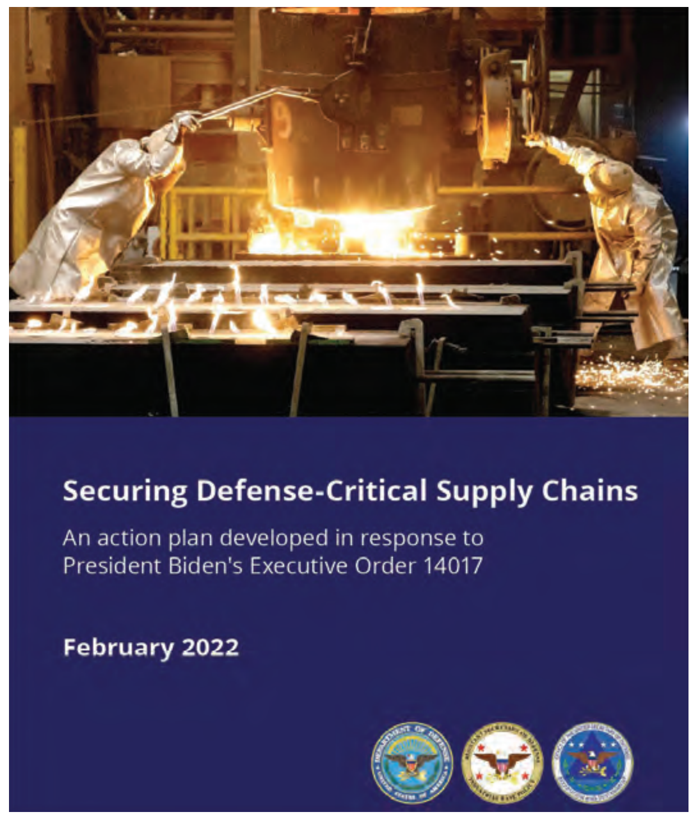
Organic Defense Industrial Base (OIB)
The OIB includes government-owned government-operated (GOGO) and government-owned contractor -operated (GOCO) facilities that provide specific goods and services for the DoD.

Casting and Forging
Casting is the process used to create geometrically complex parts by pouring molten or high-temperature metal or composites into a mold.

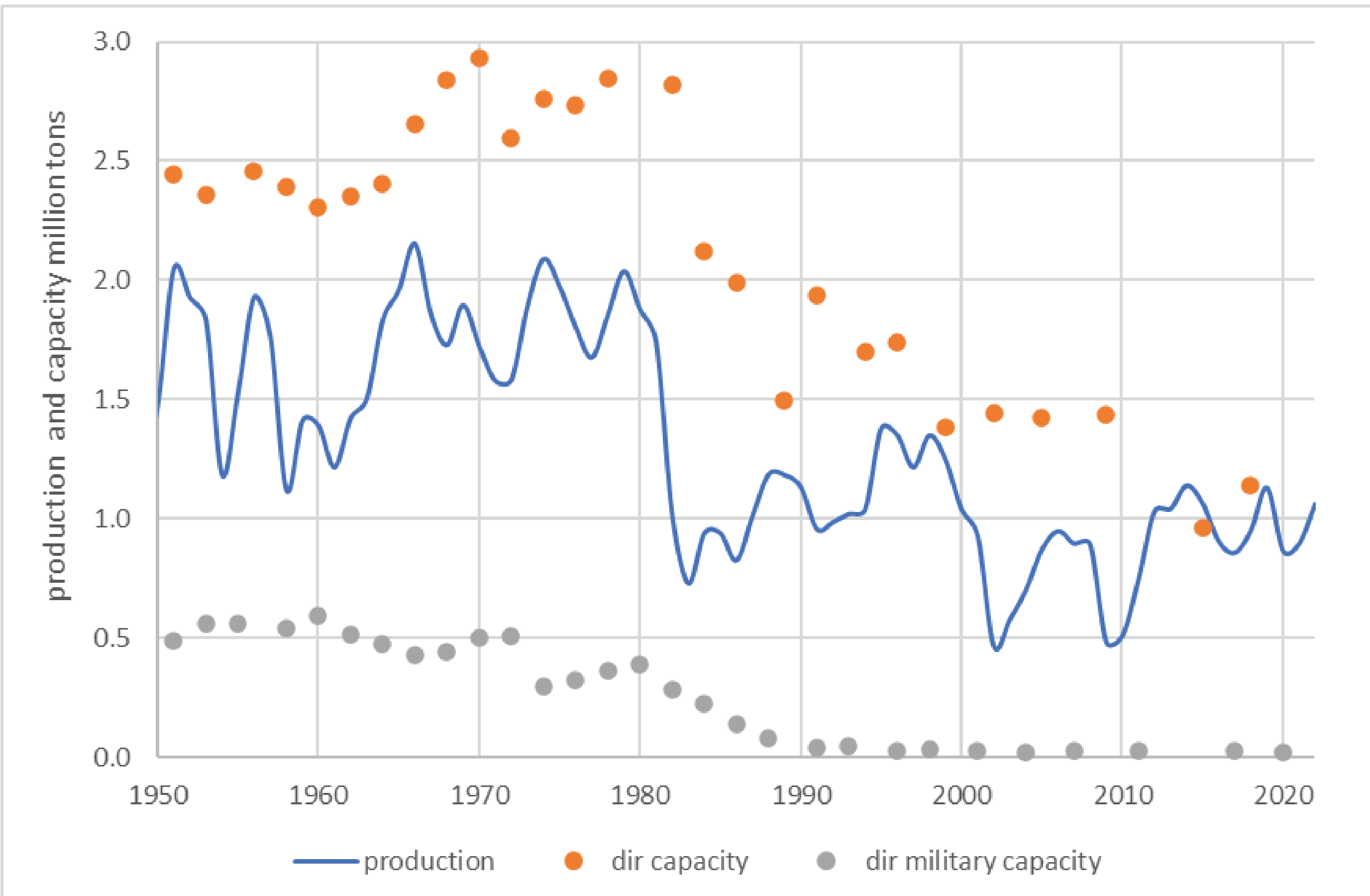
"About Metalcasting," American Foundry Society

Forging is the process used to develop metal parts by pounding, pressing, or squeezing metals under great pressure; the metals are often preheated before working but are never melted.

"Forging Facts: What is Forging?" Forging Industry Association

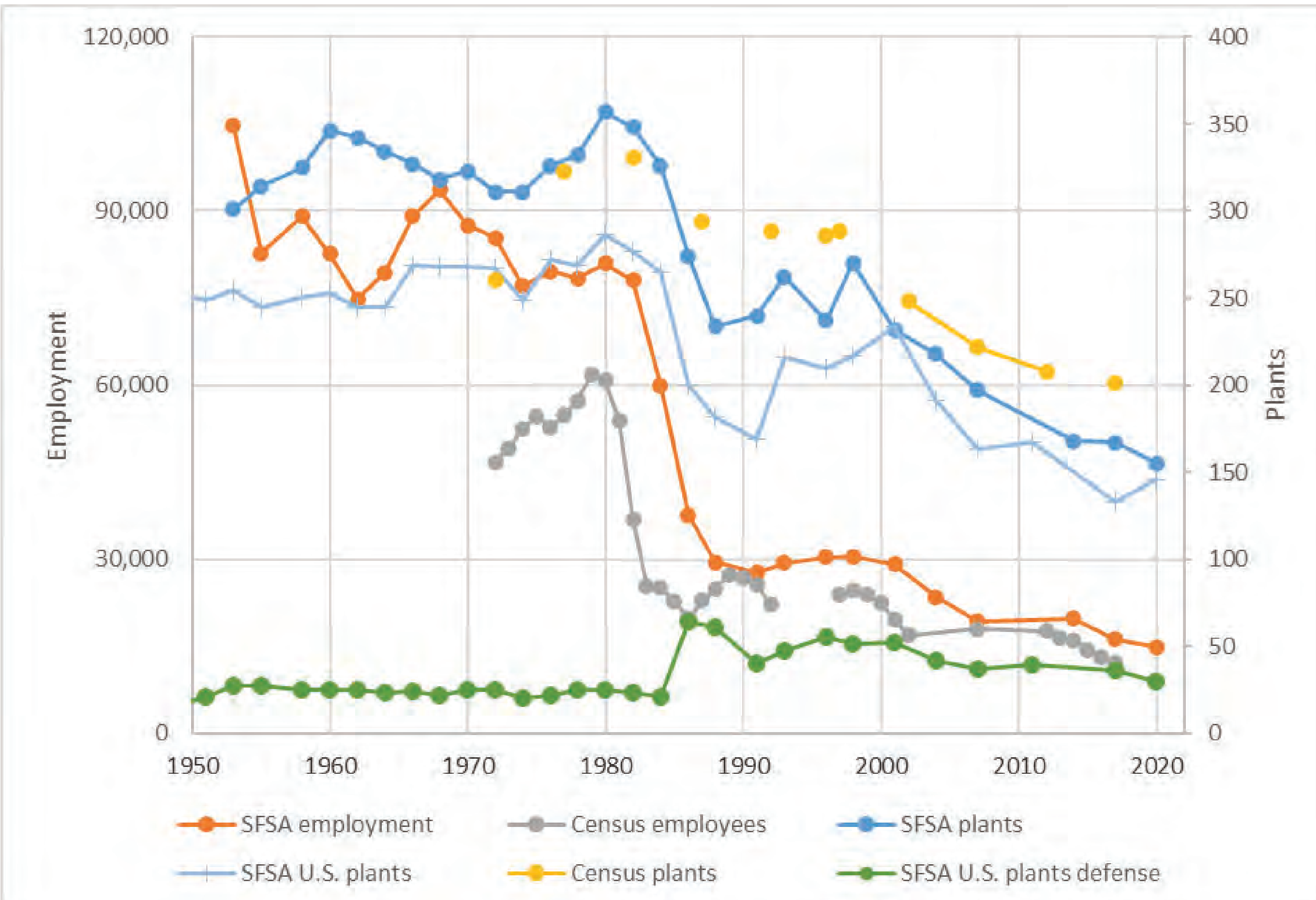


Steel Casting Production and Capacity



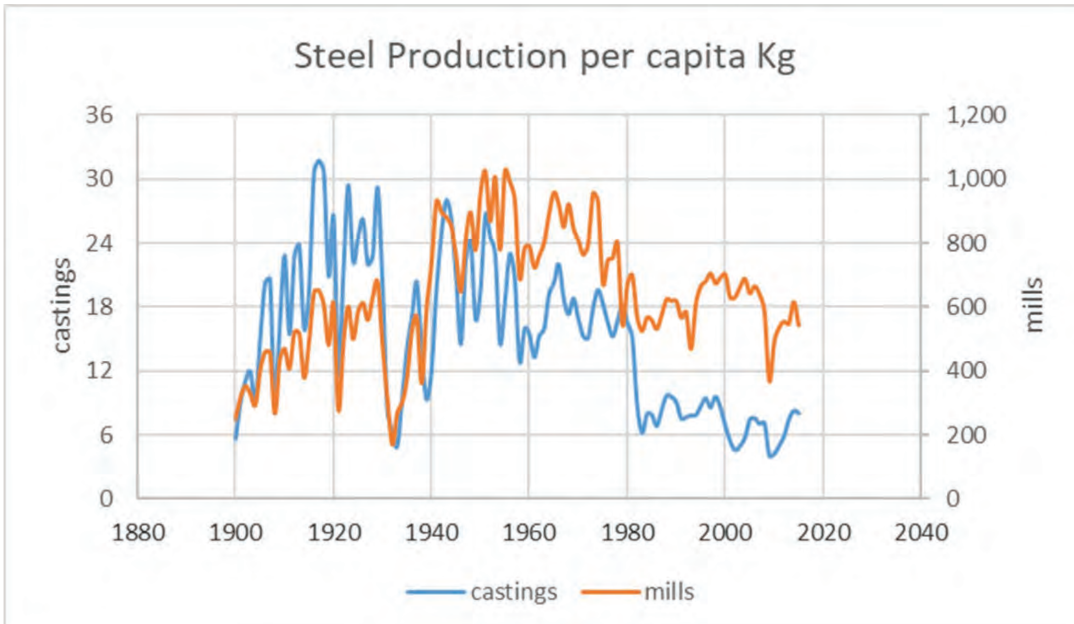
Steel Casting Capacity has dropped dramatically since 1980 including for military applications. A major challenge is the reduction in customers as critical manufacturers were replaced with global suppliers.

Steel Casting Plants and Employees



The number of plants and employment has continued to drop since 1980 while the industry still is capable of making over 1 million tons.

SFSA Strategic Roadmap



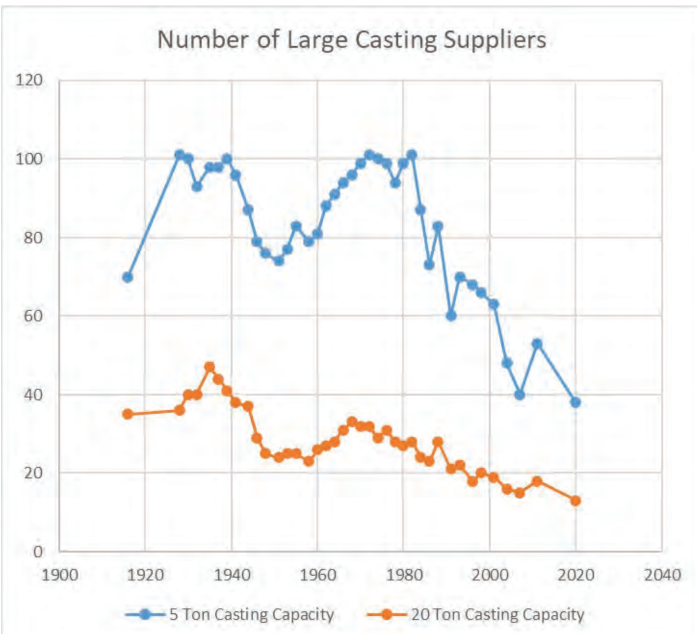
- People
  - Workforce
  - Perception
- Capital
  - Trade
  - Profitability
  - Re-investment
- Technology
  - Process
  - Product

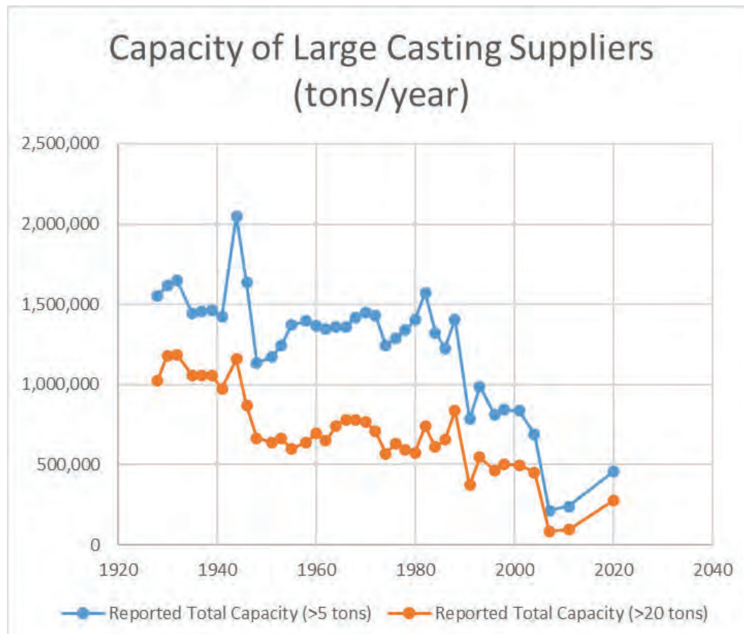
Before 1930, steel castings were 2% of steel production and were the premium product.
Since 1980, steel castings are 1% of steel production and are seen as problematic.

Challenges for Castings and Large Parts

- U.S. Public Policy
  - Public Policy limits profitability with economic externalities
  - Trade policy benefits services and neglects goods – loss of volume, agreements, FDI, currency,
  - Tax and Regulatory policy uniquely burden capital intensive manufacturing- depreciation and liability, ALARP
  - Lack of R&D investment in basic industrial materials – hollow out basic technical infrastructure
  - Cultural and educational priorities neglect artisan skills for virtual reality
- Economic and Demographic Realities
  - Lack of incoming workforce – cultural discouragement, no economic need, fewer numbers
  - Cultural barriers- NIMBY, not my kid, preference for services, IT, finance, software, etc.
  - Best domestic sources are world class in quality, value and efficiency but lack the market demand and public policies needed to operate profitably enough to meet DoD or domestic economic requirements sustainably.
- DoD Acquisition
  - Lack of response for needed information and decisions- months not days, no answer= busted schedule
  - No information on timing, size, schedule of orders- No long term agreement with a business case that justifies new capacity, small lots from low-cost suppliers limits innovation
  - Complex purchase organization – DOD/OEM + lack of expertise
  - Risk driven decisions keeps old technology with tightening requirements of no demonstrated value.
  - Purchase is not a market transaction but a government contract – FAR, ITAR, CMMC, etc.

Large Steel Castings for high performance critical equipment is a concern.

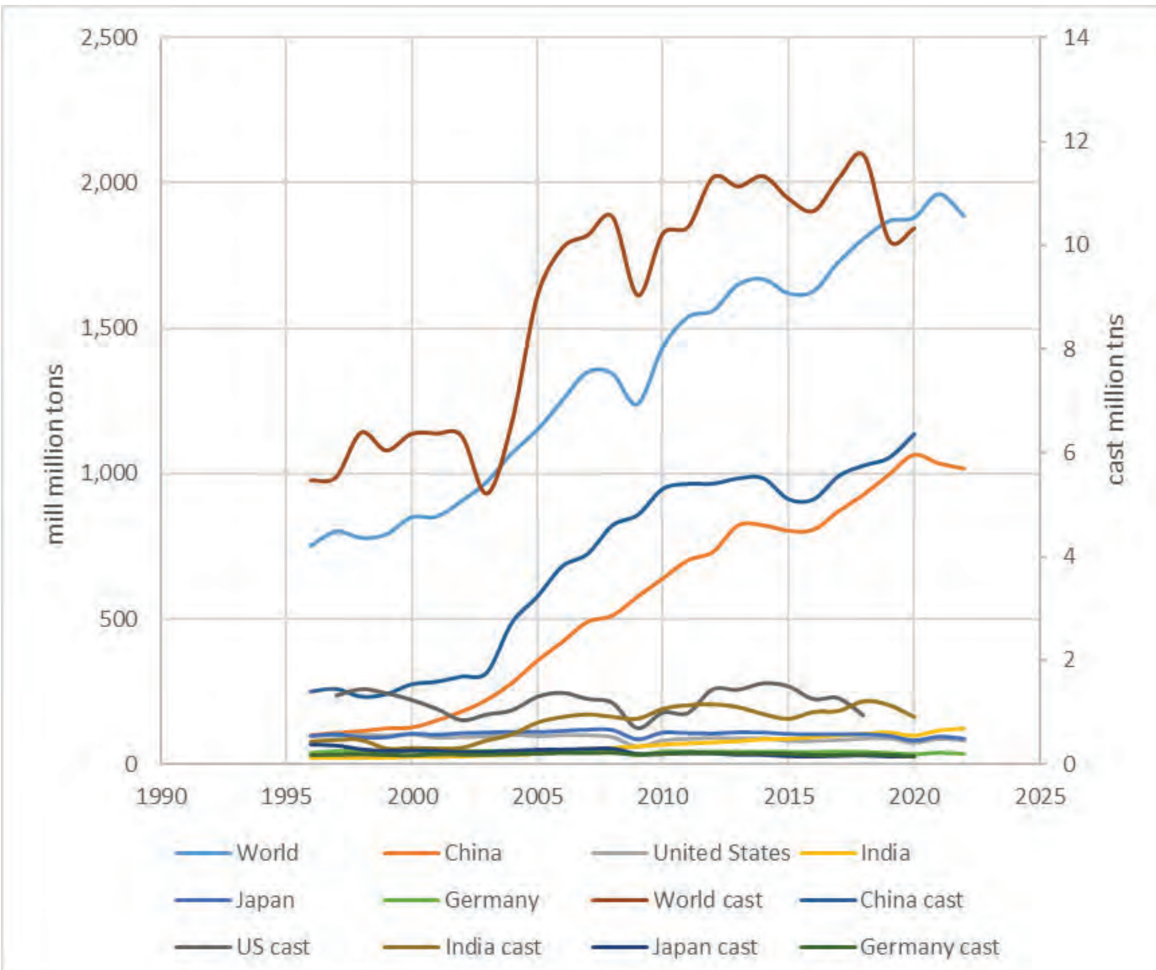




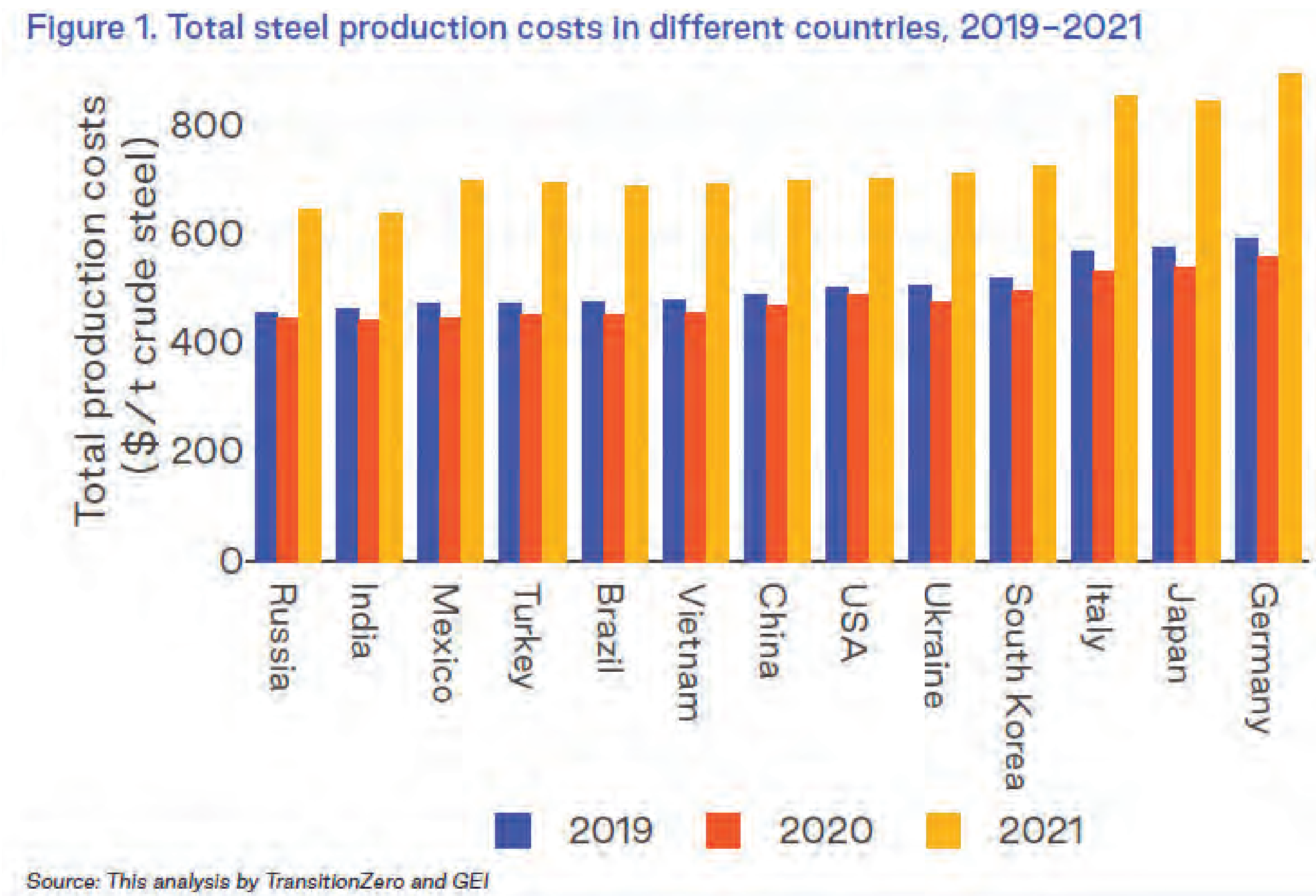
The move from integrated steel mills that made steel from ore to re-cycling scrap in EAF continuous casting reduced the ability to make large steel castings in North America.

One unintended consequence of global trade is the reduction of volume that limits the ability of domestic industry to justify the capital equipment for modernization and reduces the resources available for innovation.

Globalization was not a free market discovery of best value but a mercantilist geo-political structure.

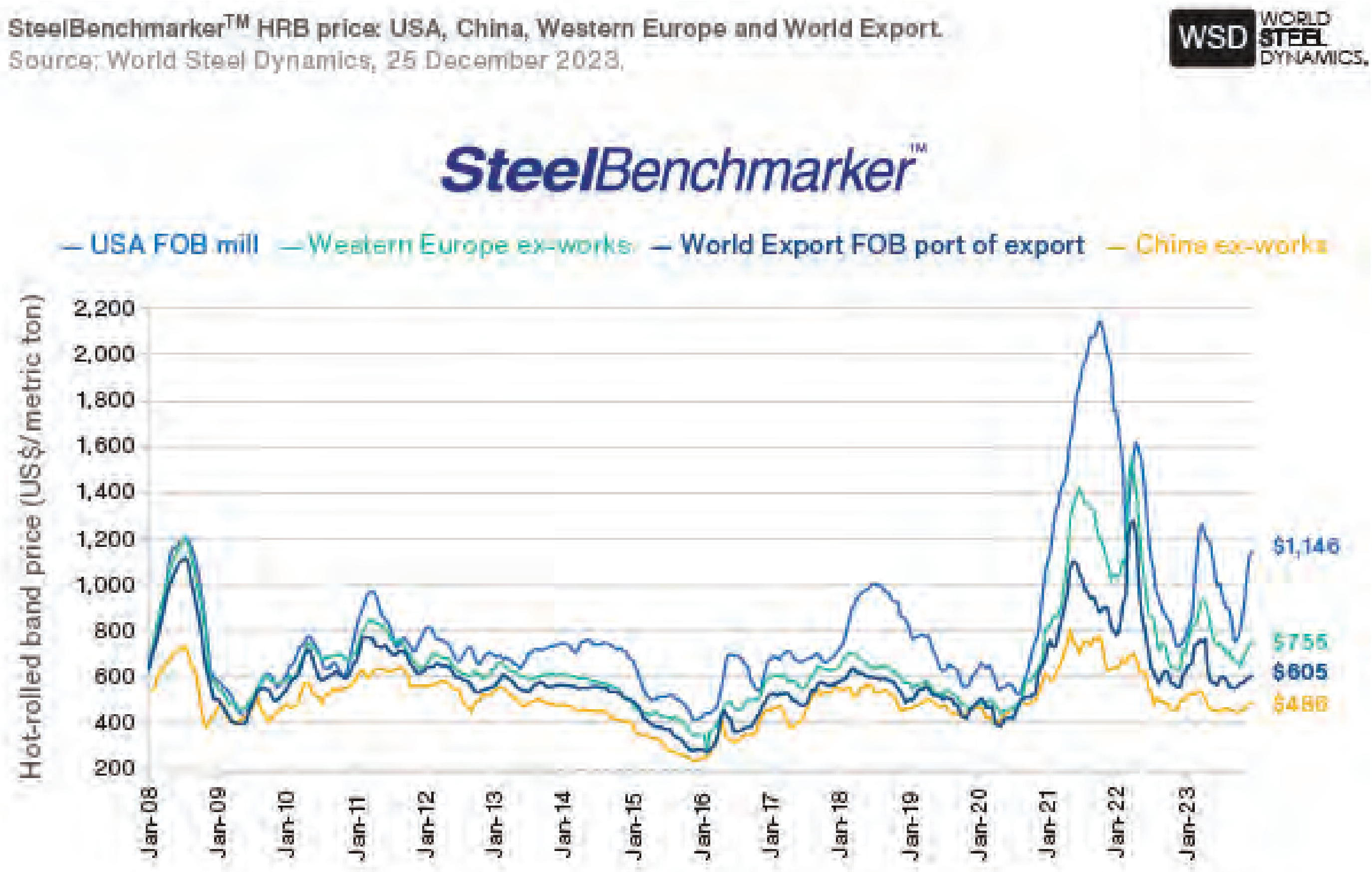


Production Costs are not significantly different

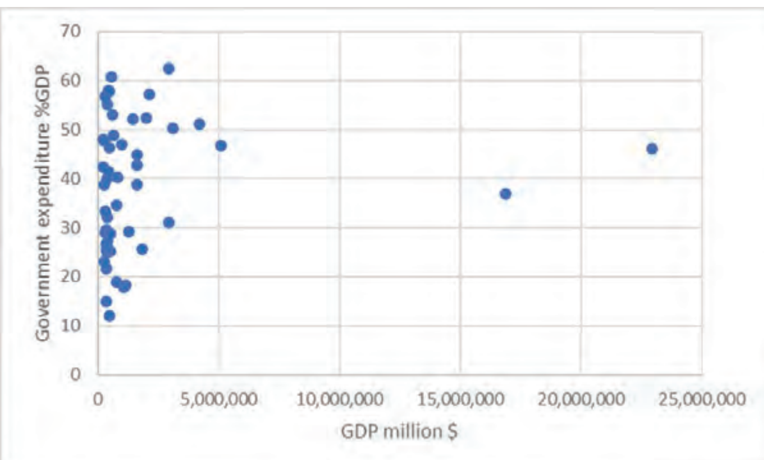


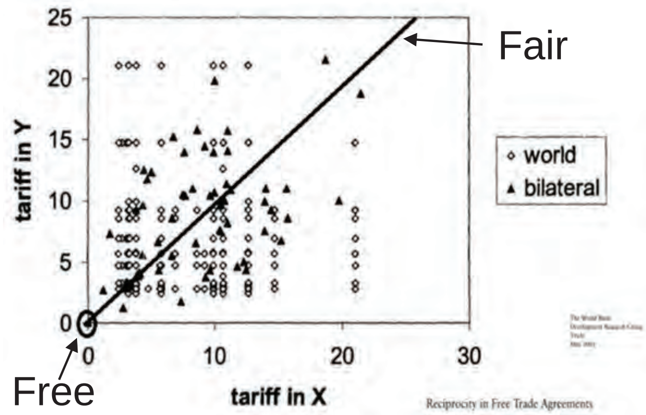
https://www.globalefficiencyintel.com/global-steel-production-costs-report

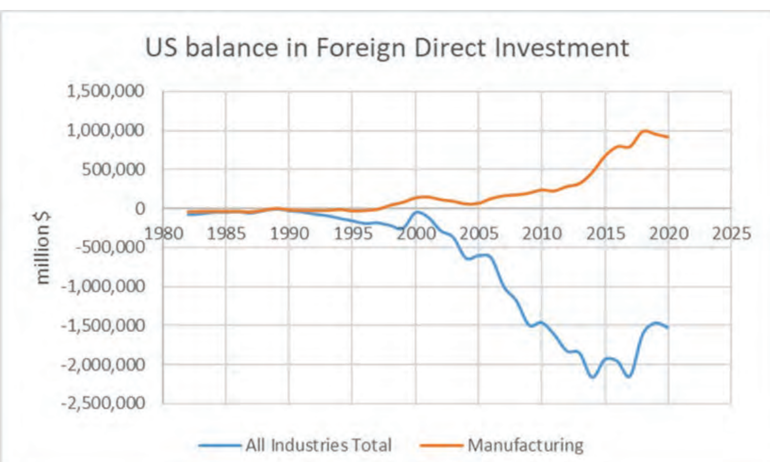
Steel prices at the mill are different.

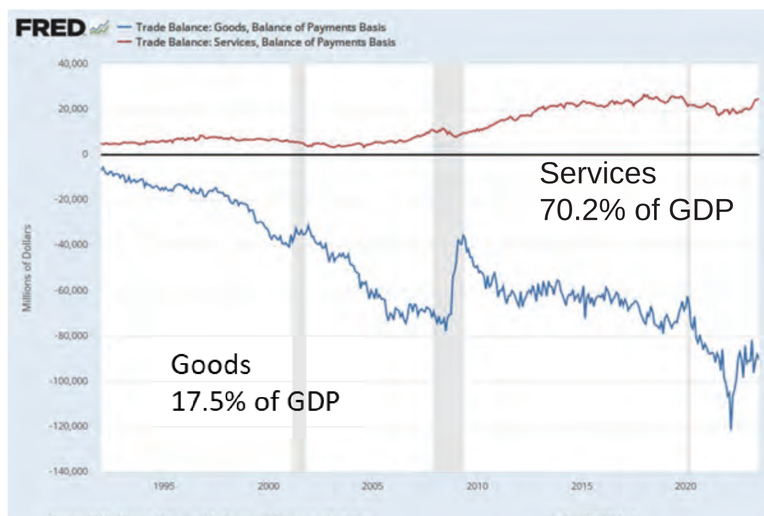


Trade is about Policy and National Interest.





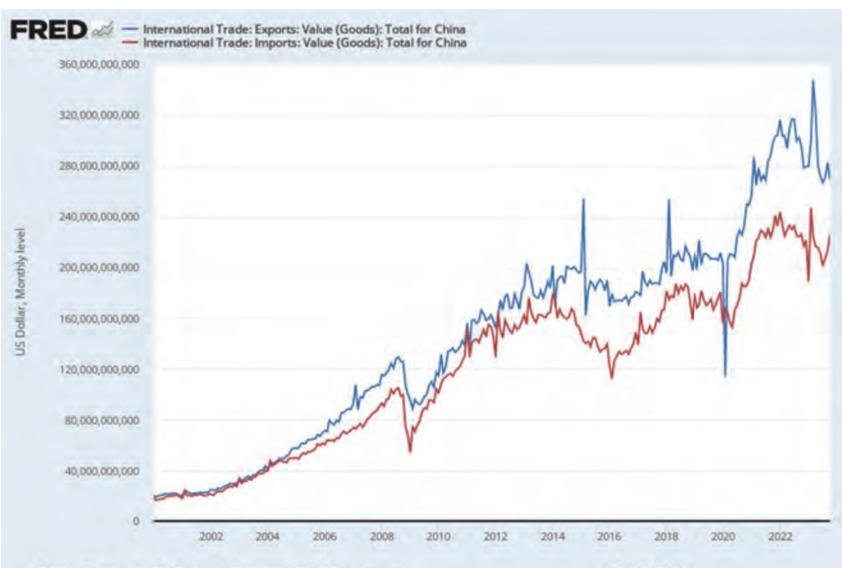


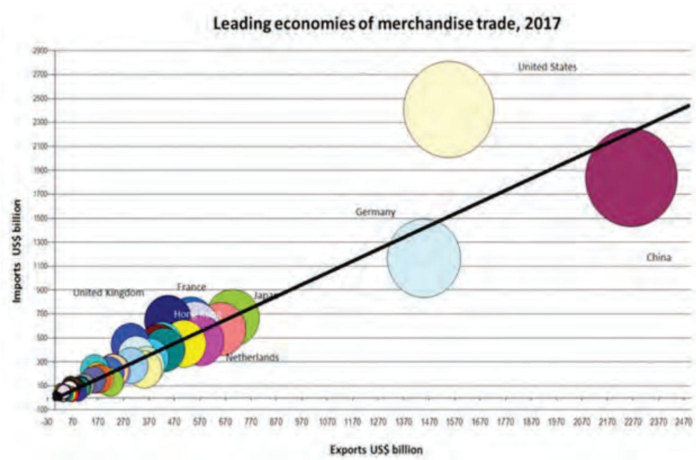


Trade is not a global challenge but a fundamental encounter between the EU (Germany), China and the US.

Germany and China face severe challenges on resources and demographics. Their ability to dominate economically in exporting products like steel are becoming limited.

Germany has no immediate source of energy that can support their industry. China mainly imports raw materials and energy and processes them.





ALARP – As Low As Reasonably Practicable

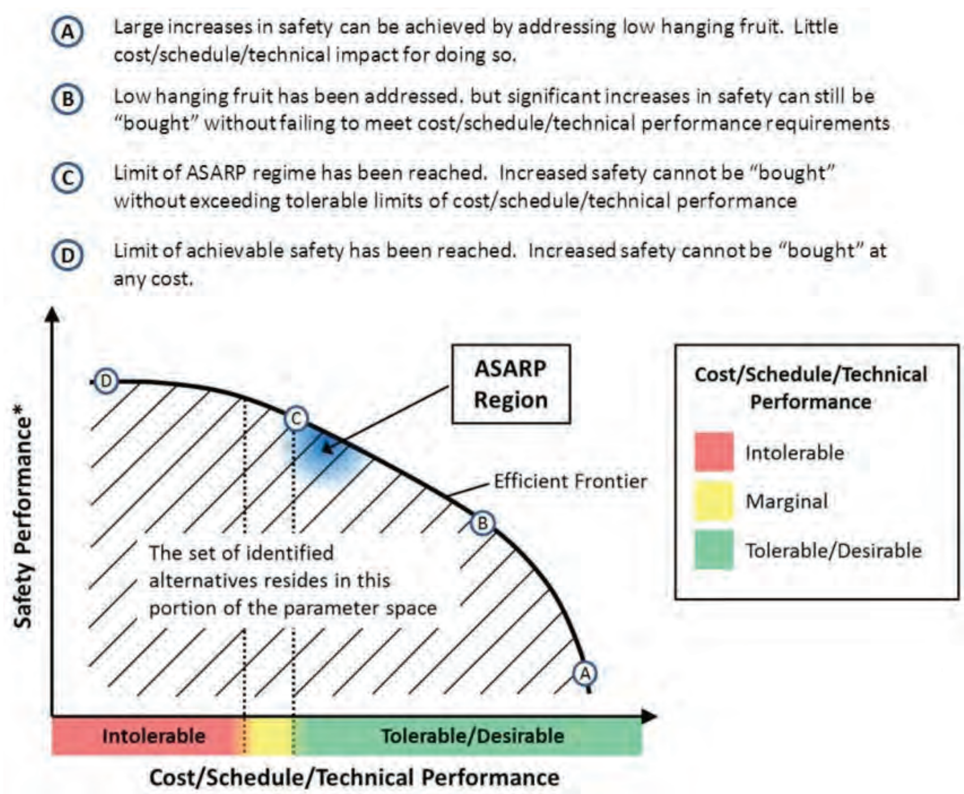
Regulations and other economic externalities burden capital intensive industries

Environmental and Safety regulations often require mitigation investments that have little effect on performance but are costly to capital intensive industries like steel producers.

These investments come directly from available profits. In 2005 according to the PACE Survey, primary metals had capital investments of $4,474.6 million and spent $511.9 million on environmental compliance or over 11%. They spent 1.1% of sales on compliance. A study has shown to full cost on environmental regulations is over 3 times the direct cost.

The idea that since all producers must comply so they can pass the cost of these investments to customers is problematic in a market with global trade.

The cost limit for regulators for ALARP is that fewer than 5% of the industry fails because of the added cost.



https://www.researchgate.net/publication/287645897_NASA_System_Safety_Handbook_Volume_2_System_Safety_Concepts_Guidelines_and_Implementation_Examples

Steel Additive Manufacturing

Sweet spots

- Fast when away from Amazon or part is not available soon
- Tooling because failure is an option
- Small parts where the model is easy to create
- Non-critical so qualification and quality not necessary barriers
- One-off where engineering, tooling and finishing with conventional methods is slow and costly
- Complex shapes with internal passages
- Weird materials like refractory metals, composites, or constitutionally graded
- Replacing or adding features to conventional components
- Repairing or replacing non-compliant materials in critical components

Limits

- Large parts bigger than a bread box reduces the advantages and increases the post processing required.
- Qualification may require a process+ first article+ machine+ operator+ powder+ etc.?
- Quantities that are large makes the speed of production critical and AM is slow building a layer at a time.
- Quality certification requires undeveloped material and NDT verification for process? part?
- Materials are limited with current powders and wires and expanding the supply is slow.
- Materials and energy required exceeds conventional when including the wire or powder production.
- Cost and Time?

Challenges for Large Scale Additive Steel parts

1. Feedstock- Is the quality, availability and performance comparable to parts with produced with current methods?
2. Material properties- What is the strength, toughness, ductility for heavy sections and in different orientations on large scale AM builds using quantity feedstocks?
3. Process qualification- Can the process be qualified for parts with first articles to demonstrate the ability to meet material properties in heavy sections? What first production item tests will be needed? What product variations from requirements will be allowed?
4. Process control- What measures of process control will be required and how will they be measured and documents? What options are there for variations from the control ranges?
5. Part qualification- What tests and test material will be required for part qualification? What re-tests or added re-processing like re-heat treat will be permitted?
6. Fabrication Compatibility- Will these parts respond similarly to traditional items in welding into larger structures and maintain the needed performance?
7. Inspection- What NDT and other inspection tools will be required? What will the inspection specification levels be required for parts made with AM?
8. Legacy issues- The specifications and requirements for castings and forgings are dated and burdensome without providing direct assurance of reliable performance. Revising or adding options to the requirements would be a major step to improve the supply of needed components.

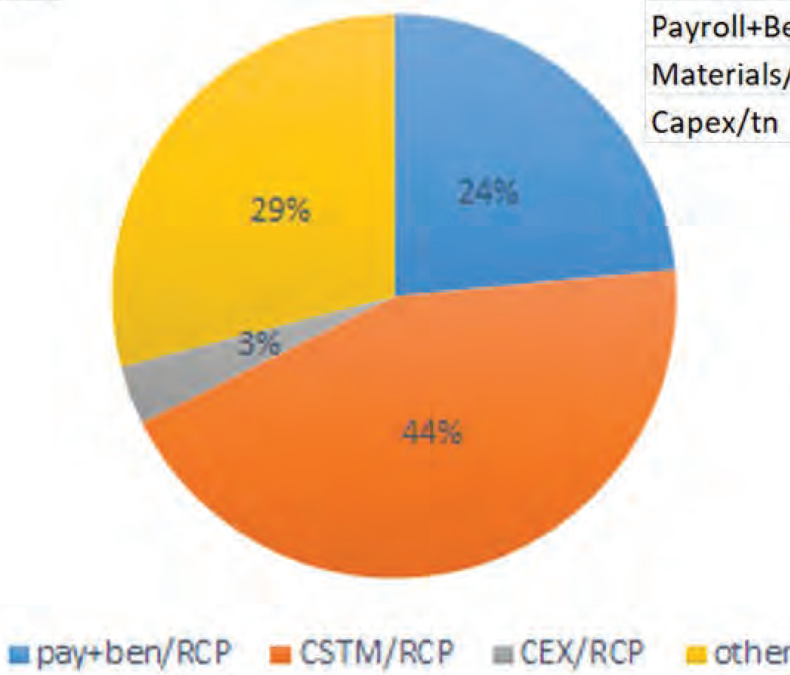
Thanks!
Questions?

Raymond Monroe
815-263-8240
monroe@sfsa.org

PROD (tn)	1,182,000
RCP ($million)	4,457
EMP (#)	16,045

Steel Foundry

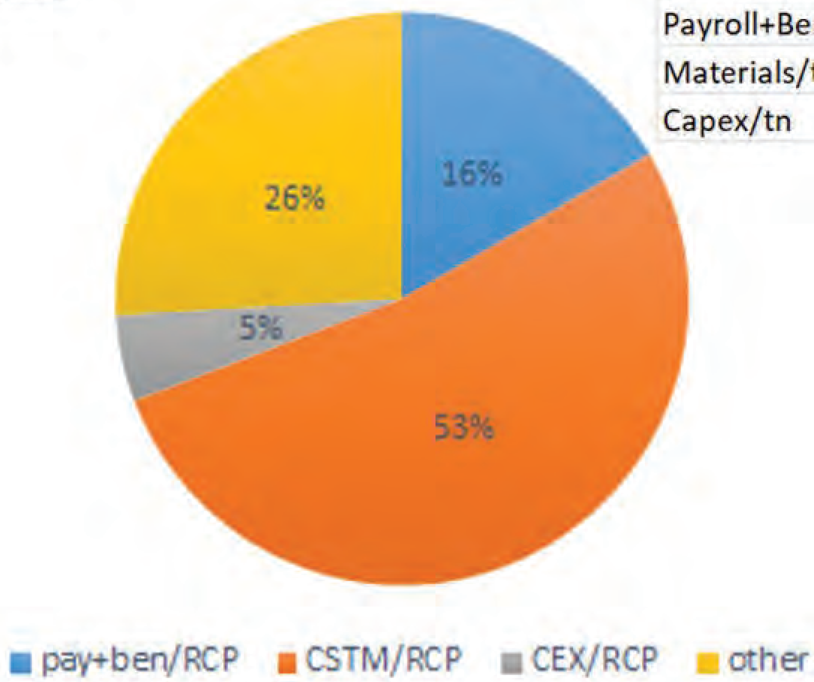
RCP/tn	$3,770.92
Prodval/tn	$3,394.79
Valadd/tn	$1,948.11
Payroll+Benefits/tn	$917.54
Materials/tn	$1,720.34
Capex/tn	$132.55



PROD (tn)	2,450,837
RCP ($million)	9,219
EMP (#)	21,282

Steel Forge

RCP/tn	$3,761.41
Prodval/tn	$3,745.59
Valadd/tn	$1,658.41
Payroll+Benefits/tn	$655.48
Materials/tn	$2,080.39
Capex/tn	$193.04



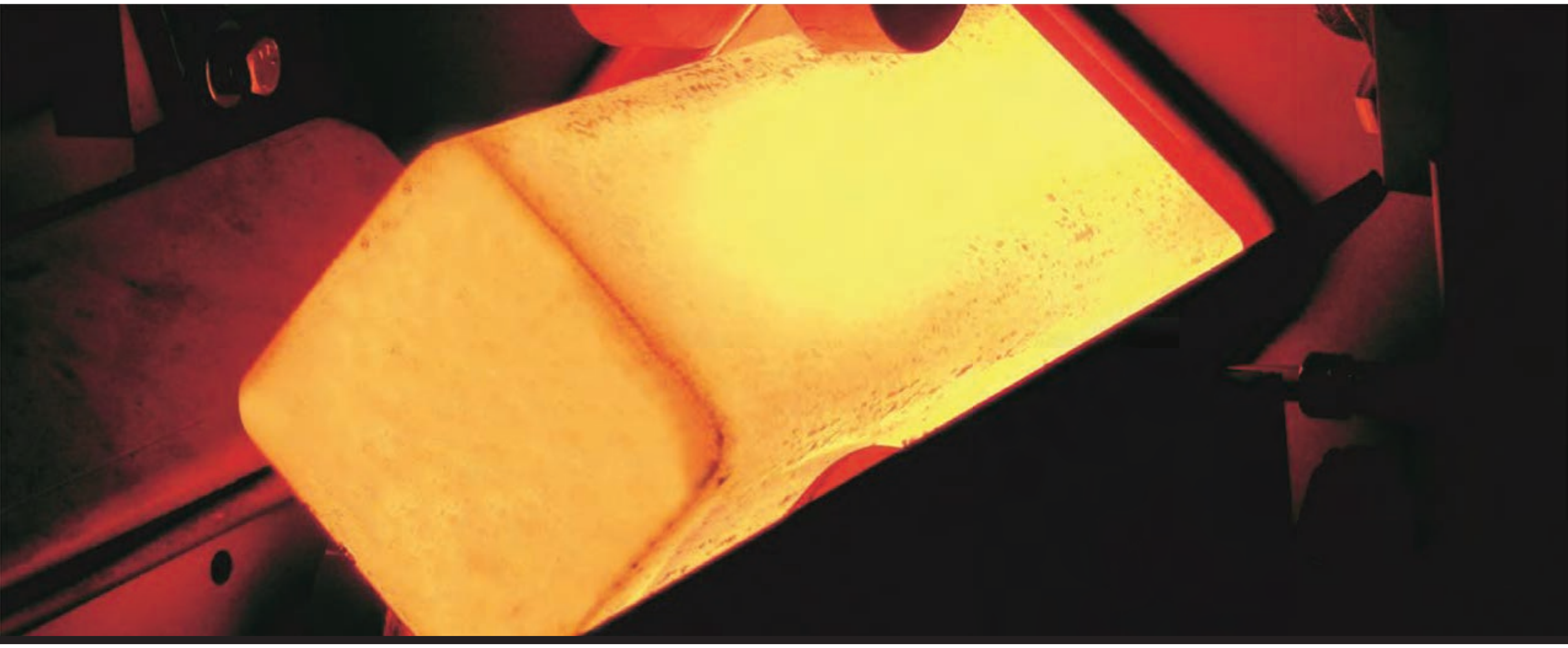
Steel Casting and Forging Plants can still meet the domestic demand

Forgings Priorities

Forgings Roadmap and Priorities

FORGING INDUSTRY ASSOCIATION

JIM WARREN, DEKLAND BARNUM



FIA Membership

Membership Numbers

❖FIA membership grew 8% from YTD (‘22-23)

❖The association is made up of 230 member companies (352 operations)

- ❑ 106 producers (197 forging operations)
- ❑ 124 suppliers (155 supplier operations)

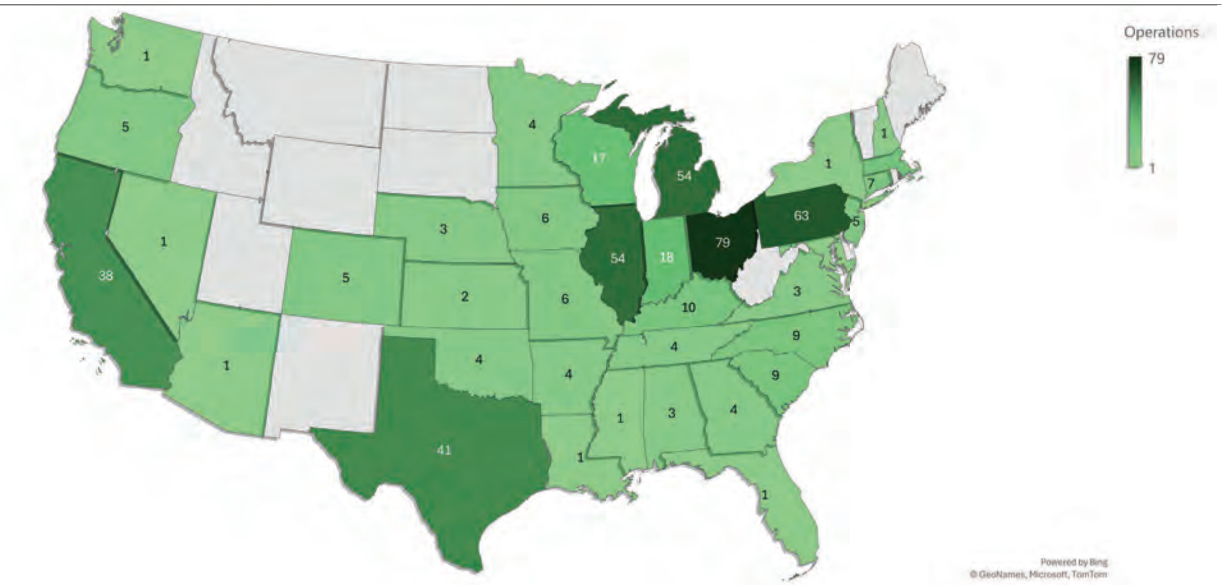
❖FIA membership is 75% of North American forging market

❖FIA has served the forging industry since 1913

❖FIA is:

- ❖Forge Fair
- ❖FIA Magazine
- ❖Govt Affairs Advocate for Forging

Forging Operations by State



THE ONLY NORTH AMERICAN TRADE ASSOCIATION DEDICATED TO PROMOTING AND SERVING THE FORGING INDUSTRY

FORGING INDUSTRY ASSOCIATION

State of the Industry

4/8/2024

THE ONLY NORTH AMERICAN TRADE ASSOCIATION DEDICATED TO PROMOTING AND SERVING THE FORGING INDUSTRY

FORGING INDUSTRY ASSOCIATION

Forging Producers Have Capacity

❖North American forgers have the open capacity needed to serve the warfighter

❖The forging industry has a capacity utilization rate of 65% (March 2024) which equals its February 2023 rate and an estimated 67% capacity utilization for remaining months in 2024

❖FIA members represent 75% of the forging output for North America and can take on more customers, including DOD and DOE

Capacity Testimonials

"We were asked 'do you have the excess capacity to meet our needs?' Our response was 'absolutely, without a doubt.' And their response was 'Are you sure?' We don't really believe you.' It speaks exactly to what we're up against."

–FIA Board Chairperson

"We've made those things for 40 years. When somebody says something can't be made here, or the capacity or the capability doesn't exist, we clearly can show them that it does."

–FIA Defense Advisory Committee Chairperson

How Capacity Utilization is Calculated

The Federal Reserve Board defines capacity as the sustainable maximum machine output, which represents the greatest level of output a plant can maintain with a realistic work schedule after factoring in normal downtime and assuming sufficient availability of inputs to operate capital in place. As an example, a typical forging plant may realistically run 40-60 hours across a four-to-six-day work week (some run 24/7). Capacity reflects a sustainable maximum instead of a short-lived, unsustainable peak.

Evidence We Have the Capacity

In a March 2024 survey conducted by the association:

1. The forging industry has a capacity utilization rate of 65% (MARCH 2024) which equals its FEBRUARY 2023 rate, and estimated 67% capacity utilization for remaining months in 2024.

   Current capacity utilization in overall manufacturing: 76.6% (January 2024 – Federal Reserve Board).

   Full capacity utilization in manufacturing is accepted at 85% (factoring in normal downtime and assuming sufficient availability of inputs to operate the capital in place). Over the period from 1972 to 2022, average capacity utilization in manufacturing was 78.2%, with utilization rates exceeding 90% only during wartime.

Monthly Index Overview

JAN 2024

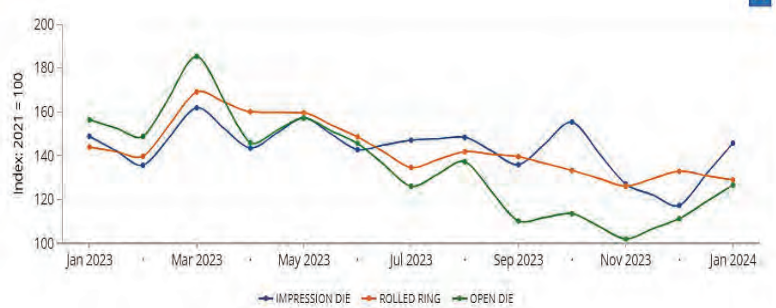
TOTALS

	INDEX	% M/M	% Y/Y
SHIPMENTS	131.58	11.52	-13.2
BOOKINGS	252.44	163.85	38.77

4/8/2024

PRODUCTS

	INDEX	% M/M	% Y/Y	% Y/Y (SHP/WT)
IMPRESSION DIE	145.71	24.27	-2.1	15.67
ROLLED RING	128.9	-2.99	-10.45	16.19
OPEN DIE	126.61	13.85	-19.05	-11.81

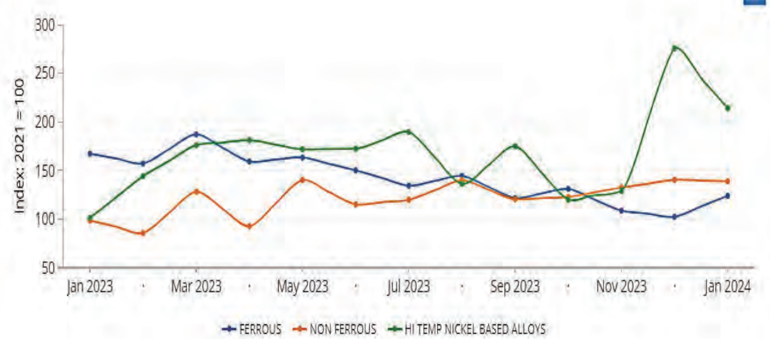


METAL PROFILES

4/8/2024

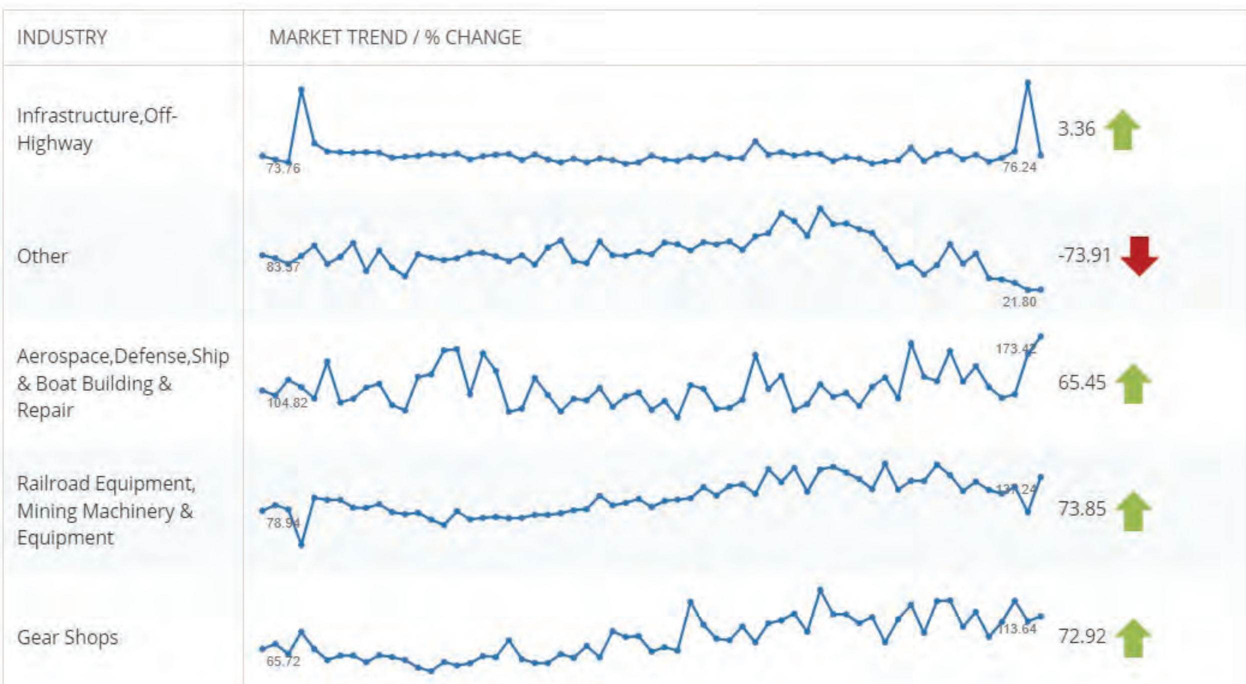
METAL PROFILES

	INDEX	% M/M	% Y/Y
FERROUS	123.86	21.06	-26.01
NON FERROUS	138.84	-1.14	40.97
HI TEMP NICKEL BASED ALLOYS	214.17	-22.33	111.46



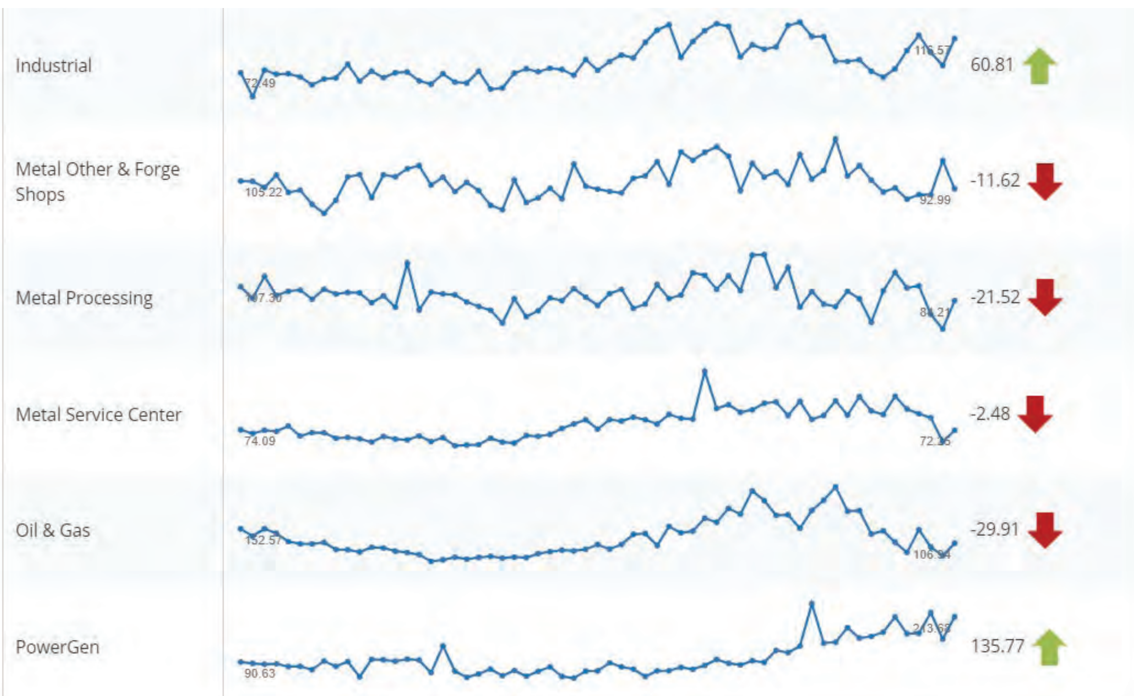
4/8/2024

Open Die – 2019 to present (Index 2021 US Mfg Census



4/8/2024

Open Die – 2019 to present (Index 2021 US Mfg Census



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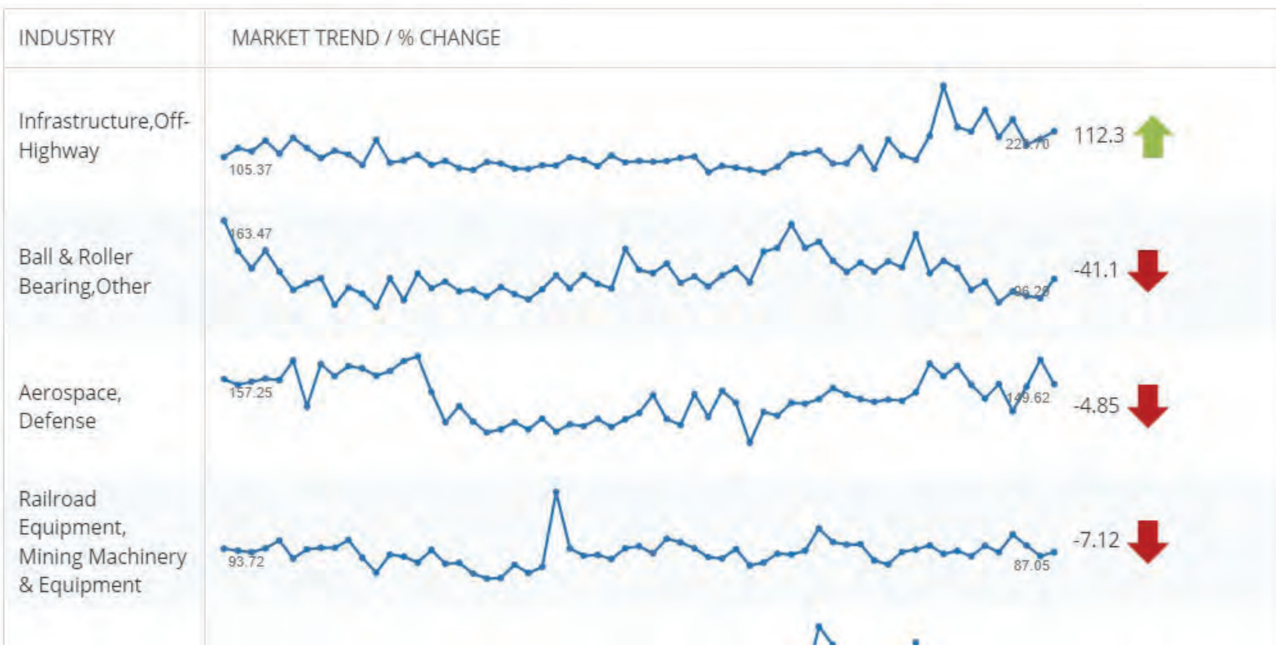
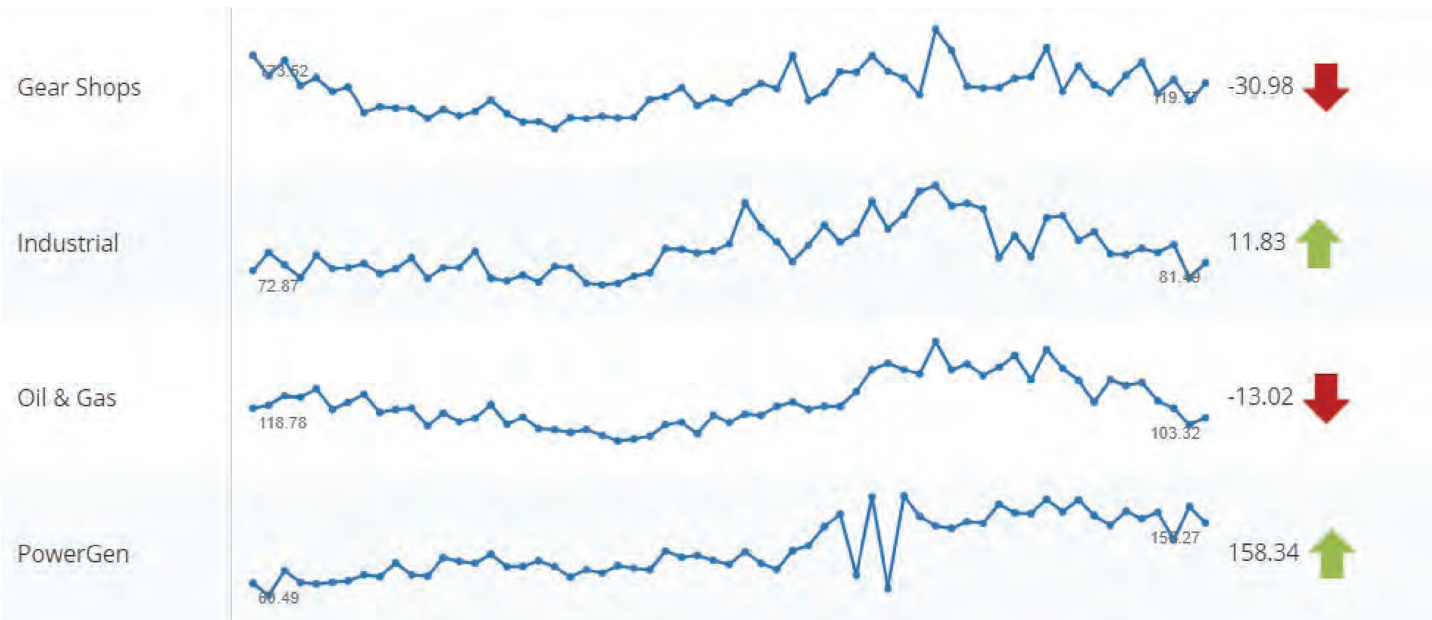
Rolled Ring– 2019 to present (Index 2021 US Mfg Census



4/8/2024

Rolled Ring– 2019 to present (Index 2021 US Mfg Census



4/8/2024

FIA Technology Roadmap

4/8/2024

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PROMOTING AND SERVING THE FORGING INDUSTRY

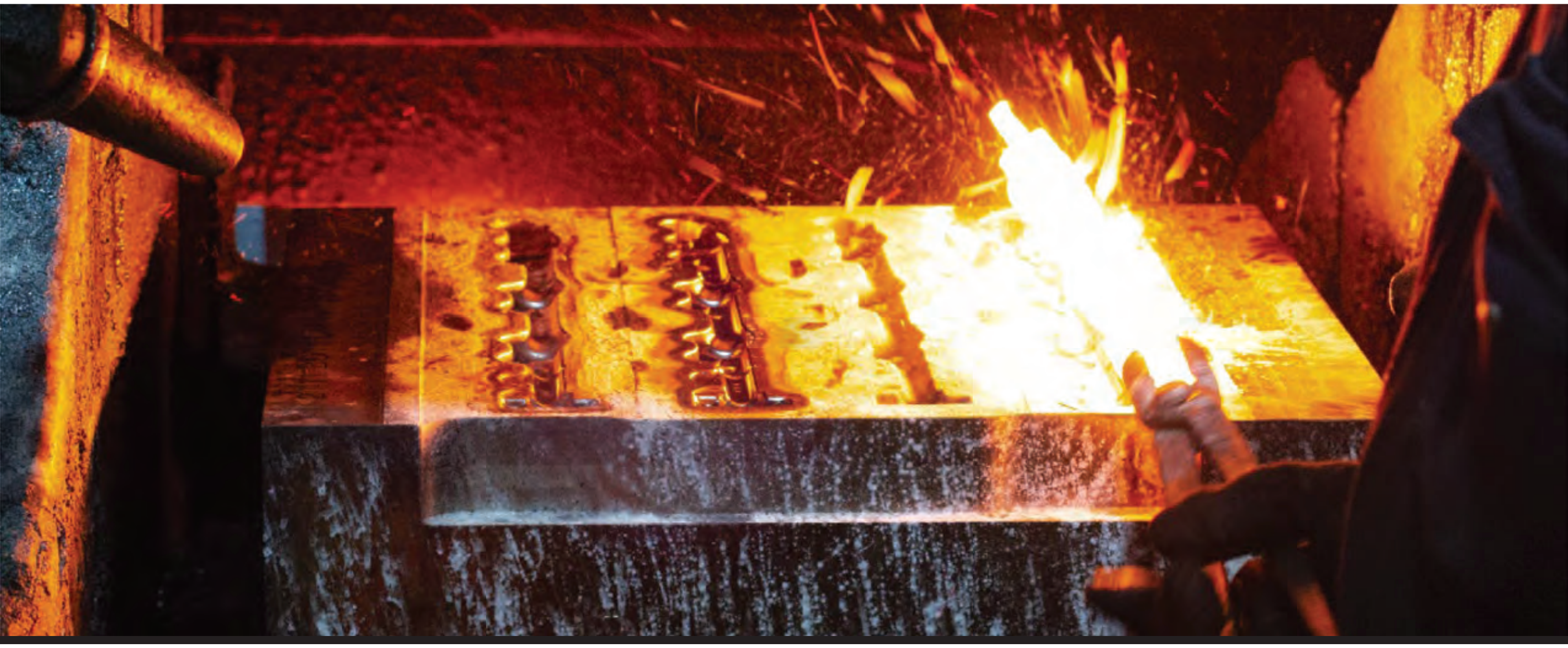
FORGING INDUSTRY ASSOCIATION

Background

The FIA Technical Committee facilitates, develops, and disseminates technical knowledge relative to the forging process and forging supply chain for the benefit of FIA Members while also working closely with Magnet Schools. After discussion, the committee feels that there is a need in the industry for projects pertaining to a select topic areas. These topic areas were sent along with the call for projects for 2024.

Technology Roadmap Topic Areas

1. Metallurgical Processing and Process Design
2. Process Simulation
3. Metallic Materials Development
4. Lightweighting
5. Die Materials, Surface Technologies and Die Repair
6. Inspection Techniques
7. Materials Characterization
8. Forging Lubrication
9. Automation, Ergonomics & Robotics
10. Industry 4.0 & Digital Manufacturing, including AI or Machine Learning
11. Carbon Emission Reduction and Environmental, including Recycling
12. Forging Industry Equipment Lifecycle Extension
13. Forging for Extreme Environments



Forging Industry Education Research Foundation (FIERF)

4/8/2024

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FORGING INDUSTRY ASSOCIATION

Education Opportunities

FIERF offers multiple scholarships each year

1. Charles W. Finkl Scholarships: $2,000 to college juniors and seniors
2. Forging Industry Women's Scholarship: $5,000 scholarships to fulltime graduate and undergraduate women
3. The Al Underys Engineering, Metallurgical & Material Sciences Memorial Scholarship: $2,500 to undergraduate and graduate students

FIERF is hosting three Forge the Future Summer Camps this year

1. Cleveland, OH: July 8-10, ages 11-15
2. Chicago, IL: July 22-24, ages 15-18
3. Warren, MI: August 5-6, ages 11-15

For additional information contact Amanda Dureiko, Senior Manager for Foundation and Workforce Development at amanda@foging.org or 216-781-6260

Forging Club for Students

❖Request for Proposals: $5000 to schools to develop forging clubs

❖First year of awards, twelve applications received

❖Awarded schools will:

1. Start an official Forging Club at their school
2. Compete in FIERF's Forging Competition in 2025

For additional information contact Amanda Dureiko, Senior Manager for Foundation and Workforce Development at amanda@foging.org or 216-781-6260

Forging Research Opportunities

- Research Proposals: Ten projects from nine universities received this year
- Foundation investment in university research:
  - $280k in 2023
  - $300k in 2022
  - $400k in 2021
- Save the Date: 33rd Forging Industry Technical Conference: September 17-18 in Erie, PA

For additional information contact Dekland Barnum, Senior Technical Manager at dekland@forging.org 216-781-6260

Ongoing Forging Projects

Friction Stir Processing	Colorado School of Mines
Metamorphic Manufacturing	Colorado School of Mines
Preform Design for Flash-less Die Forging	North Carolina State University
Digital Twin for Metal Forging	Colorado School of Mines
Fabrication of Forging Preforms	Cleveland State University
Wire-arc Additive Manufacturing	Georgia Southern University
Predicting Site-Specific Microtexture	University of Florida
Manufacturing Automation Cell (MAC) Project	Blackhawk Technical College
Intensive Quenching of Die Steels: Compressive Stresses	The University of Akron
Predicting the Occurrence of Central Burst During Open Die Forging of High Strength Steels : A Metallurgical and Mechanical Analysis	Université du Québec
Assessing deviations from Flow Stress Models at the Extremes of the Aluminum Forging Range	University of Cincinnati
50-ton Forging Demonstration/Experimental Press Build	Marquette University
Numerical Modeling of Tooling Improvements for Forging Processes	Lehigh University
Tracking Non-metallic Inclusions During Primary and Secondary Melting	Carnegie Mellon University
Creating Ohio State's First Forging Club with Focus on Forging Future	Ohio State University

Workforce Development
Defense Logistics Agency (DLA)

Workforce Development Toolkit Project Status

Workforce Dev. Toolkit Overview

❖A toolkit that: (1) provides the latest essential skills and knowledge for the next generation workforce; (2) provides specification support training; and (3) facilitates the transition of current and emerging forging process technology developments

❖Needs and Benefits

1. No cost access for DOD personnel, continuous updates with industry input.
2. Workforce development opportunities for the warfighter in relation to forged content.
3. Automation toolkit for rapid training of shrinking workforce

❖Partnering with FIA member companies as well as universities and community colleges near concentrated forging operations

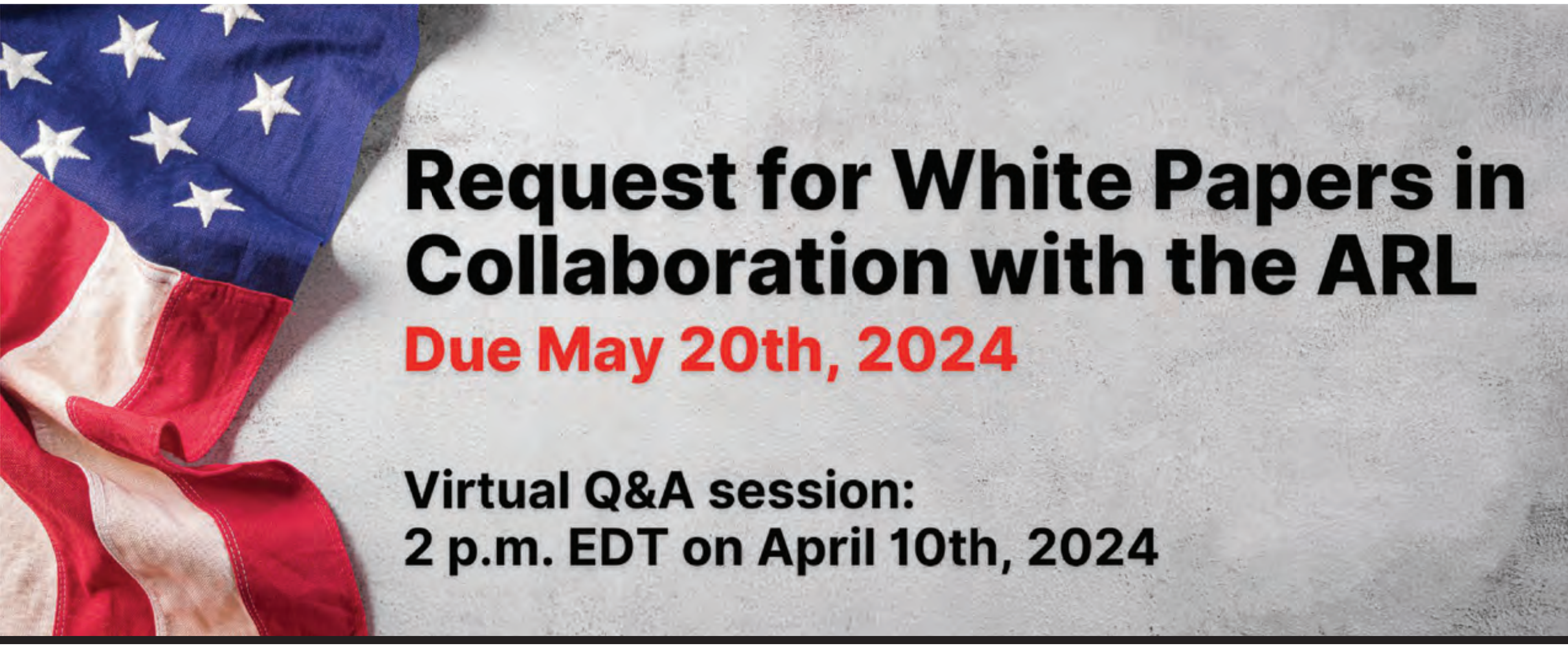
❖Numbers: 3,383 accounts open, 63 accounts are .mil, 10 accounts are .gov, and 146 are.edu accounts

Deliverables

- ❖ Provide complete access to all courses for DOD personnel at no cost
- ❖ Implement 1-2 seminars annually at Defense Acquisition University or alternate Learning Management System
  - ❑ Eight modules uploaded to DAU testing environment in February
- ❖ Deliver six e-learning courses annually to strengthen and preserve forging knowledgebase
  - ❑ Delivered 21 custom e-learning courses to date and 34 modules
- ❖ Three web courses and three workforce development webinars
  - ❑ Delivered ten live webinars recorded to date

Acknowledgements

This research is sponsored by the Defense Logistics Agency Information Operations, J68, Research & Development, Ft. Belvoir, VA, and by DLA-Troop Support, Philadelphia, PA.



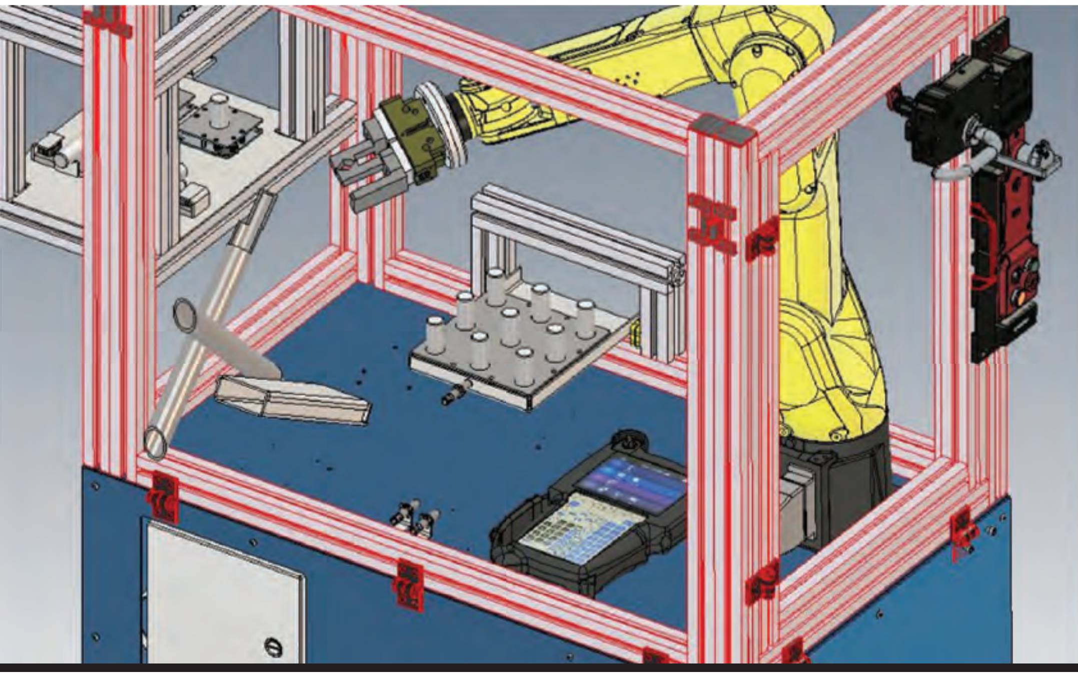
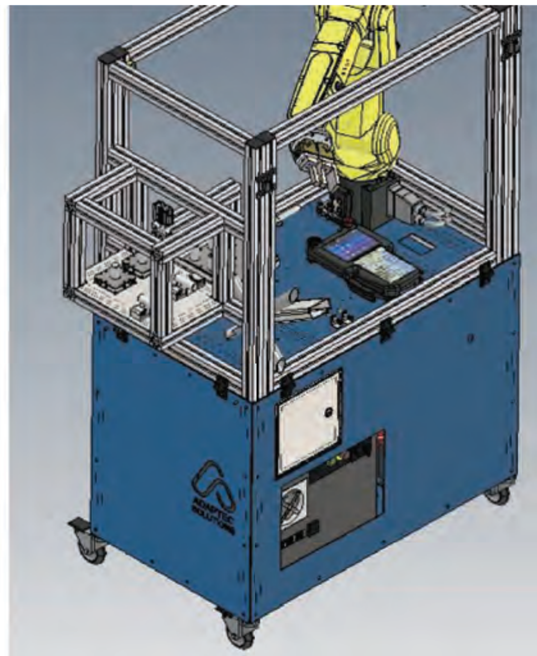
Current and Future Work with Army Research Lab (ARL)

Overview

FIA is announcing a formal request for white papers in collaboration with the Army Research Lab (ARL). ARL understands the critical role forgings play in the Defense Industrial Base (DIB), and the need for investment in the forging industry to ensure a robust and healthy DIB.

ARL will consider FIA member and non-member white paper submissions for funding. The primary objective of this opportunity is to maximize the probability of project results transitioning to implementation within the industry. White paper selection is subject to the submissions received and the criteria outlined on the FIA website forging.org under the Advocacy tab.

All questions can be directed to dekland@forging.org. Questions will be published on FIA's website.

FIA Automation Initiative

4/8/2024

THE ONLY NORTH AMERICAN TRADE ASSOCIATION DEDICATED TO PROMOTING AND SERVING THE FORGING INDUSTRY

FORGING INDUSTRY ASSOCIATION

Proposed Automation Course

❖The primary objective of this course is rapid adoption of automation

❖Impediments

1. Capital
2. Trained Employees

❖Teach existing employees robotics by bringing the training to their job site and alleviate competition for automation technicians with compact, pertinent training

❖Certificates: FIA will award certificates after successful completion of the courses

1. Basic robot operation/programming
2. Advanced robot programming/troubleshooting

Proposed Automation Course Cont.

- ❖FIA will work with forging companies to schedule training sessions including a qualified instructor and cart(s)
- ❖Each class has a defined curriculum which includes specific sections pertinent to forging and grinding
- ❖The training sessions will be recorded and available in Forging University alongside existing content
- ❖FIA will coordinate with local community colleges to provide the training cart and arrange for training sessions
- ❖Some carts will be permanently deployed to forging & casting plants with significant automation investments

RAPLSS National Conference Slides

Roadmap for Accelerating Production of Large Structures and Systems

National Conference
Review of Draft Roadmap
March 19-20, 2024

NIST Award #: 70NANB22H045

DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of NIST.

Antitrust Guidelines

The Roadmap for Accelerating Production of Large Structures and Systems is a collaboration among industry sponsors to assess and roadmap the state of technology in production of large structures and systems using pre-competitive surveys, interviews and workshops. The roadmap will meet the National Institute of Standards and Technology (NIST) Manufacturing USA Technology Roadmap objectives.

This meeting is for the specific purpose described in the agenda and not for the purpose of reaching any agreement that affects the competitive business activities of companies represented.

1. Steering committee meetings are conducted in accordance with the antitrust provision provided to all committee members;
2. All participants should have the Agreement and should be familiar with the antitrust provision;
3. Participation in the committee and its meetings is completely voluntary;
4. Any questions or concerns about antitrust or any other legal matter should be directed to your company's counsel.

Agenda

Day 1 - Tuesday, March 19th (Eastern Standard Time)

12:00-1:00 – Arrive / Check-In / Networking Lunch
1:00 – 1:15 – Introduction to NIST RAPLSS Conference
1:15 – 1:45 – **NIST keynote – NIST – Dr. Kelley Rogers**
1:45 – 2:15 – EWI NIST RAPLSS Program Overview
2:15 – 3:55 – **Advanced Energy**
- 2:15 – 2:40 - **Wind Roadmap Priorities – Doug Fairchild, Welding, Metallurgy, and Steel Consultancy, LLC**
- 2:40 – 3:05 – **Nuclear Roadmap Priorities – Dave Gandy, EPRI (Virtual)**
- 3:05 – 3:30 – BREAK
- 3:30 – 3:55 – **Carbon Capture and the Hydrogen Economy - Josh James, EWI**

3:55 – 4:20 – **Workforce Development Roadmap Priorities – Gardner Carrick, Manufacturing Institute (Virtual)**
4:20 – 4:30 - BREAK
4:30 – 5:15 – **Day 1 Subject Matter Expert Panel – Rogers, Fairchild, Gandy, Carrick**
5:15 – 7:00 – EWI Tours + Reception

Day 2 – Wednesday, March 20th (Eastern Standard Time)

8:00 – 8:30 – Arrive / Check-In
8:30 – 8:35 – Agenda Review
8:35 – 10:15 – **Large Structure Mfg & Fab Supply Chains**
- 8:35 – 9:00 – **Challenges in the Development, Adoption, and Scale-up of Robotics in Manufacturing – Chuck Brandt, ARM Institute**
- 9:00 – 9:25 – **Cobots for Fabrication of Large Structures – Doug Rhoda / Drew Akey, Vectis Automation**
- 9:25 – 9:50 – **Castings Roadmap Priorities – Ray Monroe, SFSA**
- 9:50 – 10:15 – **Forgings Roadmap Priorities - Jim Warren / Dekland Barnum, FIA**

10:15 – 10:25 – BREAK
10:50 – 11:30 – **Day 2 Subject Matter Experts Panel – Brandt, Rhoda/Akey, Monroe,Warren/Dekland**
11:30 – 11:45 – BREAK
11:45 - 1:00 – **EWI Roadmap Results** (working lunch)
1:00 – Dismiss

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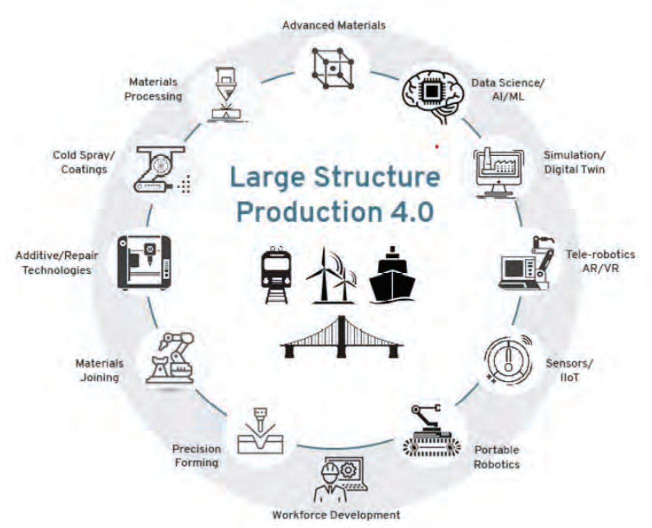
Introduction/Background

- America's ability to manufacture large structure affordably has diminished in recent decades.
- American industries need Large Structure Production 4.0 technologies to be competitive and establish world-leading capabilities or else risk lagging the world in:
  - Advanced transportation infrastructure
  - Advanced civil infrastructure
  - Advanced power infrastructure
  - Supply chain capabilities



Objectives

- The objective of this project was to develop the first comprehensive U.S. Roadmap for Accelerating Production of Large Structures and Systems (RAPLSS). The Roadmap meets the National Institute of Standards and Technology (NIST) Manufacturing USA Technology Roadmap objectives.
- This roadmap focuses on making large structures and systems better, faster, and cheaper through development of Large Structure 4.0 technologies, next generation manufacturing, fabrication and inspection processes, and advanced training programs.
- **NIST Award No.: 70NANB22H045**

EWI and OSU Project Teams

- EWI
  - Dennis Harwig, Technology Leader
  - Katie Hardin, Senior Program Manager
  - Larry Brown, Senior Project Manager/Technical Advisor
  - William Mohr, Principal Engineer
  - Technology Leaders
  - Business Development Managers
  - Steve Levesque, Former Director of Innovation
  - Doug Fairchild, Technical Consultant
- OSU
  - Boyd Panton, Assistant Professor
  - Antonio Ramirez, Professor and Director Ma^2JIC
  - Heather Spisak, Assistant Director Ma^2JIC
  - Ania Grimm, Administrative Assistant Ma^2JIC

Overview of Steering Committee Role

Provide perspectives on industry sectors, OEMs, suppliers, SMEs, and research institutions.

Banker Steel	Cloos	RIA-JMTC	Army ERDC
EVRAZ North America	Steel Founders Society of America	BP International Ltd.	Haynes International
Insyte Consulting	Komatsu	Visioneering	ORNL
America Makes	Caterpillar	GE Power	AWS
EPRI	ATI	IPG	Arcelor Mittal

- Guide roadmap development and participate in steering committee meetings
- Input for planning for interviews, surveys, and focus groups with key industry stakeholders
- Review progress and provide recommendation for ongoing project improvement and tactics
- Review roadmap draft(s) and prioritize technology portfolio and research topics within the roadmap

Project Activities

- Reviewed existing roadmaps, research center capabilities, and industry consortia capabilities to establish a baseline for the existing ecosystem
- Conducted targeted interviews to establish baseline needs and identify industry gaps for technical areas for each industry vertical
- Managed four focus group workshops across key industry stakeholders and locations to gather detailed data specific to industrial sector needs and gaps
- Conducted surveys to expand upon and validate findings
- Conducted four steering committee meetings
- **Organized national conference at EWI headquarters in Columbus, OH, to present and discuss findings of the roadmap and proposed research topics**
- Finalized roadmap report – submit to NIST, the steering committee, and national stakeholders

EWI Gap Analysis Workshop

Industry Verticals

- Off-shore Wind / Maritime
- Hydrogen/CCUS/Petro-chemical/ Refining
- Nuclear
- Primary Metals
- Mega Building / Bridges
- Rail and Mass Transportation

Industry Capability Areas

- Design: Methodologies and Models, Digital Thread and Twins
- Fabrication Technologies
- Integrity: Condition Monitoring, Service Life Extensions and Optimization
- Conventional and Advanced Materials
- Supply Chain
- Workforce Development
- Capex Costs
- Standards and Codes

Previous Roadmap Summary

- 16 roadmaps were reviewed for the following industries:
  - Offshore Wind Energy
  - The Rail Industry
  - Casting and Forging
  - Manufacturing, Welding, Joining, and Forming
  - The Nuclear Industry
  - Hydrogen Energy Systems

Interviews

- Individual interviews were conducted to establish a baseline of needs and identify industry gaps for technical areas for each industry vertical.
  - Yielded similar feedback amongst the industry verticals
  - Supported development of industry survey questions
- Types of industries/organizations interviewed:
  - Oil and Gas Industry
  - Steel Founders Society of America
  - BWXT
  - AISI
  - U. S. Navy Shipbuilding
  - America Makes – Additive Manufacturing
  - Pipeline Industry

Focus Group Sessions

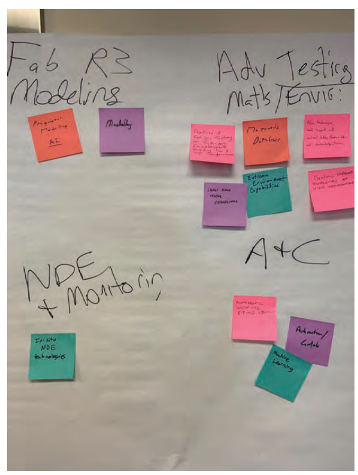
Venue/ Focus Group	Location	Date	Attendance
General Session (Focus Group 1)	Columbus, OH	Dec. 2022	31
Ma2JIC (Focus Group 2)	Miami, FL	Feb. 2023	64
FabTech 2023 (Focus Group 3)	Chicago, IL	Oct. 2023	19
EWI IAB (Focus Group 4)	Buffalo, NY	Dec. 2023	18

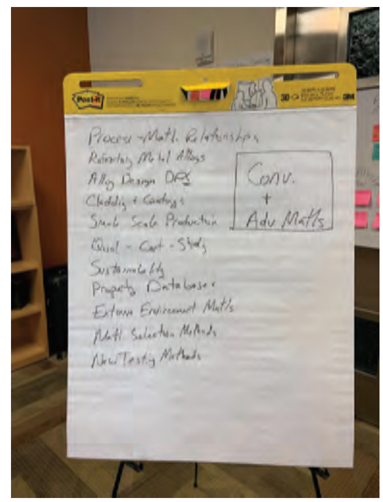
First Focus Group – Columbus, OH, December 2022

- Briefed the participants on the RAPLSS roadmap
- Better define the gaps listed in the Gap Analysis Matrix
- Feedback was rolled into a new version of the matrix that was used to support development of survey questions and interview content.

Second Focus Group – Miami, FL, February 2023

- Held in conjunction with OSU's NSF IUCRC Ma2jic IAB meeting
- Identified gaps in three industry capability areas:
  - Fabrication Technologies
  - Advanced Materials and Performance
  - Workforce Development





Third Focus Group – Chicago, IL, September 2023

- Third focus group was held just as survey was begun.
- Agenda was directed to provide input to the general needs of industry description.
- Open discussion where each participant shared what they identify as the biggest gap in their industry vertical
  - Featured speakers:
    - Ray Monroe – Steel Founders Society of America – Castings and Forgings
- General Comments:
  - Automation – Welding and NDE
  - Workforce development at all levels – Skilled Trades and Technical Professionals
    - Mentorship
    - Workforce Retention
  - Codes and Standards
    - Updates codes and specifications to be amenable to new materials and technologies
    - Real world applications vs. “just read the spec”
  - Models to support fitness for service/life predictions
  - Hesitation to embrace new technology – not willing to be the “early adopter”

Fourth Focus Group – Buffalo, NY, December 2023

- Agenda was designed to capture an additional range of industry comments and gap ideas.
- Presented on results from this project thus far, including feedback from other focus groups, surveys and interviews.
  - Featured speakers:
    - Ray Monroe – Steel Founders Society of America – Castings and Forgings
    - Scott Shurgots – BWXT – Advanced Technologies for Nuclear
- Open discussion where each participant shared what they identify as the biggest gap in their industry vertical
- General Comments:
  - Large equipment capabilities need to be a consideration in the production of large structures.
  - Big capital investments are needed to modernize large scale manufacturing capabilities.
    - At casting facilities, a new piece of equipment is from the 1970s.
    - If we invest in new technology, the new equipment comes from overseas.
    - We have know-how to create large forging products yet lack workforce and equipment – not a technology issue.
  - Aerospace industry sector should be included in this discussion. Aerospace has similar issues/situations common to those identified.
  - The United States has federal policy challenges in comparison to foreign counterparts regarding support of its manufacturing infrastructure.

Electronic Survey

- A series of industry surveys was conducted to gather business/technology needs data from a broader range of industry perspectives, with a goal to establish industry roadmap priorities.
- Capture specific input across the industrial sectors from a broad range of working professionals engaged in advanced manufacturing and production of large structure and systems.
- Prior interviews and focus group exercises provided the primary source for the multiple-choice options questions for the survey.
- Survey questions queried the likelihood of participating in collaborative research programs and implementing new large structure production technologies.

> - 18 questions available online from September 2023 to March 2024
> - Completed by 63 participants from 49 different organizations
> - 23% requested individual interviews/follow-up

Summary of Feedback Collected

- Various forms to support identifying additional gaps, priorities, and potential solutions
  - Interviews and focus groups led into the development of electronic survey questions.
  - Electronic survey window was open for about eight months in which data was collected and summarized.
  - Interviews and focus groups continued to collect additional input for the roadmap.
- Various participants = various perspectives
  - Level and type of connection to large structures and systems of the participating companies
  - Four general levels of participation were included:
    - Provided large structures and systems to customers
    - Used large structures or systems to provide goods and services
    - Provided goods and services to fabricators or users of large structures and systems
    - Provided knowledge useful to the above three categories.

Roadmap Results

- First cut – by capability area
- Second cut – by industry verticals
- Overall Summary – Measuring the hurdles to success

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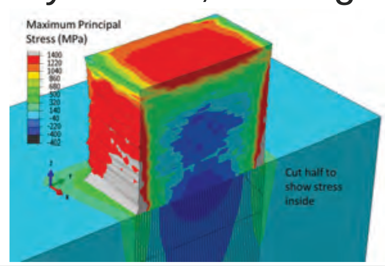
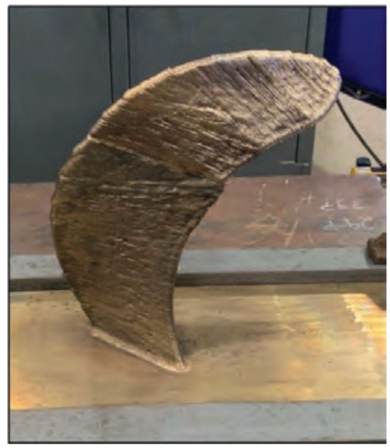
Roadmap Result – Models and Digital

- Pushing to grow models and digital applications so they can take the most difficult welding challenges in module building and leave more standard welding to field erection.
- The growth of models and digital applications is further advanced in some areas than others.
- Computation for production will include tools and processes for facility design, automation of manufacturing processes, inspection and quality control, and digital platforms and architecture.



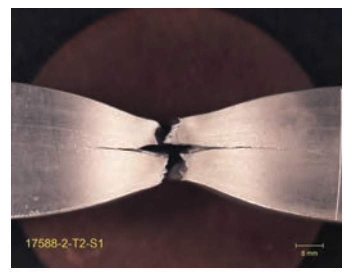
Roadmap Result – Fabrication Technologies

- Fabrication technologies scored very high among the areas where those contacted thought that increased value could be provided to new large structures and systems.
- Many large structures and systems are not limited by the material properties available alone, but rather by those that can be obtained and reliably joined into the entire structural system.
- Additive manufacturing adds prototyping and limited number production capability.



Roadmap Result - Integrity

- Transferability of information is crucial to integrity, such information as:
  - Strength
  - Crack resistance
  - Presence and sizing of imperfections
- What people “think that they know” is crucial.
- Gain through experience of prototyping, using the differing processes that work better for one-off and small batch production.



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Roadmap Result – Advanced Materials and Performance

- This area had the least consensus among the areas reviewed in Focus Group 2.
- The variety of material needs in different systems (perhaps symbolized by the different meaning of “high strength steel” or “light-weight alloy”) in different industries is likely to play out here.
- Sustainability and recycling was the highest ranked item in the focus group.
- An open-source but reliable property database with properties relevant to design of large-scale structures was the second highest ranked item.

Roadmap Result – Supply Chain

- Two types of supply chain items got the most comments.
- One was the need for capability for the largest items: forgings, castings, and beams as examples. For steels, this limitation has been the result of turning toward more steel and other alloy products from scrap rather than ore.
- The other was that the equipment for factories for large structural item production was more likely to be imported.

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Roadmap Results – Workforce Development

- EWI's previous roadmap on joining and forming followed the lead of the industry representatives, who described a culture and mindset gap that was making it tough to hire for technical and trades jobs.
- The responses this time indicated an even more drastic need to even get people to the entry level jobs at all, given the need to train-up those inside industry to greater skills.
- The highest ranked item was for technical and trades education to provide effective capability transformation that the large structural and system creating industries can use.

Roadmap Results – Capex Costs

- Both large systems and large machines to build their parts are expensive capital items that will need the right kind of financial environment to show a positive return on investment.
- Most corporate investment decisions will have a “will it be susceptible to supply chain disruption?” component.
- Singular capabilities need special kinds of customers to maintain their interest.

Roadmap Results – Standards and Codes

- Standards for fabrication technologies for new methodologies were listed as a critical need.
- One area of standards difficulties is new technologies, where the effort to include new materials is slowed by a combination of incomplete testing and questions about final application needs.
- Another area is the inability to change outdated standards, where technical requirements can now more easily and cheaply be achieved in other ways.

Roadmap High Priorities

High Priorities – Offshore Wind – Maritime

- Everyone surveyed from the maritime industry indicated workforce readiness as a critical item holding back the industry's production capability.
- A close second critical item was supply-chain readiness.
  - Supply chain readiness needs can be several layers deep:
    - Need offshore support vessels
    - Need shipyard capacity
    - Need the shipyard inputs – plate, welding systems, hardware
- One specific item is heavy steel plate for wind turbine structures offshore.

High Priorities – Hydrogen/CCUS/Petrochemical/Refining

- Interviews with this sector indicated that many of the capabilities for building large systems are in place, but that large systems are limited by permitting that allows many respondents to object to routing or locating infrastructure.
- In some areas of new service (Hydrogen, CCUS), new standards are needed to say what to build.
- Need connection to new pieces of physical plant
  - Electrolyzers
  - Pyrolysis
  - CCUS units at concrete manufacturers
- Automation of NDE and fit-up for pipe girth welds are opportunities.

High Priorities – Energy (Nuclear/Wind/Solar)

- Survey respondents were the most unanimous on the need for advanced materials as a capability limitation in energy systems.
- There is a tendency to look at optimizing of individual modules for size, given the expense of site work.
  - SMR (small modular reactors)
  - Wind towers in segments
- Regulatory approval is needed to convert to in-process and in-situ monitoring from NDE after production.

High Priorities – Mining/Primary Metals

- One area of difficulty for casting suppliers is the use of outdated standards.
- Government purchasers particularly are still using requirements for film radiography.
- Commercial pressures have allowed digital radiography to catch up to and now outstrip film radiography, but the rigidity in the government contract system prevents those gains from being incorporated.
- These industries are limited by large Capex costs.

High Priorities – Mega Buildings/Bridges

- Like in nuclear, there is a stronger tendency to go to modular approaches, providing pieces that can be shipped to the job site.
- Like rail and mass transportation, limitations of the site often dominate planning, needing planning software that accommodates site limits.

High Priorities – Rail and Mass Transportation

- Like buildings and bridges, limitations of the site often dominate planning, needing planning software that accommodates site limits.
- Modularity has been built into these systems from the beginning.
- Large-scale construction requires personnel to be at many locations for limited time-periods, which is less easy when this workforce is limited.
- Automated inspection is an opportunity area.
- Hydrogen is a future fuel opportunity for rail.

High Priorities – General Supply Industries

- Two areas led the responses for general supply industries
  - Supply chain readiness
  - Workforce readiness
- These two items indicate the general operating difficulties for businesses crucial to the large structure and system ecosystem, but without their own large size to insulate their environment.
- Additive Manufacturing perhaps has more opportunities in the general supply industries than in large structures and systems themselves.

Comment on Workforce Readiness

- Workforce readiness is a cross-cutting item through many industry verticals.
- A particular and growing difficulty with the American labor market is the availability of staff who can be at remote locations and not available to family for emergencies or care.
- As the United States population has aged and more people need part-time care, this prevents workers from taking otherwise attractive jobs that involve remote locations.

Comment on Supply Chain Readiness

- Supply chain readiness is a cross-cutting item through many industry verticals.
- A particular and growing difficulty with the American supply chain is the expectation of general availability of items that may have quite limited sourcing.
- The United States needs to account for international connections of the supply chain, since many supply chain companies reduce their risk by becoming international.

Roadmap Surveys Results

These slides were removed – see the RAPLSS Roadmap for final data charts

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Reoccurring Themes

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Fabrication Technology Themes

- Standards – Cannot implement new process/materials without standards
- Large Fab Processes – Need more U.S. capabilities/capacity (lead times can currently be in years)
  - Missing large forging and casting
  - Desired weld and additive of large structures
  - What is "large" in tonnage:
    - Nuclear 10s of tons (high ton, low volume) > Shipbuilding (mid) > Windmill (low ton, high volume)
- Hubs/Modeling – Need centralized but open database to support modeling and process development
- Wire DED Productivity – User base expansion is limited by lack of knowledge. Very large-scale wire DED will benefit from further research and development.

Conventional and Advanced Materials Themes

- Sustainability + Recycling Alloys – Reduce energy usage, reuse (rare) materials, improve recycled material performance, and limit mineral extraction damage.
- Property Database – Open database for base/weld/additive material properties in extreme environments to support alloy and end-use design
- Feedstock Material Design – Weldability, productivity, custom use applications, and mass production of custom feedstock
- Lightweight + Advanced Alloys – Weldability; need greater performance and lower weight

Workforce Development Themes

- Tech/Trade Programs – Massive lack of skilled trades workers (welder, boiler makers, pipe fitters, machinists, etc.); lack of internships especially for DED
- Culture/Mindset – Need to change manufacturing to good not taboo, need to attract next generation to this industry, need to build effective teams
- Modern Tech Training – Need advanced tech at trade schools to ensure workforce is prepared for the realities of the rapidly advancing manufacturing world
- Curriculum and Multimedia – Curriculum focused to industry needs

Thank you for your time.

NIST Award No.: 70NANB22H045