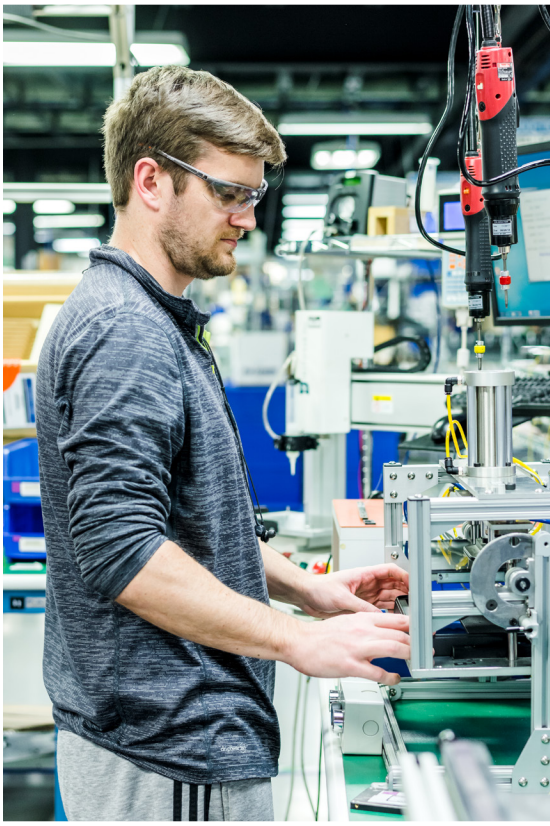
SEIZING THE MANUFACTURING 4.0 OPPORTUNITY:

A STRATEGIC PLAN FOR IOWA'S MANUFACTURING INDUSTRY

Prepared For: Iowa Economic Development Authority
Prepared By: TEConomy Partners, LLC

JANUARY 2021



TECONOMY PARTNERS LLC

Photos included throughout this report were provided to the Iowa Economic Development Authority by Iowa manufacturers and other organizations. TEConomy partners wishes to credit and thank the following companies and one university for providing photos:

Ag Leader Technology, Deere & Company, MakeuSafe, Metalcraft, Pella Corporation, Ramco Innovations, University of Northern Iowa, and Vermeer Corporation

TECONOMY
PARTNERS LLC

For more information on this report please contact its authors with TEConomy Partners:
Ryan Helwig, Martin Grueber, and Joe Simkins
1.800.TEC.1296 | info@teconomypartners.com | www.teconomypartners.com

TABLE OF CONTENTS

This page intentionally left blank.

EXECUTIVE SUMMARY

Iowa has a proud history and impressive legacy in manufacturing. Just as the state has long fed this nation as a leading agricultural producer, its innovative manufacturers have supplied global markets with value-added food products, farm and construction machinery and equipment, advanced materials, chemical products, aerospace electronics, and medical devices, to name just some examples. Iowa has thrived and remained competitive by moving toward increasingly advanced manufacturing products and processes that incorporate innovative technologies such as data analytics, automation, sensing, and networking. The sector represents a major pillar of Iowa's economy and it is critical for the state to continually examine its position and performance and to look ahead to "what's next" to ensure it remains a manufacturing leader that is vibrant and globally competitive.

It is with this spirit and foresight that Iowa is embracing and planning for the rise of a technological and innovation movement that represents a paradigm shift so significant industry experts have referred to it as the arrival of the "Fourth Industrial Revolution" or "Industry 4.0."[1] While "Industry 3.0" leveraged the "digital revolution" of the late 20th century to embed computers and robotics into single processes or machines, Industry 4.0 is utilizing a new wave of technologies to fully automate processes and decision making across the production life cycle. The "4.0" terminology has been repurposed for use in strategies targeted at specific segments of the manufacturing industry and the terms "Manufacturing 4.0" or "Smart Manufacturing" are often used interchangeably with Industry 4.0.[2]

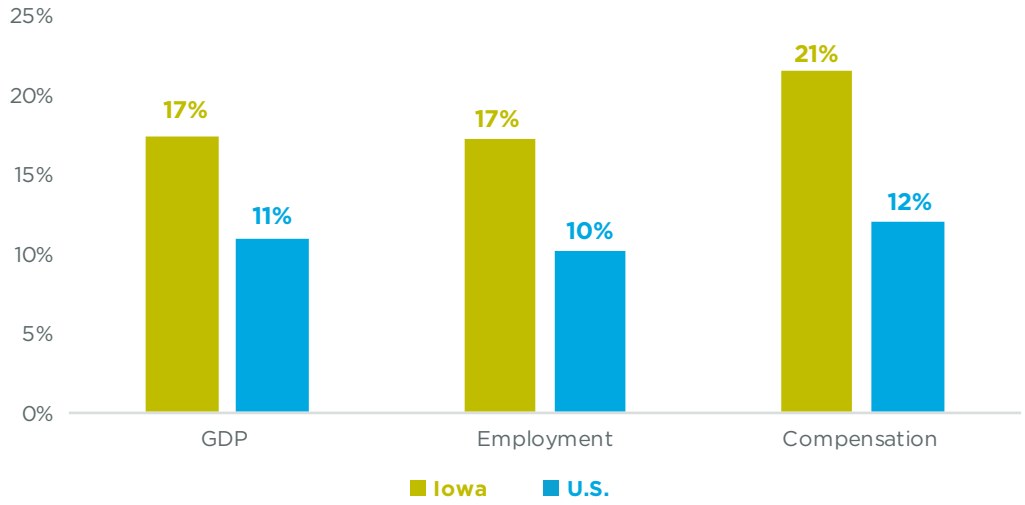
The economic stakes of Manufacturing 4.0 are significant for Iowa's future prosperity. Its economic development leadership and its state-level Advanced Manufacturing Work Group recognize the need for a comprehensive, focused, and forward-looking plan of action to enable Iowa to be a national and global leader in Manufacturing 4.0 technology adoption and utilization. This industry-led and guided Strategic Plan has been developed to maintain and enhance Iowa's vibrant, competitive manufacturing sector into the future.

1 The term and concept around Industry 4.0 (or "Industrie" 4.0) is rooted in Germany's national strategy around smart manufacturing systems.
2 This Strategic Plan uses these terms synonymously and interchangeably throughout.

Manufacturing Matters to Iowa's Economy: A Highly Specialized and Growing Industry Base

Today, 226,000 Iowans work in more than 4,100 manufacturing establishments across the state's rural and urban areas and leverage their skills, education, and training across a wide range of corporate, innovation, and production roles. The industry's significance in Iowa is hard to overstate—these thousands of workers and the products they manufacture contribute $30 billion to Iowa's Gross Domestic Product (GDP). Combined, this economic footprint represents 17 percent of state GDP, 17 percent of private employment, and 21 percent of total employee compensation—significantly outsized shares when compared against national averages (see Figure ES-1). This means Iowa is highly "specialized" in its concentrations of manufacturing output and employment.

FIGURE ES-1: MANUFACTURING SHARE OF IOWA'S KEY ECONOMIC INDICATORS, 2019



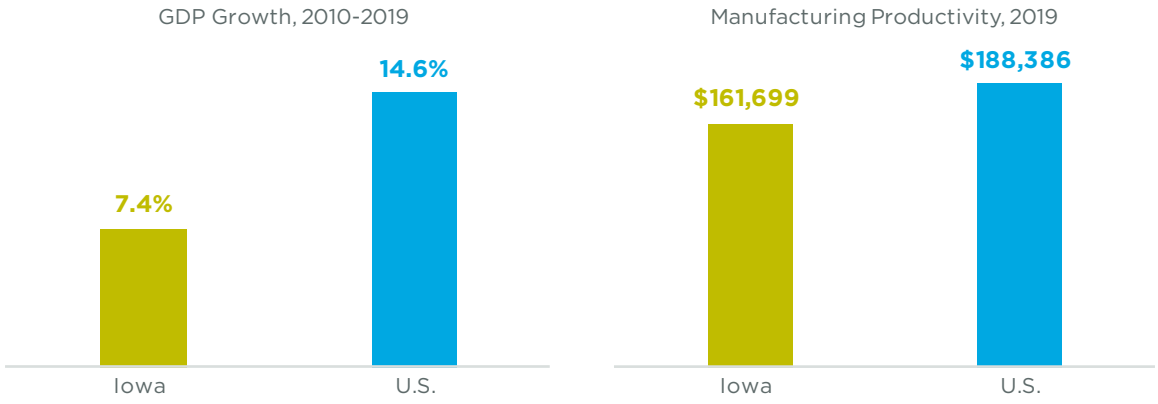
Source: TEConomy Partners' analysis of Bureau of Labor Statistics, CEW employment and compensation data; Bureau of Economic Analysis, Real GDP (chained 2012 dollars). Data and percentage calculations are based on private sector activity.

Not only is Iowa's share of manufacturing employment outsized, the industry's job growth has outpaced national growth during the economic expansion and in recent years. And while there is no doubt the COVID-19 pandemic and resulting global economic shutdowns have negatively impacted the industry, heading into the pandemic-induced health and economic challenges of 2020, Iowa's manufacturers were generally in a strong position.

Iowa's Manufacturing Competitiveness Challenge: Lagging Productivity and Output Growth Combined with Acute Workforce Shortages

Despite its outsized importance to Iowa and recent growth, digging deeper into the industry's dynamics one finds areas of concern for Iowa's manufacturing competitiveness. Despite the industry's specialization and strong employment growth in recent years, Iowa lags just behind the national averages in overall measures of manufacturing productivity—measured as value-added (GDP) per worker—and this plays out across many of the industry's major subsectors (Figure ES-2). In addition, GDP growth has been slower in Iowa compared with U.S. averages during the lengthy economic expansion of the last decade.

FIGURE ES-2: MANUFACTURING REAL GDP GROWTH (2010-19) AND PRODUCTIVITY (2019) FOR IOWA AND THE U.S.



Source: TEConomy Partners' analysis of Bureau of Economic Analysis, real GDP trends (chained 2012 dollars); estimated GDP data per Employee (Productivity) from Emsi (Emsi Release 2020.2).

While there are numerous factors that influence manufacturing productivity, Iowa's industry is undoubtedly hindered by workforce constraints. Iowa manufacturers have operated under acute, well-documented workforce shortages as the state's labor supply has strained under the weight of a lengthy economic expansion and less than 3 percent unemployment rates in recent years, combined with slow population growth.[3] A limited talent pool—often exacerbated in rural areas which are home to just over half (53 percent) of Iowa's manufacturing jobs—places an emphasis on increasing and enhancing production capacity through technology investments.

Iowa companies are embracing and adopting industrial automation, but investments and deployment of new technologies are often discrete and limited to individual machines or systems (for example,

3 According to the U.S. Bureau of Labor Statistics, Iowa's statewide unemployment rate averaged 2.7 percent in 2019, 5th lowest in the nation.

a welding robot or 3D printing capability). While these represent important steps forward for the state's manufacturers, particularly its small- and mid-sized enterprises (SMEs), investments are not yet occurring in a holistic, fully integrated manner required to realize the full benefits of Industry 4.0. Iowa manufacturers must look to the combination of a skilled workforce and strategic technology investments to realize continued growth and remain competitive.

The Increasingly Digital Present and Future of Manufacturing: Importance of Leveraging Industry 4.0 Technologies & Capabilities

Digital industrial technology, or Industry 4.0, is transforming the modern global manufacturing sector, with major implications for industry competitiveness. Drawing from a host of technologies that enable data collection and analysis across and among machines, Industry 4.0 technologies are driving bottom-line outcomes for manufacturers in terms of increased productivity and efficiencies, faster and more flexible production, and ultimately higher-quality goods at lower costs. Digitization of manufacturing is not wholly new—manufacturers have long used digital technologies and automation. However, technology development has progressed today to where a number of formerly disparate tools and applications are now not only commercially available but also able to interconnect in a "smart" manufacturing environment. As one would expect from such transformational technology, Industry 4.0 has significant implications for all facets of the manufacturing ecosystem including innovation, supply chains, infrastructure, the workforce, and even customer engagement—implications that will have tremendous impacts on state and regional competitiveness within advanced manufacturing clusters.

"We know our factory has a lot to tell us… and these [Industry 4.0] technologies can enable it."

-Representative from a large Iowa manufacturer

While the Industry 4.0 concept includes an expansive portfolio of new technologies, capabilities, and services, there are several key goals that industry leaders seek to realize in transitioning manufacturing operations to Industry 4.0 models:[4]

- **Interconnectivity** – generation of Big Data, machine to machine/machine to human communication;
- **Decision support** – use of analytics for predictive action and autonomous decision making;
- **Customization and flexibility** – ability to create highly tailored production runs with minimal downtime and waste;
- **Decentralization** – outsourcing low level tasks and decision making to machines and increase modular capabilities of production assets.

4 M. Hermann, T. Pentek and B. Otto, "Design Principles for Industrie 4.0 Scenarios," 2016 49th Hawaii International Conference on System Sciences (HICSS).

As a result of integrating new technologies that achieve these goals, companies hope to achieve further optimization of production processes (reducing costs and energy usage), improving operational efficiency and worker safety, and greatly improving customization and flexibility in meeting customer demand.

The ability to gather, store, manipulate, and leverage data from manufacturing operations toward actionable insights is at the core of enabling the technologies and capabilities of Industry 4.0. Advancements in computing, connectivity, and sensing technologies that enable data-driven insights have made it increasingly cost-effective for manufacturers to adopt and integrate these systems in recent years. However, many segments of the manufacturing industry are still in the process of transitioning from legacy operations models to the "cyber-physical" models described in Industry 4.0 principles that leverage the joint capabilities of hardware, software, and workers in an integrated way. This aspirational integration of technologies within companies based on the use of near real-time data on operations is also sometimes referred to as "smart manufacturing" or "intelligent manufacturing."

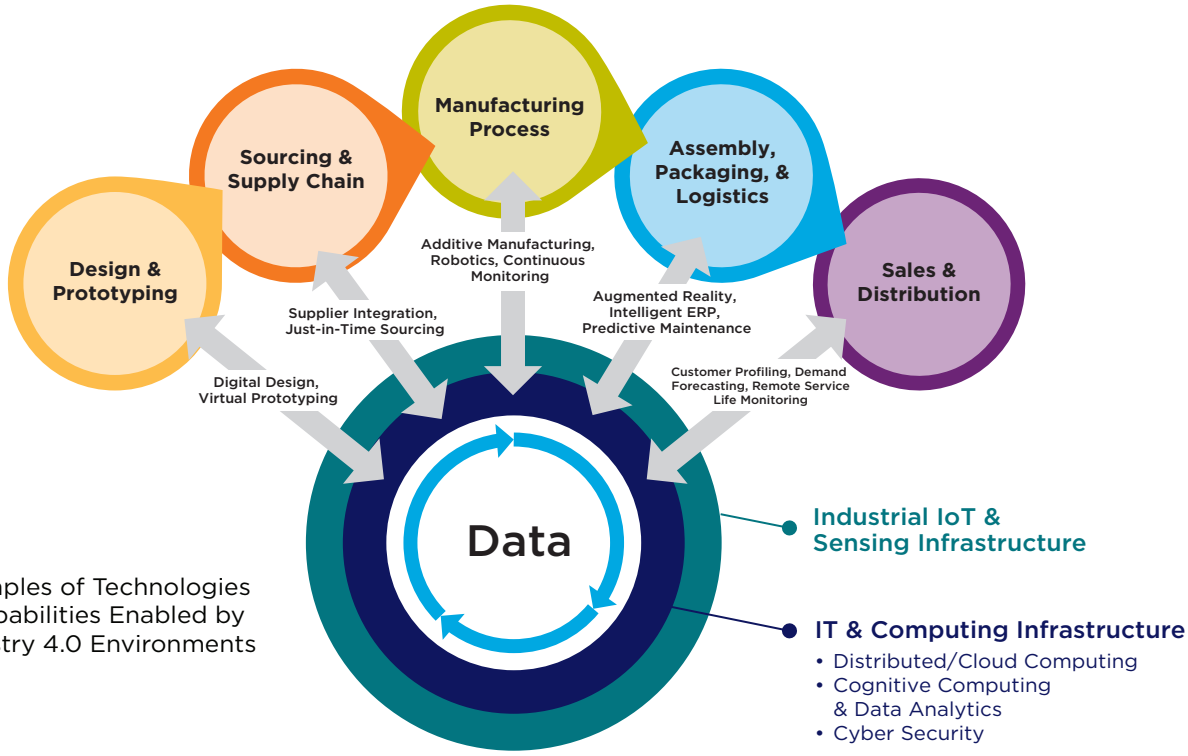
As shown in Figure ES-3, the Center for Industrial Research and Service (CIRAS) at Iowa State University has developed one perspective on describing the broader suite of technologies and capabilities encompassed by Industry 4.0.

FIGURE ES-3: ISU-CIRAS DEPICTION OF VARIOUS INDUSTRY 4.0 TECHNOLOGIES

Source: Center for Industrial Research and Service (CIRAS) at Iowa State University.

An aspirational goal of Industry 4.0 technology adoption at the company level is to enable the concept of a "smart factory"—a fully integrated digital environment where a broad suite of Industry 4.0 technologies is deployed to create a positive feedback cycle that allows the site to be highly adaptive and flexible. In an example of this model shown in Figure ES-4, data from each step in the production process is gathered using foundational Industry 4.0 infrastructure and then aggregated and accessed by subsequent production stages and processes, with data on end-stage distribution, sales, and customer usage then feeding back into the design and prototyping stages in a cyclical way. The result is a resilient, flexible manufacturing enterprise that allows for continuous improvement. Although many manufacturers are not yet at this stage of integration or may be in partial stages of adoption with many legacy non-digital elements still embedded in their production process, it is critical to recognize the role of foundational technologies in enabling other value-added capabilities through insights provided by data.

FIGURE ES-4: DEPICTION OF A FULLY INTEGRATED INDUSTRY 4.0 ENVIRONMENT ILLUSTRATING THE KEY ROLE OF DATA-DRIVEN FEEDBACK CYCLES



Source: TEConomy Partners, LLC.

Significant Manufacturing Industry Investment in Transitioning to Industry 4.0 Models

For many manufacturers, transitioning to Industry 4.0 models has become a question of "how" rather than "if" based on rising investments in digital technologies by competitors both locally and globally. PwC's recent Global Industry 4.0 Survey found that U.S. companies planned to commit $907 billion annually to digital technologies.[5]

A further indication of the fast pace of adoption of Industry 4.0 and smart manufacturing are the market research forecasts for its growth. BCC Research considers the major technology areas associated with Industry 4.0 manufacturing applications and estimates the global market will grow from nearly $8 billion in 2018 to almost $22 billion by 2023, a rapid compound annual growth rate of 23 percent.[6] It is increasingly clear that those slow to adopt, or left behind in a Manufacturing 4.0 environment, risk losing their competitive edge.

Survey findings also reinforce that sourcing and hiring skilled talent able to operate within this increasingly digital environment remains a challenge, representing a key constraint often cited by manufacturing industry stakeholders and an important reminder that fully integrated cyber-physical environments also require significant investments in training and workforce development. Ultimately, the ability of regional manufacturing-driven economies such as Iowa's to compete in global markets hinges on successful transition to Industry 4.0, and will face increasing cost and customer service pressures from competitors who have prioritized the process of adoption and integration of these technologies.

The strength and competitiveness of a state's manufacturing industry is never guaranteed, and the disruptive nature of Manufacturing 4.0 technologies and the high rates of investment and adoption globally should give pause to industry leaders and stakeholders. To remain competitive, Iowa manufacturers need to embrace and adopt new technologies. Adopting the suite of digital technologies described herein poses significant challenges, particularly for small- and mid-sized manufacturers facing costly technology purchases, planning for integration in ongoing operations, seeing limited digital expertise in their current workforce, and phasing out or reconfiguring legacy IT systems to prepare for new interoperability requirements. These are just some of the hurdles that manufacturers face in the Industry 4.0 journey.

These challenges raise the need for what the United Nations Industrial Development Organization emphasizes in lessons learned from the experience in Germany:

> *"The German experience [with its Industrie 4.0 strategy] underscores the relevance yet again of multi-stakeholder coordination and collaboration as the foundation for the design and implementation of coevolving innovation and industrial policies."*[7]

5 PwC 2016 Global Industry 4.0 Survey.
6 BCC Research, "Industry 4.0 Technologies: Global Markets through 2023," July 2018.
7 United Nations Industrial Development Organization, "What can Policy Makers Learn from Germany's Industrie 4.0 Development Strategy?" Inclusive and Sustainable Industrial Development Working Paper Series, 2018.

Iowa has a Breadth of Manufacturing-Related Assets and Expertise to Leverage in Advancing Manufacturing 4.0 Technologies

Iowa has significant organizational and infrastructure assets for industry to draw from and partner with on Manufacturing 4.0 development. Some examples and highlights include:

- **Iowa's research universities** are active and advancing expertise in both education and R&D activities related to Manufacturing 4.0:
    - **Iowa State University (ISU)** stands out in its engineering and computer science strengths and infrastructure including in cybersecurity; materials testing; virtual reality applications; machine learning and AI research.
    - **University of Iowa (UI)** stands out with unique manufacturing assets and capabilities, including UI Pharmaceuticals; the Center for Biocatalysis and Bioprocessing and investments in rapid prototyping capabilities.
    - **University of Northern Iowa (UNI)** stands out in its focused education mission in Industrial Technology, placing 90 percent of graduates in Iowa's high-demand technical roles; as well as its world-class Metal Casting Center and the new and growing Additive Manufacturing Center at TechWorks.
- **Iowa's Community Colleges** are actively engaged in education and workforce training activities across each of the primary Industry 4.0 technology areas, with each of the state's 15 colleges engaged in academic programming in at least one Industry 4.0 area.
- **CIRAS at ISU** is seen as a key partner, serving a vital need for directly assisting manufacturers and demonstrating Manufacturing 4.0 technologies in its new Digital Manufacturing Lab.
    - CIRAS leads numerous outreach programs, including:
        - Manufacturing Extension Partnership; Technology Assistance Program; Procurement Technical Assistance Program; Iowa Lean Consortium; and the Economic Development Administration (EDA) University Center Program.
    - CIRAS further provides key Industry 4.0 resources, services, and programs including digital manufacturing/Industry 4.0 assessments.
- **TechWorks** is a 30-acre advanced manufacturing, R&D, innovation, education, commercial, and manufacturing campus in Waterloo. It plays a unique role as a center of gravity/connectivity for industry-academic collaborations on industry-relevant equipment. UNI and the Metal Casting Center have invested heavily in a fast-growing presence at TechWorks with its industry- and customer-focused Additive Manufacturing Center and Design Lab (AMC).
- **Quad Cities Innovation Hub** represents a multifaceted organization providing operational, technical, and business resources and events to the Quad Cities region's manufacturers. It represents a valuable (free) resource for regional, primarily DoD-focused companies along their Industry 4.0 journey providing technology "playbooks"; facilitating user groups; organizing a supply chain mapping tool; and more.

To boost and ease this transition to increasingly digital operations and functionality, Iowa must leverage and coordinate its manufacturing expertise, assets, and institutional know-how; and re-visit its existing economic development incentives, considering ways in which to direct strategically targeted resources to this vital segment of the state economy.

Strategies and Actions to Advance Manufacturing 4.0 and Further Enhance Iowa's Manufacturing Ecosystem

The voice of industry has guided the development of the Iowa Manufacturing 4.0 Plan from the outset. Input and feedback from manufacturing leadership through one-on-one interviews, focus groups, and regular meetings with the Advanced Manufacturing Work Group has been vital to understanding the underlying dynamics of the state's manufacturing situation and validating the narrative presented by the quantitative analyses and qualitative inventory of key Iowa assets.

What has emerged are a set of five strategic priorities and corresponding recommended actions for consideration to advance Iowa's Manufacturing 4.0 ecosystem (see sidebar). **The goal of the Iowa Manufacturing 4.0 Plan is as follows:**

Five Strategic Priorities for the Iowa Manufacturing 4.0 Plan:

1. Manufacturing 4.0 Technology Adoption & Utilization
2. Enabling Infrastructure for Digital Technologies
3. Improved Supply Chain Linkages
4. Accelerating Manufacturing Startups & Scale-ups
5. Ensuring an Effectively Trained Manufacturing 4.0 Workforce

> *Iowa will become a high-adoption state in Manufacturing 4.0 technologies over the next 5 years, with broad integration and leveraging of advanced, smart manufacturing technologies across its diverse manufacturing base—with respect to both size of firm and industry sector.*

While this Strategic Plan is primarily focused on advancing and integrating technology adoption and utilization among Iowa's manufacturers, it further addresses enhancements in some key elements of the broader manufacturing ecosystem. With an intentional, strategic effort, Iowa will enhance its global manufacturing competitiveness by:

- Adopting Manufacturing 4.0 technologies to increase productivity and to narrow the gap with the national average;
- Re-training and upskilling its manufacturing workforce to address acute workforce shortage issues and to successfully implement the suite of Manufacturing 4.0 technologies;
- Investing in infrastructure for digital technologies to ensure their optimal integration and effectiveness;

- Understanding and improving supply chain linkages throughout the industry; and
- Accelerating the connectivity and opportunities for manufacturing startups and scale-ups.

Key overarching principles have emerged during this strategic planning process and should serve to guide plan development and implementation of the plan. These principles include:

- Leveraging strategic **collaborations**;
- Increasing the **scale** of interactions;
- Promoting a **sense of urgency** for all manufacturers and the state recognizing that global and national competitors are adopting and utilizing Industry 4.0 technologies at rapid rates.

The following outlines the rationale behind each strategic priority area as well as the recommended actions for implementation.

Strategic Priority 1: Manufacturing 4.0 Technology Adoption & Utilization

Rationale: Iowa's manufacturers demonstrate, in general, a strong awareness of Industry/Manufacturing 4.0 technologies and the specific technologies needed to enhance their competitiveness by increasing productivity and addressing acute workforce shortages. A number of Iowa's large manufacturers are implementing digital roadmaps. Further, many of the companies interviewed for this strategy, regardless of size, have made recent investments in Manufacturing 4.0-related technologies. Yet among all size categories, and particularly among the state's SMEs, significant barriers to acquiring and integrating these technologies into existing operations remain. At the core of this first Manufacturing 4.0 strategy is addressing how to "de-risk" significant technology investments and where the public sector and public-private partnerships have roles to play in doing so.

Issues, Challenges, Gaps—Consistent Themes Raised by Industry Leaders Related to Technology Adoption, Utilization:

- Significant costs for SMEs
- Need for staging investments
- Limited expertise
- Rural broadband infrastructure
- Rapid rate of tech obsolescence and keeping up
- Where to start the Industry 4.0 journey and access resources?

Strategy #1: Manufacturing 4.0 Tech Adoption & Utilization
Action 1.1: Implement state economic development incentives for Manufacturing 4.0 technology investments and adoption by Iowa manufacturers, including digital investments, allocating a sizable portion of incentives to SMEs.
Action 1.2: Accelerate depreciation schedules to support the integration of Manufacturing 4.0 technology investments.
Action 1.3: Increase usage and availability of CIRAS' Industry 4.0 Assessment tool, counseling, and implementation planning as a key starting point for Iowa manufacturers developing actionable technology adoption plans specific to their company.
Action 1.4: Advance the knowledge base, expertise, and collaboration among Iowa's economic development professionals and other business support professionals and organizations around the importance of Industry 4.0 and key technologies.
Action 1.5: Monitor and track Iowa's Manufacturing 4.0 adoption rates regularly via CIRAS surveys and forums, segmented by size of company and industry.

> *"Manufacturers are beginning to embrace the suite of technologies represented by Industry 4.0. From emerging automation tools such as collaborative robots (cobots) to machine connectivity and advanced engineering tools, manufacturers are interested in action. This survey and the forums indicate that foundational tools are in place more and more throughout Iowa. Manufacturers need to execute on Industry 4.0."*
>
> *- CIRAS, Iowa Manufacturing Needs Assessment, 2019-2020*

Issues, Challenges, Gaps—Consistent Themes Raised by Industry Leaders Related to Enabling Infrastructure:

- Rural broadband infrastructure
- Cybersecurity needs
- Interoperability challenges, legacy IT infrastructure

Strategic Priority 2: Enabling Infrastructure for Digital Technologies

Rationale: Adopting and integrating the suite of digital Manufacturing 4.0 technologies requires fundamental infrastructure in place to optimize and realize its benefits. Enabling "infrastructure" in this context includes and spans statewide access to fiber and reliable high-speed broadband; the IT backbone and ability to achieve "digital integration" within individual companies; and critical cybersecurity infrastructure required for increasingly interconnected factories in a cyber-physical context. Just as reliable and well-maintained roads, railways, airports, and bridges have been foundational to advanced economies, this modern digital infrastructure is fundamental to advancing a competitive Industry 4.0 economy with high rates of technology adoption.

Strategy #2: Enabling Infrastructure for Digital Technologies
Action 2.1: Prioritize investments in rural fiber and broadband infrastructure for Iowa's rural manufacturers, aligned with ongoing state investments and initiatives.
Action 2.2: Support cross-industry and industry-university collaborations and implement company-specific assessments to address critical manufacturing-specific cybersecurity challenges.
Action 2.3: Provide resources to Iowa manufacturing SMEs to help address interoperability challenges in a dynamic Industry 4.0 operating environment.

Strategic Priority 3:
Improved Supply Chain Linkages

Rationale: A holistic Manufacturing 4.0 strategy must consider ways in which new technologies are enhancing supply chain dynamics and relationships for more seamless processes, allowing for more customization and flexibility in specific orders, enabling enhanced traceability and security throughout the supply chain, and more. Industry 4.0 technology adoption is often advanced through the requirements and directives of larger manufacturers or OEMs pushed down to SMEs through supply chain relationships. Ensuring Iowa's SMEs understand and are able to meet and integrate key technology requirements is important for maintaining a vibrant manufacturing sector into the future.

Issues, Challenges, Gaps—Consistent Themes Raised by Industry Leaders Related to Improved Supply Chain Linkages:

- Need to "trace" supply chain using Industry 4.0 technologies
- "Tie in" to customized IT systems
- Cybersecurity compliance
- How to scale SME, supplier interactions?

In addition to these dynamics, this study has revealed opportunities to consider for growing Iowa manufacturing via better understanding, documenting, and communicating the breadth of Iowa's manufacturing supply chain to better connect with both in- and out-of-state OEMs, particularly amidst the COVID-19 pandemic and considerations around "re-shoring" production. To seize this opportunity will require identifying the state's supply chain strengths and attractiveness, as well as gaps.

Strategy #3: Improved Supply Chain Linkages
Action 3.1: Form an Iowa OEM Advisory Council to advise, counsel, and support supply chain SMEs in adopting Manufacturing 4.0 technologies.
Action 3.2: Incent and enhance in-state supply chain connectivity between Iowa's larger manufacturers and OEMs and SMEs.
Action 3.3: Update and leverage existing supply chain mapping tools to better understand and promote the strength of Iowa's supply chain network and identify opportunities to enhance connectivity.

Issues, Challenges, Gaps—Consistent Themes Raised by Industry Leaders Related to Accelerating Manufacturing Startups & Scale-Ups:

- High costs for Mfg. startups leads to challenges raising funds
- Need for a "place" or "clearinghouse" for innovative mfg. startups
- Gap in management teams/executives to lead startups

Strategic Priority 4: Accelerating Manufacturing Startups & Scale-Ups

Rationale: Manufacturing is a leading driver of the Iowa economy and a vibrant and robust industry cluster is characterized not only by strong innovation and growth among existing manufacturers but also the ability to generate new startups, and to enable them to scale. Moreover, the flexibility in product development and sourcing that Industry 4.0 technologies enable, also make the establishment of a physical footprint (and the jobs associated with it) potentially more challenging from an economic development perspective. Considering the importance of manufacturing to the Iowa economy, the state needs to excel in supporting manufacturing companies at all stages of their lifecycles.

Strategy #4: Accelerating Manufacturing Startups & Scale-Ups
Action 4.1: Develop and maintain a virtual Manufacturing Startup, Support, and Information Source.
Action 4.2: Consider personal and potentially corporate incentives (e.g., tax incentives, matching funds, dedicated fund of funds) to generate manufacturing-specific angel or venture investments in new, physical product-based, manufacturing companies located in Iowa.

Strategic Priority 5: Ensuring an Effectively Trained Manufacturing 4.0 Workforce: Meeting the Workforce Development & Upskilling Challenge

Rationale: Implementing Manufacturing 4.0 technologies is fundamentally changing the nature of work and job functions in the modern "smart" factory. To achieve its goals and benefits and compete in this environment, digital and "hybrid" skills are vital, learning must be continuous and lifelong, and preparation for modern manufacturing careers takes on a new context. Iowa's manufacturers embracing digital technologies require existing employees to be regularly and periodically "up-skilled." Workforce development is both a major barrier but also enabler of Manufacturing 4.0 technology implementation, and how quickly and efficiently training and upskilling can occur is a significant factor in how Iowa competes into the future.

Issues, Challenges, Gaps—Consistent Themes Raised by Industry Leaders Related to an Effectively Trained Manufacturing 4.0 Workforce:

- Broad demand for digital skills
- Need for adult, nontraditional learner programs; focus on "Upskilling," Re-Training
- Specific skill needs/gaps identified
- Raising Baseline I4.0 Knowledge, Get to Scale

Iowa has in place an existing suite of key workforce training programs and initiatives. This strategy is not designed to replace these existing programs; but rather seeks to allocate new resources to be more targeted to the unique workforce re-training and upskilling needs of a robust Manufacturing 4.0 environment as a high priority for Iowa to remain competitive.

Strategy #5: Ensuring an Effectively Trained Manufacturing 4.0 Workforce
Action 5.1: Restructure funding models for workforce re-training and upskilling program(s) for Iowa's existing manufacturing workforce that are not tied to new job creation.
Action 5.2: Develop and implement Manufacturing 4.0-specific "micro-credentialing," certificate programs, and otherwise applied, "stackable" credentials at Iowa 2- and 4-year institutions to upskill and re-train the incumbent workforce, particularly targeted toward the SME technician workforce and in digital skills and data analytics.
Action 5.3: Enhance cross-disciplinary undergraduate and graduate level curriculum and programming for "hybrid" Manufacturing 4.0 talent demands across engineering, IT, and data sciences at Iowa's colleges and universities.
Action 5.4: Target Manufacturing 4.0-related occupations for increased participation in Registered Apprenticeships and Industry Recognized Apprenticeship Programs and invest to lower existing barriers specific to manufacturing.
Action 5.5: Align and consolidate state support for achieving the necessary scale in Manufacturing 4.0 training/re-training.

The importance of Iowa's manufacturing industry is clear—the sector makes an outsized contribution to the state economy in terms of employment, output, and innovation activity. Simply put, manufacturing has always mattered to Iowa and it continues to, perhaps more than ever. The challenge for Iowa is maintaining its competitive position globally while adopting and integrating the technologies and corresponding benefits of Industry 4.0 to enhance productivity, to keep pace with the nation in the growth and value of its manufacturing output, and to meet the challenges posed by acute workforce shortages.

This plan represents a call to action for Iowa's manufacturers, state leaders, resource providers, economic developers, and state agencies to work together to support its manufacturers' transitioning to Industry 4.0 technologies and to maintain a vibrant manufacturing base through strategies that will drive and ensure competitiveness in the state's manufacturing sector. As Iowa works to implement these strategies, it will continue to look toward the Advanced Manufacturing Work Group, the Iowa Innovation Council, and manufacturing leaders to ensure the implementation of these strategies are industry-driven and supported by continuous collaboration among all partners and stakeholders involved in this important work.

INTRODUCTION

Iowa has a proud history and impressive legacy in manufacturing. Just as the state has long fed this nation as a leading agricultural producer, its innovative manufacturers have supplied global markets with value-added food products, farm and construction machinery and equipment, advanced materials, chemical products, aerospace electronics, and medical devices, to name just some examples. Iowa has thrived and remained competitive by moving toward increasingly advanced manufacturing products and processes that incorporate innovative technologies such as data analytics, automation, sensing, and networking. The sector represents a major pillar of Iowa's economy and it is critical for the state to continually examine its position and performance and to look ahead to "what's next" to ensure it remains a manufacturing leader that is vibrant and globally competitive.

Key Terminology Used in this Report:

- **Industry 4.0, Manufacturing 4.0, and Smart Manufacturing** are used interchangeably throughout
- **Large Manufacturers** = 500+ employees (all divisions/locations combined)
- **Small & Mid-Sized Enterprises (SMEs)** = Fewer than 500 employees (all divisions/locations combined)
- **OEM** = Original Equipment Manufacturer

It is with this spirit and foresight that Iowa is embracing and planning for the rise of a technological and innovation movement that represents a paradigm shift so significant industry experts have referred to as the arrival of the "Fourth Industrial Revolution" or "Industry 4.0."[8] While "Industry 3.0" leveraged the "digital revolution" of the late 20th century to embed computers and robotics into single processes or machines, Industry 4.0 is utilizing a new wave of technologies to fully automate processes and decision making across the production life cycle. The "4.0" terminology has been repurposed for use in strategies targeted at specific segments of the manufacturing industry and the terms "Manufacturing 4.0" or "Smart Manufacturing" are often used interchangeably with Industry 4.0.[9]

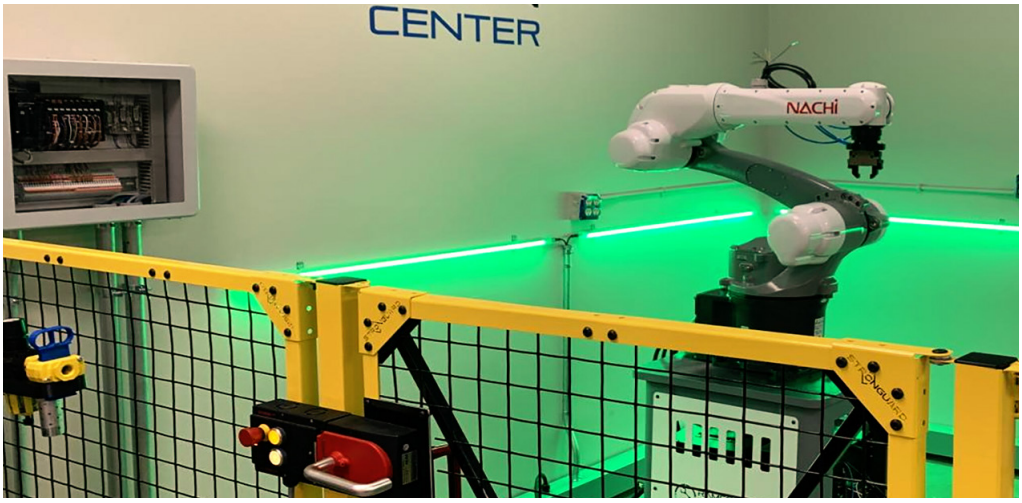
8 The term and concept around Industry 4.0 (or "Industrie" 4.0) is rooted in Germany's national strategy around smart manufacturing systems.

9 This Strategic Plan uses these terms synonymously and interchangeably throughout.

The economic stakes of Manufacturing 4.0 are significant for Iowa's future prosperity. Its economic development leadership and its state-level Advanced Manufacturing Work Group recognize the need for a comprehensive, focused, and forward-looking plan of action to enable Iowa to be a national and global leader in Manufacturing 4.0 technology adoption and integration. This industry-led and guided strategic plan has been developed to maintain and enhance Iowa's vibrant, competitive manufacturing sector into the future.

This report is organized into five sections. It starts by setting the context with an overview and discussion on the importance of Industry 4.0 technologies to manufacturing competitiveness. Section II establishes the current economic position and recent performance of Iowa's manufacturing industry and examines key workforce dynamics related to enabling 4.0 technology deployment and integration. Section III profiles the numerous manufacturing "assets" the state has to leverage from organizational, infrastructure, and expertise perspectives. Section IV leverages extensive industry and stakeholder input to assess the situation for Iowa manufacturers in terms of Manufacturing 4.0 technology adoption and utilization, infrastructure, workforce, supply chain, and startup and scale-up dynamics. The final section details strategic recommendations for advancing Manufacturing 4.0 technologies and enhancing the broader industry ecosystem.

TEConomy Partners, LLC (TEConomy) was engaged by the Iowa Economic Development Authority (IEDA) to develop this forward-looking Iowa Manufacturing 4.0 Plan under the guidance of the Advanced Manufacturing Work Group, a business-led sub-group of the Iowa Innovation Council. The principals of TEConomy Partners have been deeply involved in Iowa's technology-based economic development ecosystem and strategy development for nearly two decades and have had first-hand engagement with Iowa's advanced manufacturing cluster companies, the state's academic institutions and research universities, its broader economic development stakeholder and leadership community, and its citizens.



I. THE INCREASINGLY DIGITAL PRESENT AND FUTURE OF MANUFACTURING: IMPORTANCE OF LEVERAGING INDUSTRY 4.0 TECHNOLOGIES & CAPABILITIES

Digitization is transforming the modern global manufacturing sector, with major implications for industry competitiveness. Drawing from a host of technologies that enable data collection and analysis across and among machines, Industry 4.0 technologies are driving bottom-line outcomes for manufacturers in terms of increased productivity and efficiencies, faster and more flexible production, and ultimately higher-quality goods at lower costs. Digitization of manufacturing is not wholly new—manufacturers have long used digital technologies and automation. However, technology development has progressed today to where a number of formerly disparate tools and applications are now not only commercially available but also able to interconnect in a "smart" manufacturing environment. As one would expect from such transformational technology, Industry 4.0 has significant implications for all facets of the manufacturing ecosystem including innovation, supply chains, infrastructure, the workforce, and even customer engagement—implications that will have tremendous impacts on state and regional competitiveness within advanced manufacturing clusters.

While the Industry 4.0 concept includes an expansive portfolio of new technologies, capabilities, and services, there are several key goals that industry leaders seek to realize in transitioning manufacturing operations to Industry 4.0 models:[10]

- **Interconnectivity** – generation of Big Data, machine-to-machine and machine-to-human communication;
- **Decision support** – use of analytics for predictive action and autonomous decision making;
- **Customization and flexibility** – ability to create highly tailored production runs with minimal downtime and waste;
- **Decentralization** – outsource low level tasks and decision making to machines and increase modular capabilities of production assets.

10 M. Hermann, T. Pentek and B. Otto, "Design Principles for Industrie 4.0 Scenarios," 2016 *49th Hawaii International Conference on System Sciences (HICSS).*

As a result of integrating new technologies that achieve these goals, companies hope to achieve further optimization of production processes (e.g., reducing costs and energy usage), improving operational efficiency and worker safety, and greatly improving customization and flexibility in meeting customer demand.

The ability to gather, store, manipulate, and leverage data from manufacturing operations towards actionable insights is at the core of enabling the technologies and capabilities of Industry 4.0. Advancements in computing, connectivity, and sensing technologies that enable data-driven insights have made it increasingly cost-effective for manufacturers to adopt and integrate these systems in recent years. However, many segments of the manufacturing industry are still in the process of transitioning from legacy operations models to the "cyber-physical" models described in Industry 4.0 principles that leverage the joint capabilities of hardware, software, and workers in an integrated way. This aspirational integration of technologies within companies based on the use of near real-time data on operations is also sometimes referred to as "smart manufacturing" or "intelligent manufacturing."

There are many different descriptions of the detailed technology portfolios related to Industry 4.0 adoption and integration. These portfolios can vary across different stakeholders and specific manufacturing industries. However, several key categories of technologies commonly make up the ecosystem of an integrated Industry 4.0 environment:

- **Foundational technologies** for Industry 4.0 form the backbone of infrastructure that workers and other technologies leverage to gather and access digital information within manufacturing operations. Key examples include the back-end data storage and cloud computing technologies that make up the information technology stack of manufacturing; connectivity infrastructure such as wireless networks and high-speed broadband as well as cybersecurity systems; and sensing and monitoring hardware that makes up the Industrial Internet of Things (IIoT).

- **Enabled technologies** for Industry 4.0 leverage and are largely dependent on the foundational technologies that enable the gathering and transfer of digital information. Many of these technologies represent recent or emerging applications that have become more prevalent as a result of the ongoing digitization of many elements of manufacturing, including advanced robotics and autonomous systems, additive manufacturing, augmented and virtual reality, digital design and prototyping capabilities, and other cyber-physical systems.

- **Downstream Industry 4.0 capabilities and services** that leverage both of the technology types described above to produce new value-added capabilities for manufacturers; but are not novel technologies in and of themselves. Some examples include intelligent Enterprise Resource Planning (ERP) systems that automate and streamline workflows, horizontal and vertical integration with supply chains, predictive decision support tools for maintenance and monitoring, and simulation tools that can "virtualize" production operations for testing.

As shown in Figure 1, the Center for Industrial Research and Service (CIRAS) at Iowa State University has developed one perspective on describing the broader suite of technologies and capabilities encompassed by Industry 4.0 that incorporate many of the concepts described above.

FIGURE 1: CIRAS' DEPICTION OF INDUSTRY 4.0 TECHNOLOGIES

Source: Center for Industrial Research and Service (CIRAS) at Iowa State University.

An aspirational goal of Industry 4.0 technology adoption at the company level is to enable the concept of a "smart factory," a fully integrated digital environment where a broad suite of Industry 4.0 technologies is deployed to create a positive feedback cycle that allows the site to be highly adaptive and flexible. In an example of this model shown in Figure 2, data from each step in the production process is gathered using foundational Industry 4.0 infrastructure and then aggregated and accessed by subsequent production stages and processes, with data on end stage distribution, sales, and customer usage then feeding back into the design and prototyping stages in a cyclical way. The result is a resilient, flexible manufacturing enterprise that allows for continuous improvement. Although many manufacturers are not yet at this stage of integration or may be in partial stages of adoption with many legacy non-digital elements still embedded in their production process, it is critical to recognize the role of foundational technologies in enabling other value-added capabilities through insights provided by data.

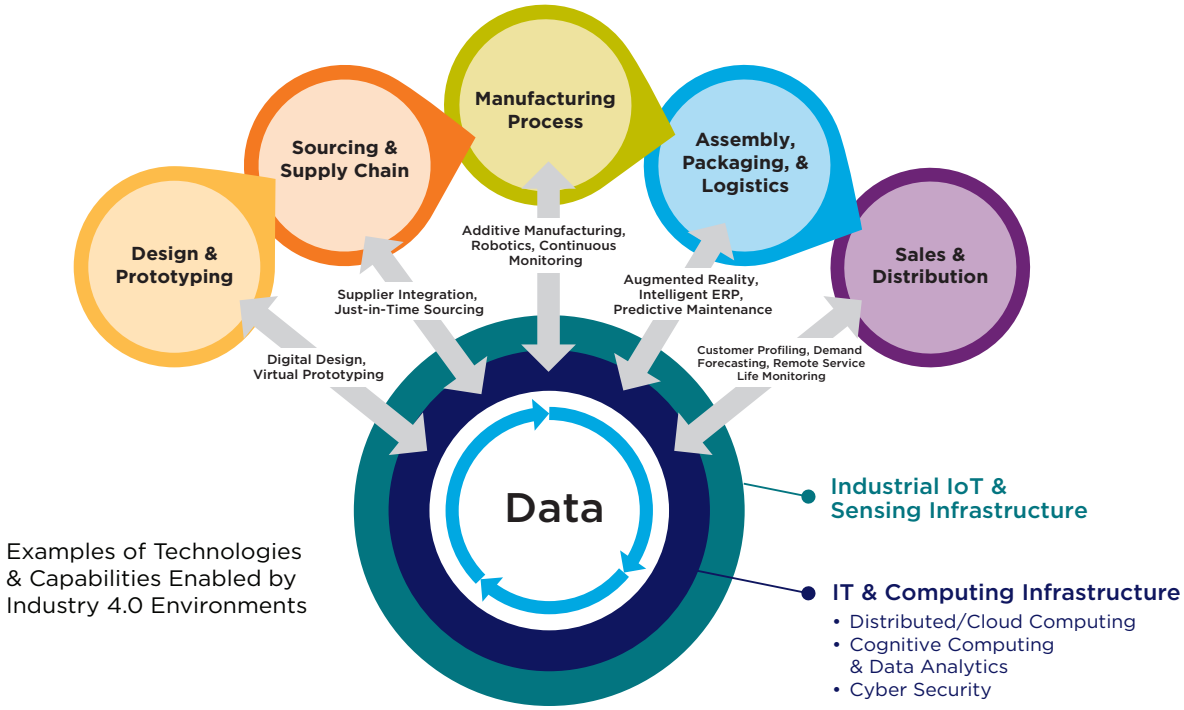
Iowa Industry 4.0 Example: Deere Manufacturing Investment in 5G Capabilities to Enable Ongoing Industry 4.0 Transition

Deere & Company recently participated in the Federal Communications Commission's (FCC) auction to acquire 5G spectrum with the goal of enabling further connectivity within its Iowa production locations. Deere's manufacturing facilities currently rely on significant embedded broadband networking infrastructure, and with the number of connected devices anticipated to continue growing rapidly in the coming years the company realized they needed to invest in increased data bandwidth to support ongoing expansion of digital capabilities. In addition to increased bandwidth, implementing an on-site 5G network will enable further flexibility in redesigning floor space or individual product line work cells which currently requires a significant physical reconfiguration of IT infrastructure. Use of 5G networks will instead allow these changes to happen with more efficiency and fewer changes to physical connectivity configurations.

Deere ultimately won its auction bid and plans to roll out the 5G backbone in several major Iowa facilities in 2022. Manager of Manufacturing Innovation and Technology Strategy Craig Sutton notes that "investment in 5G fits into a larger strategy around driving new efficiencies and digital transforming our operations. We see 5G as an underlying infrastructure technology better enabling solution sets as we continue to build out our industrial IoT."

Source: "Deere Hoping to Harvest Benefits From 5G," Industry Week, November 18, 2020.

FIGURE 2: DEPICTION OF A FULLY INTEGRATED INDUSTRY 4.0 ENVIRONMENT ILLUSTRATING THE KEY ROLE OF DATA-DRIVEN FEEDBACK CYCLES



Source: TEConomy Partners, LLC.

Significant Manufacturing Industry Investment in Transitioning to Industry 4.0 Models

For many manufacturers, transitioning to Industry 4.0 models has become a question of "how" rather than "if" based on rising investments in digital technologies by competitors both locally and globally. PwC's recent Global Industry 4.0 Survey found that U.S. companies planned to commit $907 billion annually to digital technologies.[11]

A further indication of the fast pace of adoption of Industry 4.0 and smart manufacturing are the market research forecasts for its growth. BCC Research considers the major technology areas associated with Industry 4.0 manufacturing applications and estimates the global market will grow from nearly $8 billion in 2018 to almost $22 billion by 2023, a rapid compound annual growth rate of 23 percent.[12] It is becoming increasing clear that those slow to adopt, or left behind in a Manufacturing 4.0 environment, risk losing their competitive edge.

Survey findings also reinforce that recruiting, hiring, and developing skilled talent that can operate within this increasingly digital environment remains a challenge, representing a key constraint often cited by manufacturing industry stakeholders. It is an important reminder that fully integrated cyber-physical environments also require significant investments in training and workforce development. Ultimately, the ability of regional manufacturing-driven economies such as Iowa's to compete in global markets hinges on successful transition to Industry 4.0. Until then, these firms will face increasing cost and customer service pressures from competitors who have prioritized the process of adoption and integration of these technologies.

The strength and competitiveness of a state's manufacturing industry is never guaranteed, and the disruptive nature of Manufacturing 4.0 technologies and the high rates of investment and adoption globally should give pause to industry leaders and stakeholders. To remain competitive, Iowa manufacturers need to embrace and adopt new technologies. Adopting the suite of digital technologies described herein poses significant challenges, particularly for small- and mid-sized manufacturers/enterprises (or "SMEs") facing costly technology purchases, planning for integration in ongoing operations, seeing limited digital expertise in their current workforce, and phasing out or reconfiguring legacy IT systems to prepare for new interoperability requirements. These are just some of the hurdles that manufacturers face in the Industry 4.0 journey.

These challenges raise the need for what the United Nations Industrial Development Organization emphasizes in lessons learned from the experience in Germany:

> *"The German experience [with its Industrie 4.0 strategy] underscores the relevance yet again of multi-stakeholder coordination and collaboration as the foundation for the design and implementation of coevolving innovation and industrial policies."*[13]

11 PwC 2016 Global Industry 4.0 Survey.
12 BCC Research, "Industry 4.0 Technologies: Global Markets through 2023," July 2018.
13 United Nations Industrial Development Organization, "What can Policy Makers Learn from Germany's Industrie 4.0 Development Strategy?" Inclusive and Sustainable Industrial Development Working Paper Series, 2018.

National Example: Fast Radius Digital Additive Manufacturing (Chicago, IL)

In 2018, the World Economic Forum named Fast Radius's Chicago facility as one of its "manufacturing lighthouses," representing the top 9 examples of smart factories globally. The company focuses on additive manufacturing as well as traditional CNC and injection molding platforms in a data-driven environment to perform highly customized, on-demand manufacturing of metal and plastic parts for industries ranging from aerospace to medical devices.

In addition to its leading use of additive manufacturing systems to produce industrial grade parts at scale, the company employs a proprietary software platform that enables real-time production analytics and a "virtual warehouse" of all parts the company has ever produced. This capability in turn allows the company to quickly evaluate the suitability of legacy and replacement parts for production via additive manufacturing with rapid turnaround time. The company has also invested in digital supply chain solutions that enable "virtual inventories" and has partnered with UPS to co-locate some production capacities on-site at the UPS World Port facility in Kentucky in order to enable rapid turnaround times for customer orders.

The technology-agnostic, mass customization framework employed by Fast Radius represents a glimpse at the opportunities enabled by Industry 4.0 technologies. The company has rapidly expanded over the last several years and has raised over $48 million in venture funding to continue building out its technology platforms.

Source: "Fast Radius Raises $48M to Expand Platform for Production-Grade Additive Manufacturing." GlobeNewswire, April 2, 2019.

To boost and ease this transition to increasingly digital operations and functionality, Iowa must leverage and coordinate its breadth of manufacturing expertise, assets, and institutional know-how.

II. IOWA MANUFACTURING INDUSTRY ECONOMIC, WORKFORCE, AND INNOVATION LANDSCAPE ANALYSES: SETTING THE CONTEXT

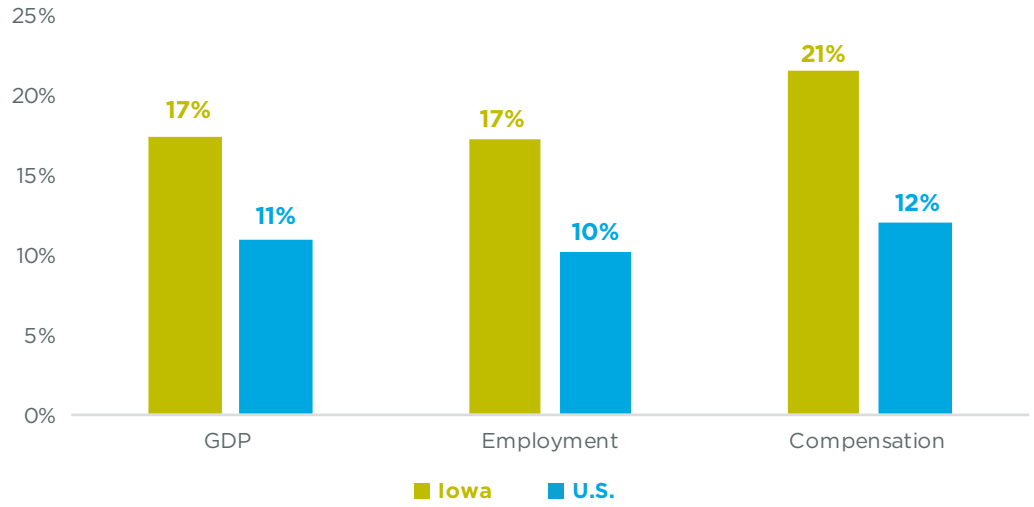
This section of the report provides a baseline assessment and sets the context for the position and recent performance of the manufacturing industry in Iowa, establishing for industry stakeholders and Iowa leadership why manufacturing and its global competitiveness matter to Iowa's economy. The analysis points toward insights into why Industry 4.0 technology investments are needed, the current workforce capacity and context for integrating and deploying new manufacturing technologies, and the innovation landscape for Iowa manufacturers. The analyses and their implications, complemented by the asset mapping detailed in Section III, and the situational assessment for manufacturers gleaned from interviews, focus groups, and surveys in Section IV all combine to paint a picture of where strategic interventions and investments are needed.

Manufacturing Matters to Iowa's Economy: A Highly Specialized and Growing Industry Base

Today, 226,000 Iowans work in more than 4,100 manufacturing establishments across the state's rural and urban areas and leverage their skills, education, and training across a wide range of corporate, innovation, and production roles. The industry's significance in Iowa is hard to overstate—these thousands of workers and the products they manufacture contribute $30 billion to Iowa's Gross Domestic Product (GDP). Combined, this economic footprint represents 17 percent of state GDP, 17 percent of private employment, and 21 percent of total employee compensation—significantly outsized shares when compared against national averages (see Figures 3 and 4). This

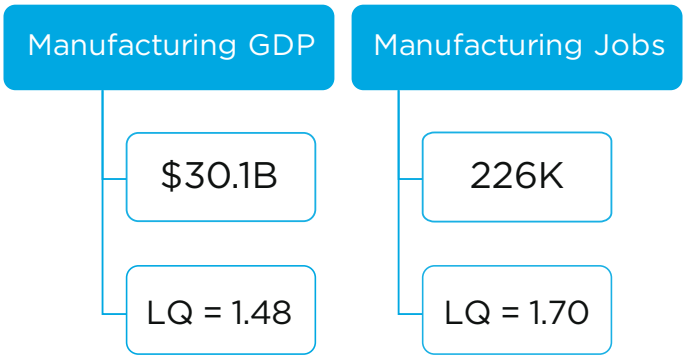
means Iowa is highly "specialized" in its concentrations of manufacturing output and employment as measured by location quotients (LQ).[14]

FIGURE 3: MANUFACTURING SHARE OF IOWA'S KEY ECONOMIC INDICATORS, 2019



Source: TEConomy Partners' analysis of Bureau of Labor Statistics, CEW employment and compensation data; Bureau of Economic Analysis, Real GDP (chained 2012 dollars). Data are based on private sector calculations.

FIGURE 4: IOWA MANUFACTURING GDP AND EMPLOYMENT TOTALS AND CORRESPONDING LOCATION QUOTIENTS (LQ), 2019



Source: TEConomy Partners' analysis of Bureau of Labor Statistics, CEW employment data; Bureau of Economic Analysis, Real GDP (chained 2012 dollars). Data and LQs are based on private sector calculations.

14 Employment concentration is a useful way to gauge the relative importance of an industry to a state or regional economy. State location quotients (LQs) measure the degree of job concentration within the state relative to the national average. States with an LQ greater than 1.0 are said to have a concentration in the sector. When the LQ is significantly above average, 1.20 or greater, the state is said to have a "specialization" in the industry.

Iowa's manufacturing industry has an impressively varied set of major subsectors and strengths. Nine subsectors make up the state's manufacturing cluster and their summary employment metrics are summarized in Table 1 below.[15] The largest three subsectors—food production; agricultural and construction equipment and other heavy machinery; and building, construction, and furniture products—combine to account for just over half (52 percent) of manufacturing employment.

Reflecting the overall "specialized" concentration of manufacturing jobs, each of the individual subsectors has a greater concentration of employment relative to the national average (LQs greater than 1.0). Seven of the nine meet the "specialization" threshold of a LQ greater than or equal to 1.20—meaning they have at least a 20 percent greater concentration of jobs in Iowa relative to the nation.

TABLE 1: IOWA MANUFACTURING INDUSTRY AND MAJOR SUBSECTOR SUMMARY EMPLOYMENT METRICS, 2019

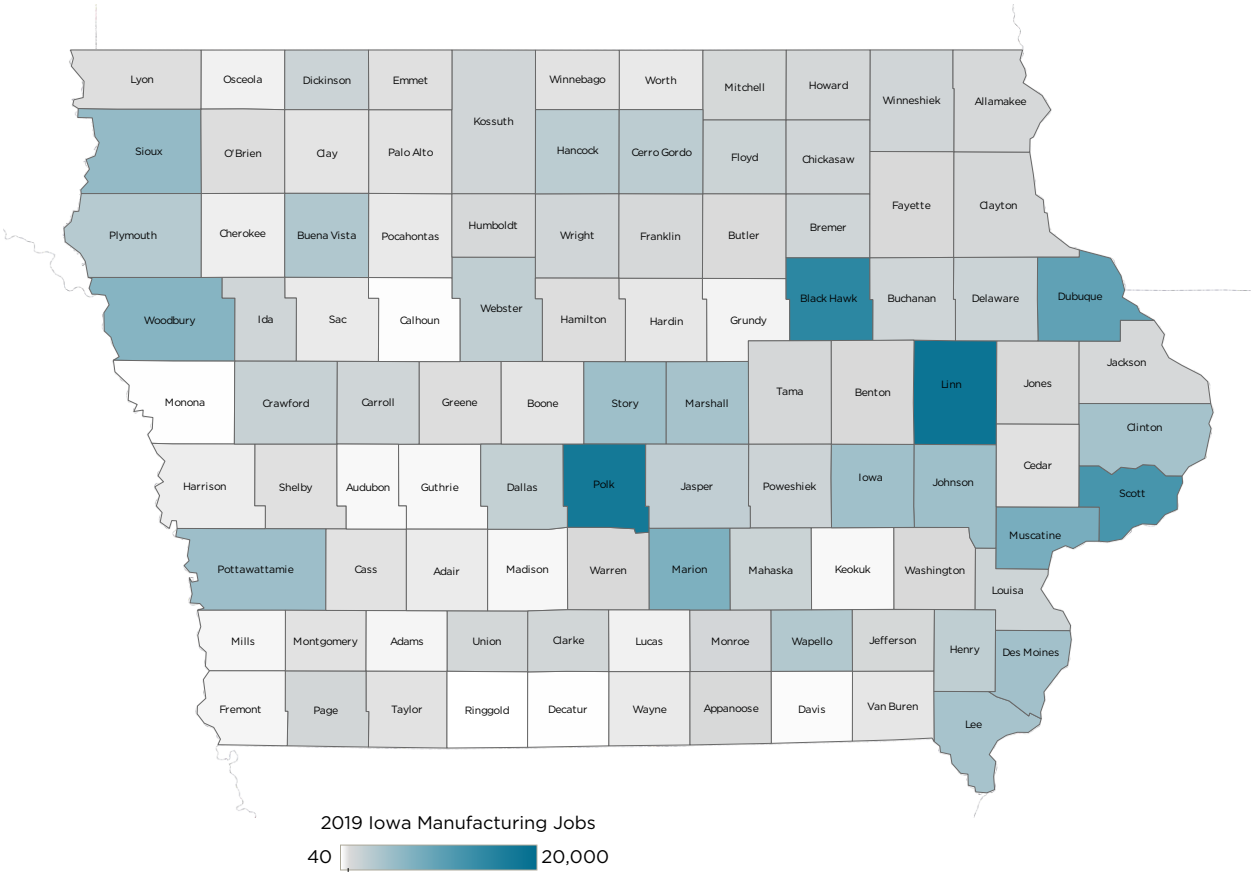
Manufacturing and Major Industry Subsectors	Iowa Employment	Iowa Location Quotient
Iowa Manufacturing Total	**225,903**	**1.70**
Food Production	62,232	2.56
Ag/Construction Equipment & Other Heavy Machinery	29,542	6.19
Building, Construction, & Furniture Products	26,275	1.90
Automation & General Industrial Machinery	13,867	2.01
Other Fabricated Metals Manufacturing	13,431	1.12
Bioscience Manufacturing	12,901	1.65
Avionics & Communications Electronics	10,633	1.54
Consumer Motor Vehicles & Parts	7,679	1.10
Primary Metals Manufacturing	7,422	1.83
Miscellaneous Manufacturing NEC	41,922	0.90

Source: TEConomy Partners' analysis of enhanced BLS, CEW data from Emsi (Emsi Release 2020.2).

15 A tenth subsector, Miscellaneous Manufacturing, NEC ("Not Elsewhere Classified"), captures all remaining parts of Iowa's manufacturing industry not captured within the specific nine subsectors. For a detailed list of industries that define each manufacturing subsector, see the Appendix to this report.

Iowa's manufacturing footprint is especially rural. Fifty three percent of state manufacturing jobs are located in a rural county—one not located in a metropolitan area—compared with just 14 percent in rural locations nationally (Figure 5). Table 2 shows the urban-rural employment composition across each of the major subsectors, with the consumer motor vehicles and parts; and the building, construction, and furniture products manufacturing segments standing out as predominantly rural. While reflective of the state's rural landscape and population, this majority rural dynamic is relatively unique in the U.S. and poses specific challenges raised in the situational assessment where rural manufacturers are struggling with issues such as access to reliable, robust broadband networks and fiber connectivity, as well as workforce and talent shortages exacerbated in rural counties. Iowa's rural manufacturing dynamics are an important consideration in developing appropriate strategic interventions.

FIGURE 5: MANUFACTURING EMPLOYMENT BY COUNTY—53 PERCENT OF IOWA MANUFACTURING JOBS ARE IN RURAL COUNTIES



Source: TEConomy Partners' analysis of enhanced BLS, CEW data from Emsi (Emsi Release 2020.2).

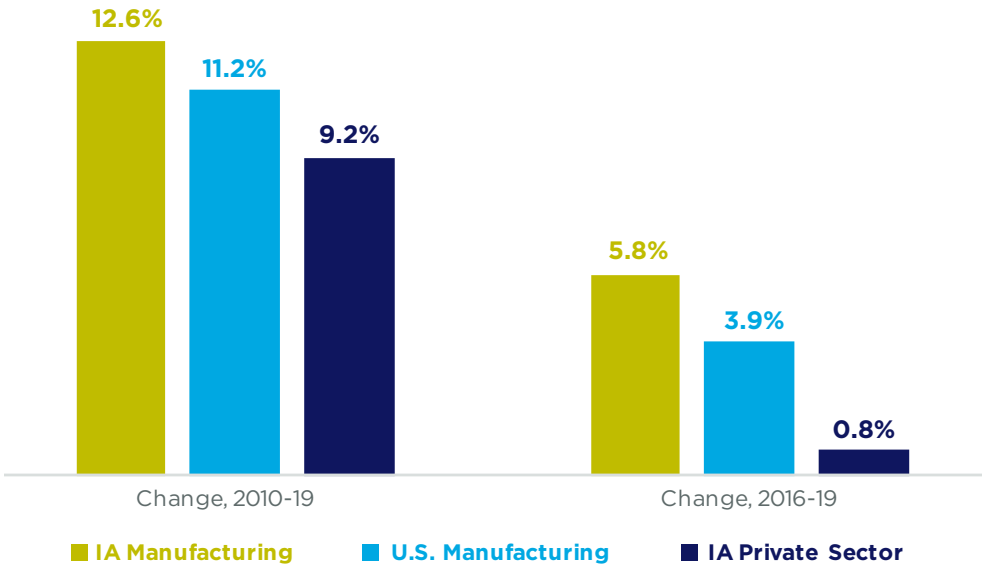
TABLE 2: IOWA MANUFACTURING SHARE OF EMPLOYMENT IN URBAN VS. RURAL COUNTIES, 2019

Manufacturing and Major Industry Subsectors	Urban Share	Rural Share
Iowa Manufacturing Total	**47%**	**53%**
Ag/Construction Equipment & Other Heavy Machinery	51%	49%
Automation & General Industrial Machinery	49%	51%
Avionics & Communications Electronics	93%	7%
Bioscience Manufacturing	41%	59%
Building, Construction, & Furniture Products	37%	63%
Consumer Motor Vehicles & Parts	27%	73%
Food Production	51%	49%
Miscellaneous Manufacturing NEC	38%	62%
Other Fabricated Metals Manufacturing	43%	57%
Primary Metals Manufacturing	61%	39%

Source: TEConomy Partners' analysis of enhanced BLS, CEW data from Emsi (Emsi Release 2020.2).

Manufacturing's importance to Iowa's economy is not only as an outsized employer and economic contributor, but also as a major economic growth driver—growing faster in employment than the industry nationally, and outpacing growth in the overall Iowa private sector. The industry experienced double-digit job growth during the prior economic expansion of the last decade, outpacing the nation over this period since 2010 (Figure 6). In addition, the industry continued to outpace U.S. manufacturing job gains in the more recent period since 2016, growing 5.8 percent in Iowa compared with 3.9 percent nationally. At the same time, Iowa manufacturers have added jobs at a faster pace than the overall Iowa private sector during both periods, acting as an important driver of Iowa's overall employment. And while there is no doubt the COVID-19 pandemic and resulting global economic shutdowns have negatively impacted the industry, heading into the pandemic-induced health and economic challenges of 2020, Iowa's manufacturers were in a strong position.

FIGURE 6: EMPLOYMENT GROWTH TRENDS IN IOWA MANUFACTURING VS. U.S. AND IOWA PRIVATE SECTOR

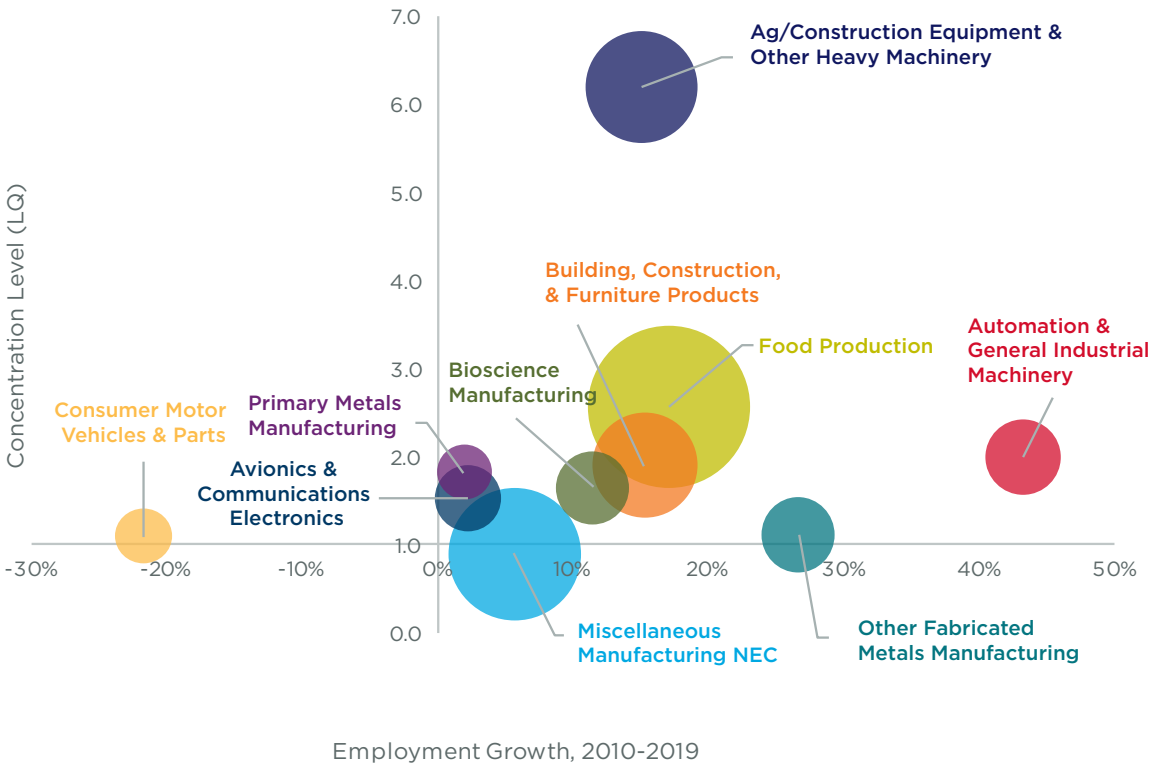


Source: TEConomy Partners' analysis of U.S. Bureau of Labor Statistics, CEW employment.

The overall job growth trends in Iowa manufacturing are playing out across most all of the industry's major subsectors as well—six of the nine major segments had double-digit job gains during the economic expansion of the last decade and just one subsector, consumer motor vehicles and parts, saw a net employment decline.[16] The "bubble" chart in Figure 7 plots the position and recent performance of each subsector in terms of three key employment variables—level (size of the bubble); concentration on the vertical axis (measured by LQs); and employment growth on the horizontal axis. Manufacturing industry "stars" such as ag/construction equipment and food production are plotted firmly in the upper right quadrant based on their job growth and high degree of specialization in Iowa.

16 The consumer motor vehicles and parts subsector includes firms engaged in manufacturing parts and equipment for recreational vehicles, travel trailers, and consumer-oriented motor vehicles. Firms engaged in manufacturing related to semi-trucks and trailers are captured in the ag/construction equipment and other heavy machinery sector. The net employment decline in the consumer motor vehicles subsector has come primarily from the motor vehicle parts industries. While much of the job loss occurred early in the decade, it also reflects more recent closures and job loss from firms such as Modine and International Automotive Components.

FIGURE 7: IOWA'S MAJOR MANUFACTURING SUBSECTORS—EMPLOYMENT LEVELS, CONCENTRATION, AND GROWTH, 2019

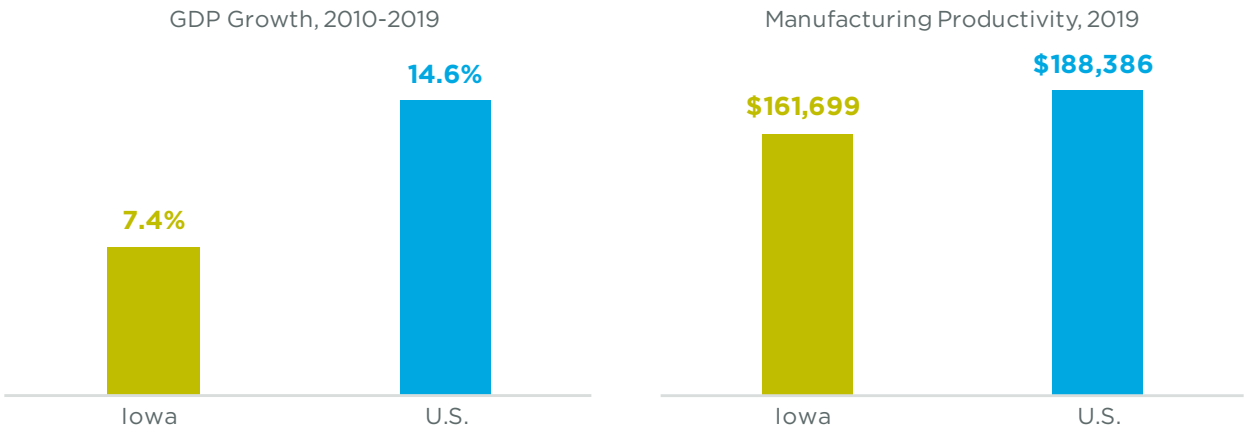


Source: TEConomy Partners' analysis of enhanced BLS, CEW data from Emsi (Emsi Release 2020.2).

Iowa's Manufacturing Competitiveness Challenge: Lagging Productivity and Output Growth Combined with Acute Workforce Shortages

Recognizing its outsized importance to Iowa and recent strong job growth, digging deeper into the industry's dynamics one finds areas of concern for Iowa's manufacturing competitiveness. Despite the industry's specialization and strong employment growth in recent years, Iowa lags just behind the national averages in overall measures of manufacturing productivity—measured as value-added (GDP) per worker—and this plays out across many of the industry's major subsectors (Figure 8). In addition, GDP growth has been slower in Iowa compared with U.S. averages during the lengthy economic expansion of the 2010s.

FIGURE 8: MANUFACTURING REAL GDP GROWTH (2010-19) AND PRODUCTIVITY (2019) FOR IOWA AND THE U.S.



Source: TEConomy Partners' analysis of Bureau of Economic Analysis, real GDP trends (chained 2012 dollars); estimated GDP data per Employee (Productivity) from Emsi (Emsi Release 2020.2).

While there are numerous factors that influence manufacturing productivity, Iowa's industry is undoubtedly hindered by workforce constraints. Iowa manufacturers have operated under acute, well-documented workforce shortages as the state's labor supply has strained under the weight of a lengthy economic expansion and less than 3 percent unemployment rates in recent years, combined with slow population growth.[17] A limited talent pool—often exacerbated in rural areas which are home to just over half of Iowa's manufacturing jobs—places an emphasis on increasing and enhancing production capacity through technology investments.

17 According to the U.S. Bureau of Labor Statistics, Iowa's statewide unemployment rate averaged 2.7 percent in 2019, 5th lowest in the nation.

Iowa companies are embracing and adopting industrial automation, but investments and deployment of new technologies are often discrete and limited to individual machines or systems (for example, a welding robot or 3D printing capability). While these represent important steps forward for the state's manufacturers, particularly its SMEs, investments are not yet occurring in a holistic, fully integrated manner required to realize the full benefits of Industry 4.0. Iowa manufacturers must look to the combination of a skilled workforce and strategic technology investments to realize continued growth and remain competitive.

Iowa's Industry 4.0-Enabling Workforce

In addition to the advanced technologies deployed as part of a Manufacturing 4.0 ecosystem, employees that have the skill sets required to fully leverage integrated digital operations models are critical to ensuring the long-term success of transitioning to a Manufacturing 4.0 framework.

Manufacturers face an especially competitive and challenging workforce landscape in attracting and retaining Industry 4.0-enabling jobs due to the combined challenges of limited supply, high-demand from and competition with other tech-driven industries for talent, and relatively large cohorts of existing workers that are likely to require "up-skilling." Given the importance of a robust, skilled workforce to a fully realized vision of Manufacturing 4.0 in Iowa, several workforce-specific analyses have been conducted to gain insights into Iowa's current situation and to inform strategy development.

Occupational Workforce Assessment

The current occupational composition of Iowa's manufacturing industry, sometimes referred to as "staffing patterns," can be examined for signals regarding the increasing adoption and deployment of Industry 4.0 technologies as well as to provide a baseline for considering strategies to support manufacturing talent development. The concept of an "Industry 4.0-enabling" workforce encompasses a broad spectrum of occupations that range from physical sciences to business services. Using federal occupational classifications, job types have been categorized related to manufacturing operations into production-related occupations that represent traditional labor-intensive manufacturing functions and operations versus Industry 4.0-enabling occupations that develop, deploy, and/or support the digitization and automation applications that are most closely related to the concepts of Manufacturing 4.0. These occupational segments and some illustrative examples are presented in Table 3.

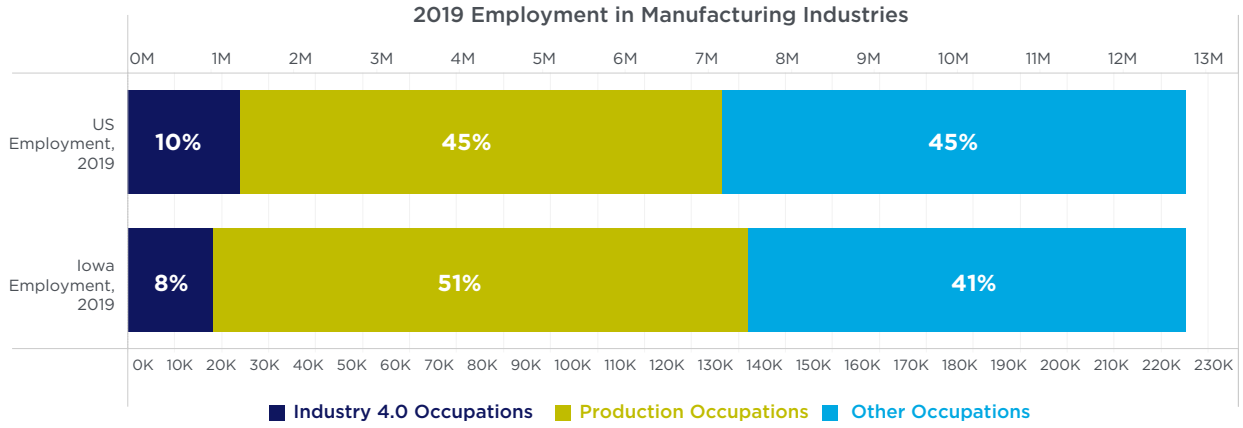
TABLE 3: INDUSTRY 4.0-ENABLING OCCUPATIONAL SEGMENTS AND EXAMPLE OCCUPATIONS

Industry 4.0-Enabling Occupational Segments	Example Occupations in Segment
Business Analytics	Management Analysts, Market Research Analysts
Computer Hardware & Networking	Information Security Analysts, Network and Computer Systems Administrators
Computer Software	Software Developers, Applications, Computer Programmers
Digital Systems	Computer Systems Analysts, Database Administrators
Engineering Technicians	Aerospace Engineering and Operations Technicians, Industrial Engineering Technicians
Engineers	Mechanical Engineers, Industrial Engineers
Modeling & Data Science	Statisticians, Mathematicians
Operations & Logistics	Logisticians, Operations Research Analysts
Scientific Technicians	Chemical Technicians, Ag and Food Science Technicians
Scientists	Chemists, Materials Scientists

Industry 4.0-enabling occupational employment totals more than 18,000 in Iowa and makes up 8 percent of the state's manufacturing workforce, slightly lower than the 10 percent share nationally (Figure 9). Iowa has a relatively greater proportion of production employment in its manufacturing workforce which is potentially vulnerable to disruption by Industry 4.0 trends. The outsized footprint of this production workforce becomes especially important when considering potential retraining and reskilling efforts that could help convert some of this labor force to high value-added occupations aligned with the Industry 4.0 transition.

The skilled technical occupations represented in Industry 4.0-enabling segments are critical to helping companies remain competitive in the future, but it is important to recognize that the existing production worker segments will still play a key role in manufacturing industries and technology deployment and are likely to see their roles shift to more closely aligned with Industry 4.0 over time.

FIGURE 9: INDUSTRY 4.0-ENABLING OCCUPATIONAL EMPLOYMENT WITHIN THE U.S. AND IOWA'S MANUFACTURING INDUSTRY



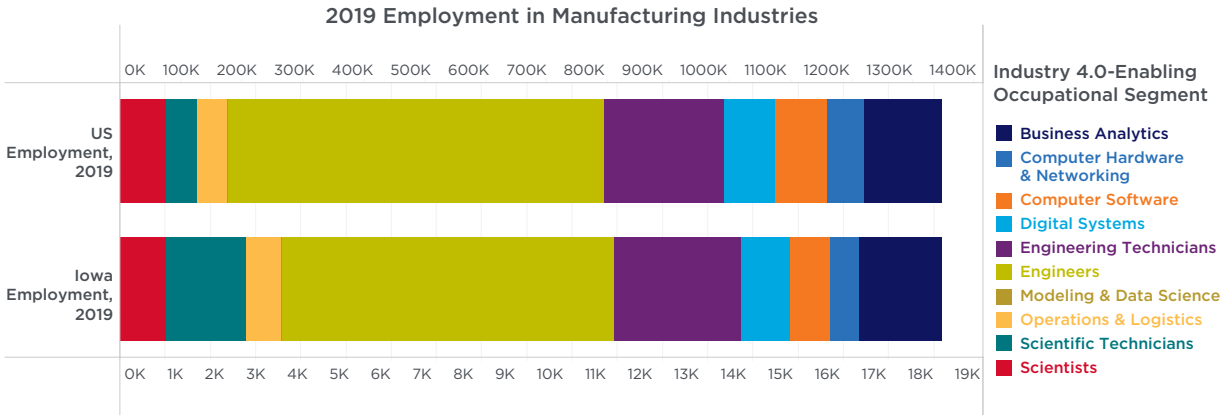
Source: TEConomy Partners' analysis of industry staffing patterns data from Emsi (Emsi Release 2020.2).

Within the Industry 4.0-enabling segment of Iowa's manufacturing workforce, Figure 10 details the composition of the workforce by specific segment comparing Iowa against the U.S. Engineers and engineering technicians make up the bulk of Industry 4.0-enabling employment, highlighting the importance of this particular workforce to the manufacturing industry both nationally, and in Iowa.

The technician workforce represents one of the key routes through which Industry 4.0 technologies and systems will be deployed in Iowa.

Where Iowa's 4.0-enabling workforce stands out, however, is its above-average deployment of engineering and scientific technicians—both representing greater shares in Iowa compared with the U.S. This situation has important implications for advancing Industry 4.0 and has been emphasized through discussions with Iowa manufacturers on the critical importance of retraining and up-skilling the technician-level workforce that is often wearing multiple tech-related hats, performing various new functions in an increasingly digital operating environment. The technician workforce represents one of the key routes through which Industry 4.0 technologies and systems will be deployed in Iowa.

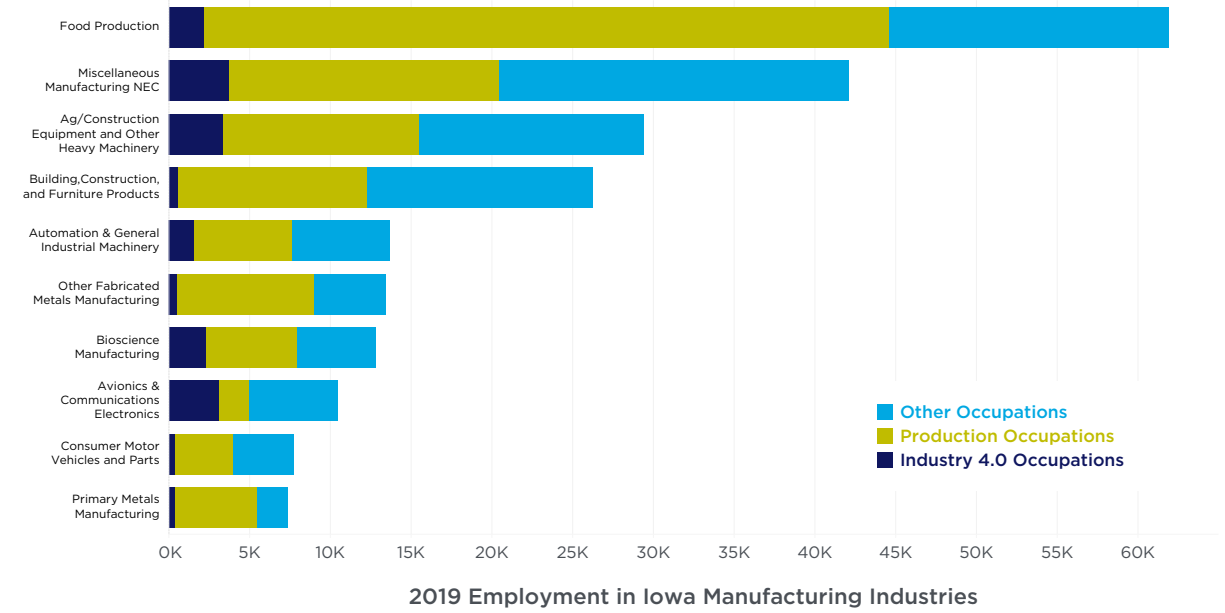
FIGURE 10: DETAILED INDUSTRY 4.0-ENABLING OCCUPATIONAL EMPLOYMENT WITHIN THE U.S. AND IOWA'S MANUFACTURING INDUSTRY



Source: TEConomy Partners' analysis of industry staffing patterns data from Emsi (Emsi Release 2020.2).

Manufacturing is not monolithic, of course, and understanding which of the major manufacturing subsectors are driving the current deployment of Industry 4.0-enabling talent in Iowa is important to identifying key skill sets and sectors to target for workforce initiatives. Figure 11 shows Industry 4.0-enabling occupational employment levels for each of Iowa's manufacturing industry subsectors.

FIGURE 11: INDUSTRY 4.0-ENABLING OCCUPATIONAL EMPLOYMENT WITHIN IOWA'S MANUFACTURING INDUSTRY SUBSECTORS



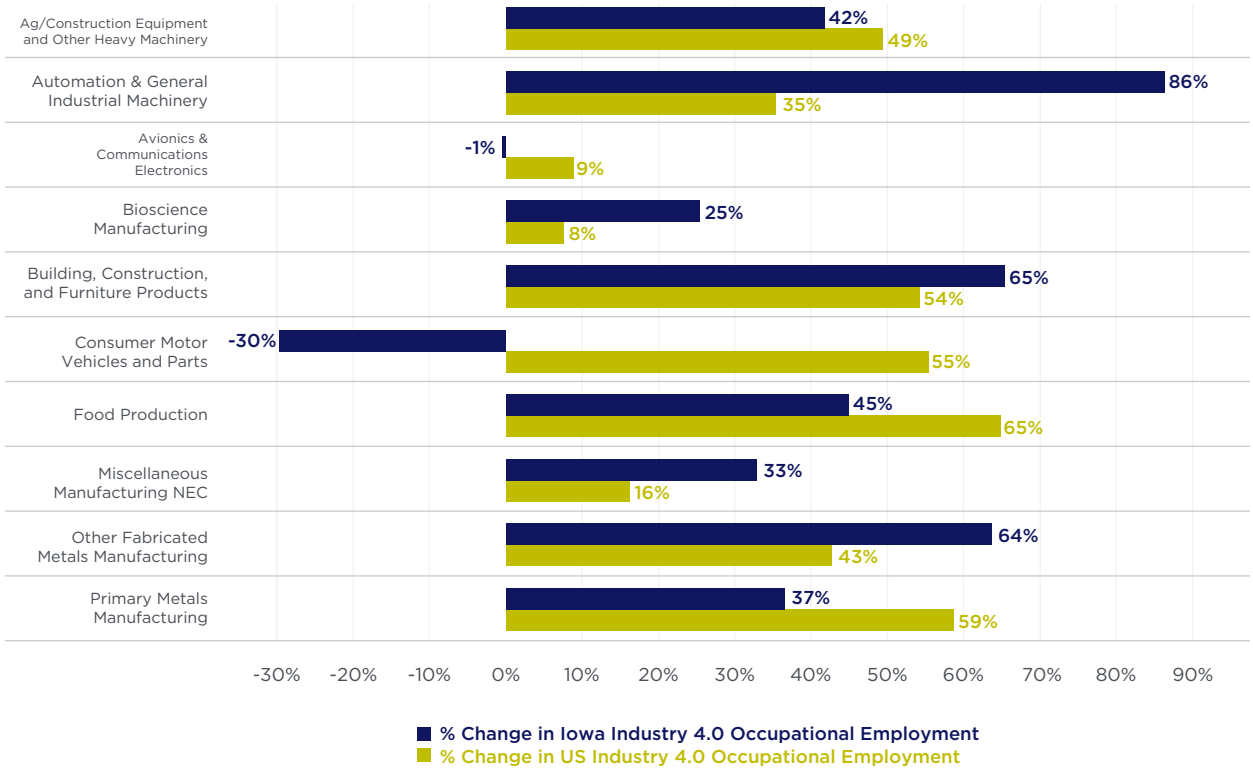
Source: TEConomy Partners' analysis of industry staffing patterns data from Emsi (Emsi Release 2020.2).

Just as with manufacturing overall, Iowa's largest manufacturing subsectors employ relatively lower shares of Industry 4.0-enabling occupations in comparison to traditional production workforces and other types of business support and administrative occupations. In particular, Iowa's largest manufacturing subsector, food production, employs a disproportionately low share of Industry 4.0-enabling talent (3.6 percent of total subsector employment in 2019) and is reliant on traditional production workforces. Many of Iowa's other largest manufacturing subsectors display a similar trend, with slightly lower Industry 4.0-enabling occupational shares than national averages but significantly higher shares of traditional production workers. A notable exception is the agricultural, construction equipment, and other heavy machinery subsector which employs a slightly higher share of Industry 4.0-enabling occupations (11.4 percent of total employment in 2019) compared to U.S. levels (10.8 percent).

Iowa's bioscience and avionics and communications electronics manufacturing subsectors represent key areas with greater shares of Industry 4.0-enabling occupations, representing 18.3 percent and 29.9 percent of total subsector employment, respectively. Biosciences manufacturing include firms such as Integrated DNA Technologies or IDT headquartered in Coralville and recently acquired by Danaher, which manufactures custom nucleic acids (DNA, RNA) for research, biotech, pharmaceutical development, and other applications. The avionics and communications electronics manufacturing subsector is represented in Iowa primarily by Collins Aerospace based in Cedar Rapids and a unit of United Technologies Corp. that has its avionics and mission systems units based in the state. While the subsectors have lower levels of overall employment than other manufacturing industries, the relatively high shares of skilled, enabling talent that are present indicate they are likely to be leaders in advancing innovative practices aligned with Industry 4.0 and are also reliant on attracting and retaining talent in these occupations to continue growing within the state.

Growth trends among Iowa's Industry 4.0-enabling occupational workforce in manufacturing have been mixed (Figure 12). Some subsectors such as automation and general industrial machinery have greatly outpaced the U.S. during the last decade, while other large employment subsectors like food production have lagged behind significantly. Altogether, five subsectors have outpaced the nation in adding enabling occupations, while the other five have either declined or grown at a slower pace. The trends across Iowa's manufacturing subsectors appear to indicate market and talent supply conditions affecting subsectors and companies on a more individualized basis, demonstrating the need for a broader strategic focus on growing a common, higher-volume pipeline of skilled talent in Industry 4.0-enabling areas for the state that can serve multiple industry subsectors as they increasingly deploy digital technologies and systems.

FIGURE 12: EMPLOYMENT TRENDS OF INDUSTRY 4.0-ENABLING OCCUPATIONAL EMPLOYMENT WITHIN IOWA'S MANUFACTURING INDUSTRY SUBSECTORS, 2010-19



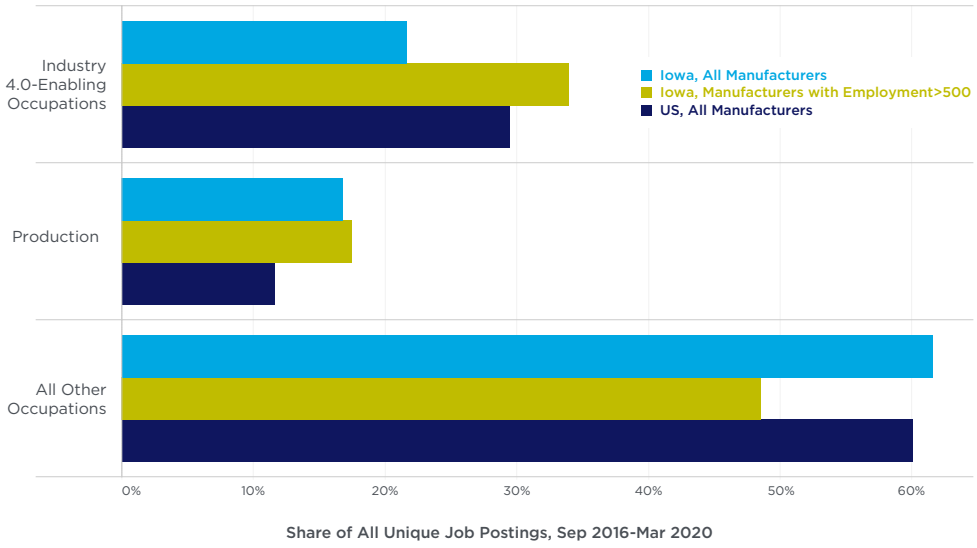
Source: TEConomy Partners' analysis of industry staffing patterns data from Emsi (Emsi Release 2020.2).

Insights from Job Postings Further Inform Industry 4.0 Workforce Demand by Iowa Manufacturers

In addition to changes in the occupational mix of manufacturing industries, another indicator of demand for Industry 4.0-enabling talent is job postings intelligence. Activity in job postings serves as another signal of industry demand from employers for specific occupations or skill sets indicative of Industry 4.0 needs. Job postings were analyzed using the Emsi Job Posting Analytics database, a service that aggregates cross-listed job postings across numerous company-specific and broader job search websites to identify unique job positions and descriptive data outlining the characteristics of the advertised positions. Job postings activity among Iowa manufacturers covering the period from September 2016 through March 2020 were analyzed to establish patterns in Industry 4.0-enabling position hiring and associated skill sets of importance.

Figure 13 shows the broad occupational employment categories associated with the more than 124,000 total job postings listed by Iowa manufacturers over the late-2016 through early-2020 period.

FIGURE 13: INDUSTRY 4.0-ENABLING OCCUPATIONS IN IOWA MANUFACTURING JOB POSTINGS ACTIVITY



Source: TEConomy Partners' analysis of Emsi Job Posting Analytics database (Emsi Release 2020.2).

While Industry 4.0-enabling occupations make up 8 percent of Iowa manufacturing employment, they represent 22 percent of recent job postings, indicating strong demand.

Job postings reveal Iowa manufacturers are emphasizing demand for Industry 4.0-enabling positions over production occupations during this latest 3.5-year period, but that other types of business support occupations such as administrative and sales roles still make up the vast majority of posting activity (under "all other occupations"). While enabling occupations make up 8 percent of industry employment, they represent 22 percent of recent job postings, indicating strong demand. The size of firm matters in the demand dynamics for enabling occupations—large Iowa manufacturers (those with more than 500 employees) are outpacing the rest of the state industry and broader national trends in postings activity for Industry 4.0-related positions. Much of the Industry 4.0-related activity is driven by bulk volume recruiting for specific positions at key employers. Examples include positions in software development at Collins Aerospace and quality assurance engineers at Deere & Company.

Among the Industry 4.0-enabling occupations, there is a clear focus on recruiting engineering talent amongst large Iowa manufacturers, highlighting the potential to expand talent pipelines at existing postsecondary programs to help meet these needs. Iowa currently lags behind broader U.S. manufacturer activity in job postings related to other types of Industry 4.0-enabling occupations such IT and digital systems-related positions as well as data science positions in areas such as business analytics, operations and logistics, and modeling. These areas represent a key enabler of data-driven business intelligence solutions for Industry 4.0 applications, making it critical to both increase the supply of these occupations but also to increase employer education and awareness of this type of workforce and the need to actively recruit and retain them in higher numbers.

As Table 4 shows, Industry 4.0-enabling occupations that are in high demand based on the volume of postings activity are focused on jobs associated with enabling software applications as well as positions related to systems engineering disciplines. Both of these groups represent key roles in the increasingly digital environment and the deployment of Industry 4.0 technologies within manufacturing industries.

TABLE 4: SUMMARY OF INDUSTRY 4.0-ENABLING OCCUPATIONAL DEMAND FROM IOWA MANUFACTURING JOB POSTINGS, SEPTEMBER 2016—MARCH 2020

Job Titles Posted by Iowa Manufacturers for Industry 4.0-Enabling Occupations	Unique Job Postings (Sept. 2016 – Mar. 2020)
Software Engineers	1,848
Systems Engineers	1,119
Design Engineers	865
Quality Assurance Engineers	860
Manufacturing Engineers	786
Engineering Co-ops	597
Product Engineers	446
Process Engineers	432
Project Managers	428
Engineering Interns	407
Mechanical Engineers	381
Project Engineers	340
Quality Engineers	335
Production Managers	327
Senior Electrical Engineers	261
Business Analysts	237
Laboratory Technicians	232
Engineering Managers	226
Research Analysts	210
Industrial Engineers	208
Software Developers	202
Controls Engineers	197
Continuous Improvement Engineers	197
Safety Managers	188
Java Developers	165
Production Technicians	153
Research Associates	152

Source: TEConomy Partners' analysis of job postings data from Emsi (Emsi Release 2020.2).

Innovation Scan: Manufacturing as a Leading R&D, Innovation Engine for Iowa

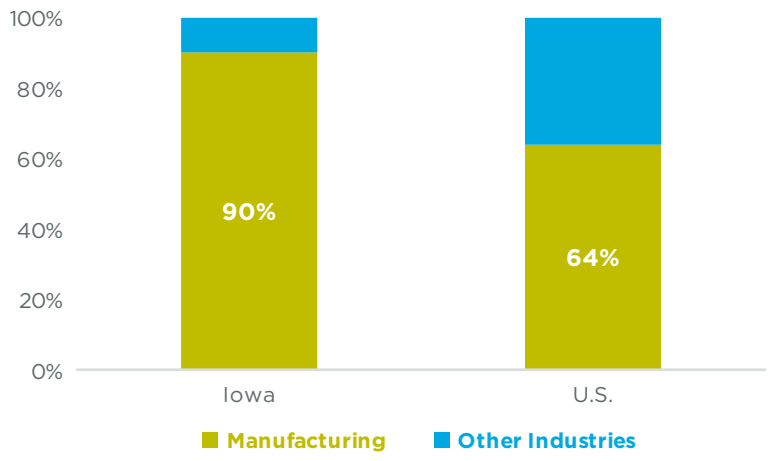
A final component of the review of the current situation for Iowa's manufacturing industry and the scan for Industry 4.0 activities and responses is a high-level assessment of key innovation metrics, Iowa's performance within these metrics, and whether this performance provides insights into manufacturers' Industry 4.0 plans or responses. Further, it is intended to better understand whether Iowa manufacturers are driving Industry 4.0 innovations themselves.

Manufacturing Research and Development

The level of R&D investment by Iowa manufacturers provides some insights into the state's Industry 4.0 potential. Firms engaged in innovative activities are often more involved with overall operational improvement activities as well—a finding confirmed by CIRAS in its most recent biennial Manufacturing Needs Assessment.[18]

According to the 2017 National Science Foundation (NSF) Business R&D and Innovation Survey (BRDIS) data (the most current available survey at the time of analysis), manufacturers in Iowa accounted for $1.982 billion or more than 90 percent of Iowa's total industrial R&D activity ($2.195 billion). Further reflecting the extreme importance of manufacturing to Iowa, this manufacturing share of industrial R&D compares to a 64 percent share at the national level—put another way, R&D is 42 percent more concentrated in manufacturing in Iowa than it is nationally (Figure 14). R&D activity among Iowa manufacturers is growing at a slightly faster pace in recent years (12.4 percent growth) compared with the U.S. overall (10.4 percent growth).

FIGURE 14: MANUFACTURING SHARE OF TOTAL INDUSTRIAL R&D, IOWA AND U.S., 2017



Source: TEConomy Partners' analysis of National Science Foundation, Business R&D and Innovation Survey (BRDIS) data, 2017.

18 Iowa State University, Center for Industrial Research and Service (CIRAS), "Iowa Manufacturing Needs Assessment, 2019-20."

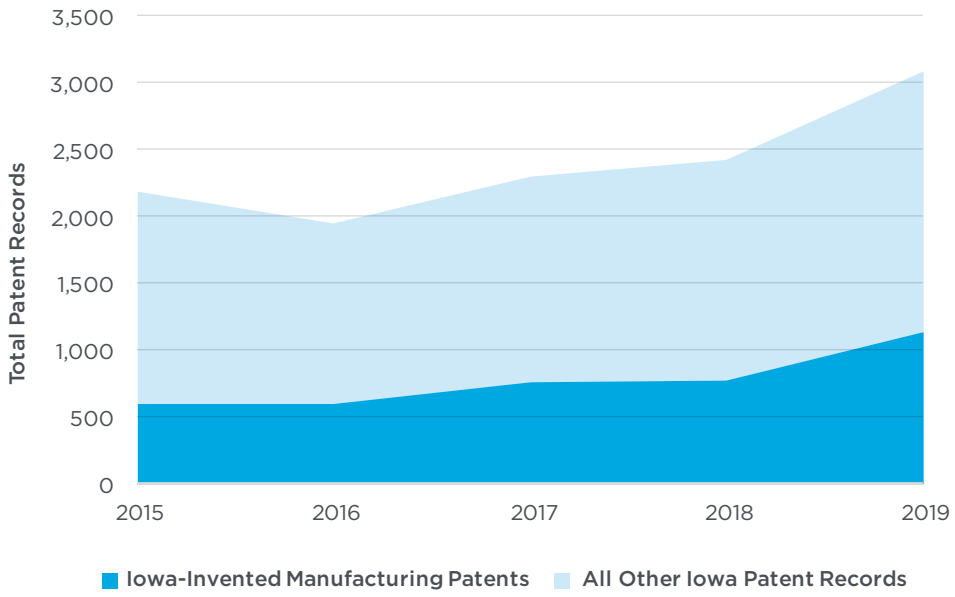
Within this overall manufacturing concentration, however, is an even more significant concentration within a few of the major manufacturing subsectors, with some unique to Iowa. Within Iowa, 35 percent of the state's industrial R&D is found within the food manufacturing sector ($778 million), compared to just over 1 percent nationally. With Iowa accounting for nearly 18 percent of all U.S. food manufacturing R&D and recent growth dramatically outpacing the U.S. (154 percent to 22 percent)—clearly there is important innovation occurring in the state. A similar situation exists within the state's agricultural machinery industry. Agricultural machinery accounts for $623 million, or more than 28 percent of the state's industrial R&D, while at the national level this share is less than 1 percent. Importantly, Iowa firms account for more than 41 percent of all U.S. R&D in the agricultural machinery sector. A third manufacturing sector, search, navigation, guidance, and aeronautical instruments, accounts for $155 million, or slightly more than 7 percent of Iowa's industrial R&D compared to 1 percent nationally. Together, these three manufacturing sectors account for 70 percent of Iowa's total industrial R&D.

These shares of R&D investment by key Iowa manufacturing sectors may signal important Industry 4.0 opportunity areas—but it should be noted that within these three sectors the R&D performance is likely concentrated in a small number of large Iowa manufacturers. Other important sectors, in terms of R&D performance in Iowa, include chemicals (basic, ethanol, agricultural, and pharmaceuticals), other machinery, furniture and related products, primary metals, and plastics.

IP Generation from Patent Activity

Examining patent activity and the intellectual property (IP) generation reflected in patents, provides another vantage from which to assess an industry's innovation activities. A patent analysis examined a total of 12,474 U.S. patent award and application records from 2015 through 2019 affiliated with an Iowa resident inventor. As shown in Figure 15, over the course of this five-year period, manufacturing-related patents accounted for between one quarter and one third of all Iowa patents, for a total of 4,040 manufacturing-related patents (both issued and applied for) over the entire 2015 through 2019 period, or approximately 32 percent of all Iowa patent activity is manufacturing-related.

FIGURE 15: IOWA MANUFACTURING-RELATED PATENTS COMPARED TO ALL OTHER IOWA PATENTS, 2015-2019



Source: TEConomy Partners' analysis of Clarivate Analytics' Derwent Innovation patent analysis database.

Further examination of these manufacturing-related patents and their patent classifications showed that most Iowa patenting activities are focused on documenting IP regarding finished or other end-state products (such as electronics or components) produced by manufacturers rather than processes or enabling technologies (where patents for actual Industry 4.0 technologies would be expected to be classified). Examples of such finished products documented in patents related to major Iowa manufacturing companies include agricultural harvesting systems, avionics and antenna systems, and machine tools. While they represent advanced technologies, these patents largely do not detail the specific production methods and processes used by companies, making it difficult to observe the deployment of Industry 4.0 technologies in their creation.

There is some innovation activity present in areas that have a high potential to be applicable to Industry 4.0 such as design and analytics tools for engineering of components and mechanical systems and sensors and instrumentation, with specific innovation happening in industrial controls and quality control instrumentation.[19] These two areas account for approximately one-third of Iowa's manufacturing-related patents, although many of these patents also describe finished products produced by manufacturers for use by customers as opposed to the technologies used in their manufacture. Some examples of patents generated by Iowa inventors documenting new IP that is

19 See the Appendix to this report for details of the technology areas and Iowa companies captured within Iowa's manufacturing patents.

highly related to Industry 4.0-enabling processes and infrastructure as opposed to products include systems for quality monitoring of additive manufacturing, sensing methods for estimation of the useful life of newly manufactured industrial control components, and embedded fault detection and testing for vehicle and agricultural machinery equipment subsystems.

A key consideration, though not surprising, is manufacturing-related patenting activity is dominated by Iowa manufacturers with large employment footprints. Deere & Company, for example, represents 31 percent of the total Iowa-invented manufacturing-related patents. Additionally, five of the largest in-state manufacturing companies—Deere, Collins Aerospace (Rockwell Collins; Delavan), Emerson (Fisher Controls), and Vermeer—encompass fully 64 percent of all Iowa-invented manufacturing patents.

The assessment of these patent data reveals that Iowa's manufacturing firms are much more oriented toward deploying and implementing Industry 4.0 technologies versus developing and producing these technologies.

Innovation and Startup Funding: Federal SBIR Awards and Venture Capital Investment

To complete the scan of Iowa's manufacturing-related innovation activity, key funding sources for startup and emerging, high-growth potential manufacturers were examined, including awards from the federal Small Business Innovation Research Program (SBIR) and venture capital investments in manufacturing.

Over the last decade (2010-2019), 22 small Iowa manufacturers received federal SBIR funding totaling $20 million. These awards to, and funding for Iowa manufacturers represent about 25 percent of both total awards and total funding to Iowa establishments.

From a venture capital perspective, small/emerging manufacturers did better, with 24 Iowa "startup" manufacturing firms receiving nearly $80 million in venture funding over the past decade. Yet, this $80 million represents only about 12 percent of the total venture capital funding to Iowa firms over the 2010 through 2019 period.

This assessment of funding resources for startup and emerging innovative small manufacturers shows that risk capital and innovation-focused federal funding has been relatively limited for Iowa manufacturers (or physical product startups) as much of the funding from these sources, particularly VC funding, flows disproportionately to IT and service-related firms.

In summary, the importance of Iowa's manufacturing industry is clear—the sector makes an outsized contribution to the state economy in terms of employment, output, and innovation activity. Simply put, manufacturing has always mattered to Iowa and it continues to, perhaps more than ever. The challenge for Iowa is maintaining its competitive position globally while adopting and integrating the technologies and corresponding benefits of Industry 4.0 technologies to enhance productivity,

to keep pace with the nation in the growth and value of its manufacturing output, and to meet the challenges posed by acute workforce challenges. The next section of the report identifies and profiles the assets Iowa has in place to navigate this journey.

III. IOWA'S ASSETS RELATED TO MANUFACTURING 4.0 TECHNOLOGY ADOPTION, INTEGRATION, AND DEVELOPMENT

Iowa has significant organizational and infrastructure assets for industry to draw from and partner with in their ongoing efforts to drive Manufacturing 4.0 development within the state. These assets represent a broad portfolio of Manufacturing 4.0 technology and development expertise that span the state's research universities, community colleges, and several key non-academic organizations. The project team conducted site visits, meetings, and interviews across these organizations to better understand and characterize these assets that can and should be leveraged and organized for collaboration and scaling up Manufacturing 4.0 technology adoption and utilization. These key organizations and infrastructure included in the Manufacturing 4.0 asset identification include:

Industry-Facing Organizations:

- Center for Industrial Research and Service (CIRAS) at Iowa State University (ISU)
- TechWorks Campus and Additive Manufacturing Center
- Quad Cities Manufacturing Innovation Hub

Academic Institutions:

- ISU and the Ames Laboratory
- University of Iowa (UI)
- University of Northern Iowa (UNI) and the UNI Metal Casting Center (MCC)
- Iowa's Community Colleges, where high-level input has been gathered and summarized in this section.

The following profiles provide an overview of each of these organizations as well as relevant assets and activities related to Industry or Manufacturing 4.0. One key conclusion drawn from this assessment

is that while these organizations and institutions are active, engaged, and/or leading in key areas of technology R&D or demonstration that are either directly or indirectly related to Manufacturing 4.0, the asset mapping and assessment has not found Iowa to be a leading technology development state in this space broadly. This finding has important implications for the overall direction of the Iowa Manufacturing 4.0 Plan and strategic interventions and positions the Plan as a guide to focus Iowa manufacturers toward technology adoption and utilization with the assistance of these organizations and assets rather than a primary focus on Industry 4.0 technology development and innovation. That acknowledged, there are exciting, highly relevant, and increasing investments and activity occurring across the state to leverage in support of the strategies outlined in this Plan.

Industry-Facing Organizations

Center for Industrial Research and Service (CIRAS) at ISU

A program of Iowa State University, CIRAS leverages the resources and capabilities of national/federal programs[20] as well as other ISU research labs and extension activities, and numerous state entities and organizations (e.g., IEDA, Iowa Association of Business and Industry (ABI), community colleges, other public and private providers, Alliant Energy) to deliver focused assistance to Iowa's small and medium-sized manufacturers. Established in 1963, CIRAS has provided customized assistance and solutions to Iowa's manufacturers through many significant changes in manufacturing and emerging requirements in areas such as process design and automation, lean manufacturing, continuous improvement, and quality management systems. With this extensive history, CIRAS is seen as a key state partner and resource in the anticipated and necessary adoption of Industry 4.0 technologies. Already engaging Iowa's manufacturers in Industry 4.0 activities, CIRAS' key resources, services, and programs include:

CIRAS' Reach and Impact

Over the past five years, CIRAS and its partners have helped more than 4,100 businesses in every Iowa county, creating an economic impact of more than $2.8 billion.

- Education, training, and demonstrations on specific Industry 4.0 technologies and applications including a series of on-demand webinars;
- Various digital manufacturing/Industry 4.0 opportunity assessments—ranging from in-person deep, comprehensive evaluations to shorter, virtual process reviews (in light of COVID restrictions), and self-assessment tools;

20 These programs include, for example: National Institute of Standards and Technology (NIST)/Manufacturing Extension Partnership (MEP) National Network; DoD/Defense Logistics Agency (DLA) Procurement Technical Assistance Center; DoC/U.S. Economic Development Administration (EDA) University Center Program.

CIRAS Industry 4.0 Assessment Example: CJ Bio

Implementation of Industry 4.0 technologies is beginning to have significant impacts on local Iowa companies. CJ Bio, a global producer of amino acids for animal feed, used an Industry 4.0 assessment conducted by CIRAS in 2019 to identify several key areas for improvement that are anticipated to save millions of dollars through implementation of new technology solutions.

Based on the CIRAS assessment, operations management at CJ Bio noted that "the company's initial priorities include automating some of the sampling and testing required during its production process and overhauling the way it handles bulk material waiting to be shipped." The company plans to have several high priority technology enhancements online by the end of 2020, with further business cases for other areas providing the blueprint for future Industry 4.0 implementation.

- Specific CIRAS experts aligned to each one of nine recognized Industry 4.0 technologies with the ability to develop and provide proof-of-concept activities and examples;
- Implementation assistance with key industry 4.0 technology and related emerging technologies;
- Connections with outside Industry 4.0 technology providers and consultants.

CIRAS' multi-step assistance provides manufacturers with an actionable plan for implementing Industry 4.0 technologies including recommendations on which of the technologies are the correct and most important for adoption, an assessment of the potential long-term impacts of Industry 4.0 technologies on the company (and a perspective on where competitors are heading), and assistance with developing a company-specific roadmap for Industry 4.0 adoption.

Recently, CIRAS, in partnership with Alliant Energy, several manufacturers, and other public and private resources, established a new Digital Manufacturing Lab. Within this "laboratory" CIRAS is able to provide exposure and hands-on experience with a host of Industry 4.0-relevant technologies including 3D scanning, 3D printing, collaborative robots ("cobots"), and sensor technologies. On-going development plans include adding additional sensor applications and machine vision systems capabilities and increasing the number of application demonstrations and training activities.

Also noteworthy, CIRAS provides an important guidepost and benchmark to the health and activities of Iowa's manufacturing industry through their biennial Manufacturing Needs Assessment, a combination of a survey and company forums with key findings summarized in a published report.

TechWorks Campus and Joint Additive Manufacturing Center

Situated on a 30-acre brownfield site in Waterloo, with current efforts housed in two historic Deere & Company manufacturing buildings, TechWorks operations bridge Iowa's manufacturing past with its manufacturing future providing a nexus for advanced manufacturing-related R&D, innovation, and education. TechWorks plays a unique role as a regional center of gravity and connectivity for industry-academic collaborations on "state of the art" and other industry-relevant equipment, especially within Iowa's significant metal casting industry and expertise. Operating as a 501(c)(3) subsidiary of Greater Cedar Valley Alliance and Chamber, TechWorks is positioning itself to be a "public-private sandbox" for industry and academia to come together to solve advanced manufacturing challenges and to showcase important technologies and equipment to the region's manufacturers.

Integral to its overall operations and plans, TechWorks has established key research and educational collaborations with the University of Northern Iowa and Hawkeye Community College (HCC), and leverages the historic and current connections to the large and varied components of Deere & Company's Waterloo operations. The collaborative environment provides existing and future potential for meeting the training needs of the region's manufacturers through a variety of educational offerings, and perhaps apprenticeship program opportunities in the near future.

The collaboration with UNI led to the location and continued expansion of the UNI Additive Manufacturing Center and Design Lab (AMC; a component of its Technology Department and Metal Casting Center) at TechWorks. Staffed by UNI faculty, researchers, and students, the AMC possesses unique capacity and capabilities especially in the areas of 3D sand printing and material characterization. These assets continue to be enhanced, including additional additive manufacturing/3D printing capabilities and recently an automated investment casting shell manufacturing cell (purchased in part with IEDA funding) allowing the facility to produce casting designs not previously possible with traditionally tooled investment castings.

While the AMC's primary focus is serving the Iowa castings industry supply chain, these capabilities, covering the spectrum of design, testing, and production, are highly sought after by multinational corporations (including those with significant Iowa presence such as Deere & Company) as well as Department of Defense-related customers. Currently, the AMC's client base is split roughly 50-50 between industry and federal customers, with about half of the customers Iowa-based. This application-based nature of the AMC brings interesting design and production challenges to UNI and leads directly to employment opportunities for many of the AMC's student workers.

The on-going development of the TechWorks/UNI-AMC partnership is leading to the development of a Supplier Integration Lab built around many of the key technologies and concepts under the Industry 4.0 umbrella. Plans include the development of integrated sensors within custom-developed molds and the data analytics needed to make use of the sensors' data, integration of factory automation linking different manufacturing operations, and providing a testbed and demonstration site for key software and systems solutions preferred by Iowa's major manufacturers. TechWorks

further envisions future expansion as an operational business accelerator for new, advanced manufacturing startups.

Quad Cities Manufacturing Innovation Hub

A program and initiative of the cross-border Quad Cities Chamber of Commerce, the Quad Cities Manufacturing Innovation Hub is a multifaceted effort providing operational, technical, and business resources and events to the Quad Cities region's manufacturers. With initial funding from the U.S. Economic Development Administration (EDA), these services range from operational assessments and identification of potential business development and partnership opportunities, to connections to the additional federal resources available through programs such as MxD, a collaborative U.S. Department of Defense and industry innovation center in Chicago, and the Quad City Manufacturing Lab, a national R&D and technology innovation resource housed at the Rock Island Arsenal.

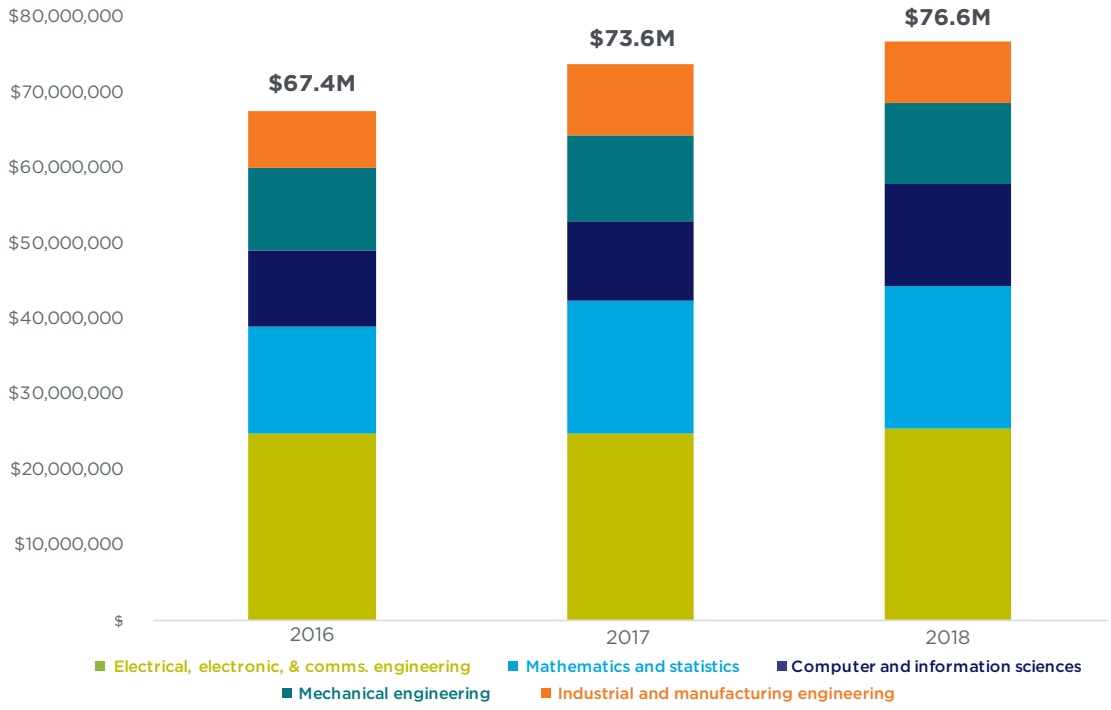
A unique resource developed by the Manufacturing Innovation Hub is a set of eight Industry 4.0-related technology playbooks or "how-to" guides. These guides provide information regarding the use and application of the specific technology, how to build the business case for the technology, and provides links to additional resources and service providers that can assist firms to better understand the opportunity that each of these technologies may provide. These playbooks are offered free to the public. The use of these playbooks is further enhanced through training and other resources to help bring companies up to speed on Industry 4.0.

An important service provided by the Manufacturing Innovation Hub relates to improving a manufacturer's marketing presence and involvement with defense-oriented supply chains. Two types of service offerings are available. First, an online Regional Capabilities Catalog (RCC) has been developed where area manufacturers can enter their capabilities into a searchable database increasing their visibility to potential customers. This database can then be used by OEMs, defense primes or subcontractors, or other manufacturers seeking regional suppliers. Second, taking this database of capabilities a step further, the Manufacturing Innovation Hub has developed a Supply Chain Mapping (SCM) Tool that utilizes proprietary software to help primarily defense-related companies identify specific contracting and partnership opportunities either as a top-down tool to help diversify a company or agency's supply chain, or as a bottom-up tool to find contracting and procurement activities where an area firm might be a valued supplier. The tool can also be used to facilitate joint business development or teaming relationships useful to pursue larger contracts with defense prime contractors. This tool uniquely tracks and visualizes the flow of the contracting opportunity (including weapons system procurements) from contracting office to the prime contractors, to the major sub-contractors, including those within and outside of the Quad Cities region. The development of the SCM Tool was funded by a federal grant from the U.S. Department of Defense's Office of Economic Adjustment.

Academic Institutions: Research Capabilities and Assets Related to Manufacturing 4.0 Technologies and Infrastructure

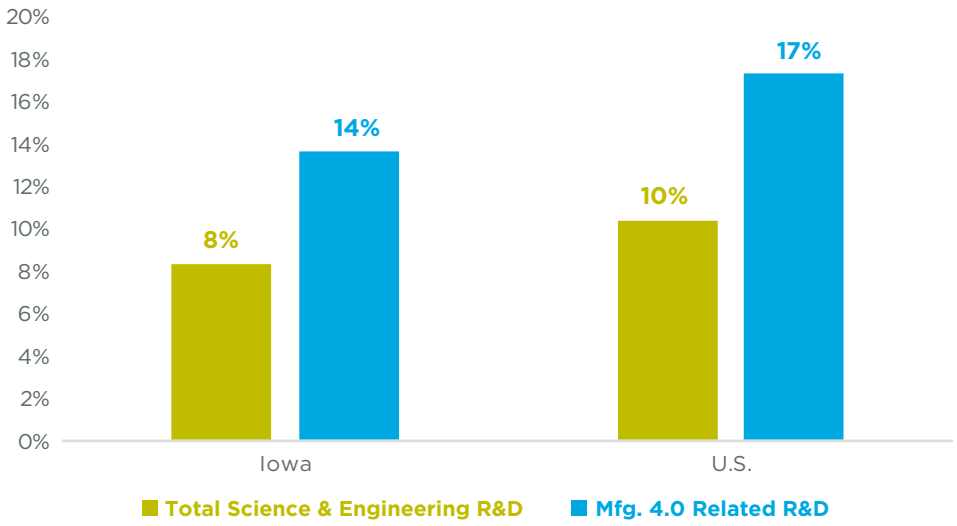
Colleges and universities contribute highly relevant capabilities and expertise to Manufacturing 4.0 development via their core educational, workforce development, and research missions as well as valuable research equipment and core infrastructure to be leveraged. To set the context before profiling individual institutions and assets, the combined R&D activities of Iowa's three primary research institutions in the five fields most closely aligned with Industry or Manufacturing 4.0 technology development totaled nearly $77 million in 2018. These R&D expenditures include the fields highlighted in Figure 16 and have been growing in recent years, outpacing the overall growth of all science and engineering fields (Figure 17).

FIGURE 16: IOWA UNIVERSITY R&D EXPENDITURES IN MANUFACTURING 4.0-RELATED FIELDS, 2016—18



Source: TEConomy Partners' analysis of National Science Foundation, Higher Education R&D Survey.

FIGURE 17: GROWTH TREND IN UNIVERSITY R&D EXPENDITURES IN MANUFACTURING 4.0-RELATED FIELDS, 2016-18



Source: TEConomy Partners' analysis of National Science Foundation, Higher Education R&D Survey.

The following provides an overview for each of the three research institutions and the state's community colleges and key assets and activities related to Industry or Manufacturing 4.0. While thorough, this does not represent an exhaustive inventory assessment or identification of individual faculty engaged in relevant teaching or research, or courses or degree programs, but is instead meant to profile major relevant assets and activities.

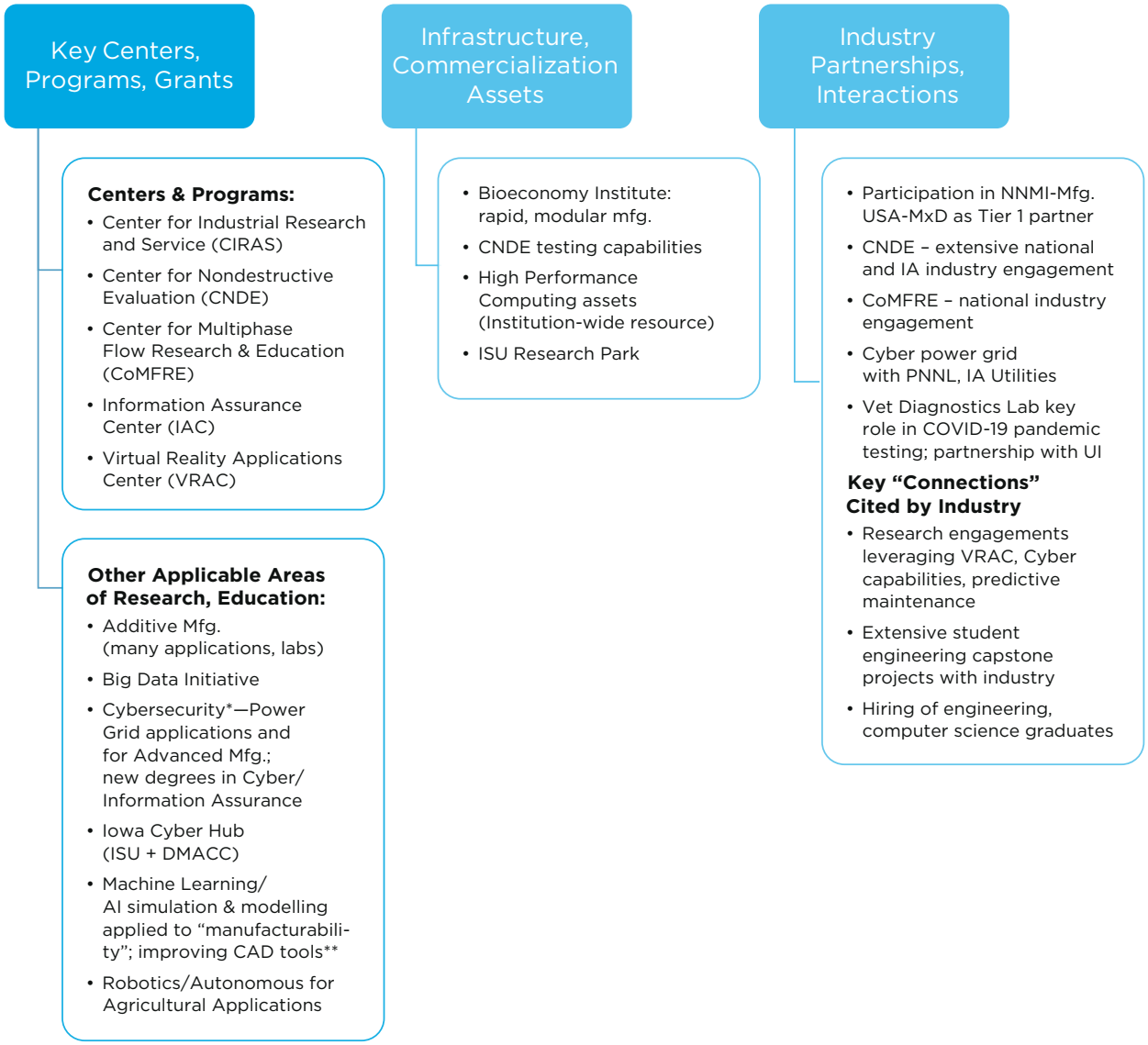
Iowa State University (ISU)

ISU represents a key institution in the Industry 4.0 technology and applications space, as home to Iowa's largest and most significant College of Engineering. The University stands out in several relevant research and educational fields and infrastructure, including with respect to cybersecurity, materials testing, virtual reality applications, and increasing activity in machine learning and artificial intelligence. A summary overview of identified activities and infrastructure is included in Figure 18.

ISU accounts for the vast majority of Iowa's University R&D in Manufacturing 4.0 Development Fields:

- $65M total in 2018
- 19% growth, 2016-18
- 73% more concentrated in these fields than national average

FIGURE 18: SUMMARY PROFILE OF ISU'S MANUFACTURING 4.0-RELEVANT ACTIVITIES AND ASSETS



**Pending major Department of Energy (DOE) Cyber Test Bed proposal (with IEDA, for $70M); will have an IIoT emphasis.*
***Proposal in for new AI Institute.*
Pending: AraNet Platforms for Advanced Wireless Research ("PAWR") project for rural broadband.

ISU has organized its research mission, including its major institutes and centers around five key applications themes and initiatives addressing 21st Century global challenges. These five initiatives include two with direct relevance to Manufacturing 4.0 applications—"Advanced Materials and Manufacturing" and "Data Driven Discovery"—and others with overlapping relevancy. Several key centers and research institutes align with Industry and Manufacturing 4.0 technologies and applications.

Advanced Materials and Manufacturing Initiative—Research Institutes and Centers relevant to Manufacturing 4.0:

- **The Center for Multiphase Flow Research and Education (CoMFRE)**. One of the newest centers on campus, the 25-faculty and industry-member CoMFRE is engaged in studying and simulating fluid systems and dynamics that play a fundamental role in a number of fields, each with applications cutting across multi-billion dollar industries including biopharmaceuticals, energy generation, materials processing, food processing, and chemical processing. The Center leverages numerous engineering competencies at the University using, for example, simulation to model fluid flows from single particle applications to large scale processing; x-ray technologies to visualize fluid flows and control for impurities in processes such as metals manufacturing; and computational fluid dynamics that leverage research infrastructure such as wind tunnels, explosives manufacturing, and more. CoMFRE works with national and multi-national companies on solving industry challenges.

- **The Center for Nondestructive Evaluation (CNDE)** was formed in 1985 as an NSF Industry/University Cooperative Research Center (IUCRC) and has evolved into a Center with highly unique expertise and capabilities, one of the few of its kind globally and the only of its kind in the U.S. CNDE works with industry members and government sponsors on a host of applications that cut across national security applications (e.g., nuclear, military), and civil infrastructure (e.g., materials characterizations for concrete). The Center uses a host of modalities for NDE including X-ray, ultrasound, microwave, particle testing, visual, MRI, and radiography, to name some. The Center sees itself leveraging and moving into more Industry 4.0 applications including advanced data analytics, AI, and additive manufacturing. Future thrusts for the Center include moving further into additive manufacturing and biomedical applications.

- **Virtual Reality Applications Center (VRAC)** is an interdisciplinary research center that leverages world-class research and technology infrastructure to support research focused on how humans and technology interact, and how to enhance the productivity and creativity of people. The VRAC includes virtual, augmented, and mixed reality (VR/AR/MR) technology applications, as well as mobile computing, developmental robotics, and haptics interaction. The VRAC is aligned with and leads ISU's interdepartmental graduate major in Human Computer Interaction (HCI) with more than 200 students enrolled. The VRAC works with federal agencies and numerous industry partners, including some Iowa manufacturers, leveraging VR/AR/MR technologies for training and simulation applications.

Data-Driven Discovery Initiative—Research Institutes and Centers relevant to Manufacturing 4.0:

- **The Information Assurance Center (IAC)** leverages ISU's long history and expertise in information assurance and cybersecurity research, education, and outreach. Created in 2000 and representing faculty from numerous departments, the IAC works to enhance cybersecurity awareness and capabilities. Since 1999, the IAC has been designated a National Center of Academic Excellence in Information Assurance Education by the National Security Agency four times.

Other notable areas of research and education and key activities with relevance to Manufacturing 4.0 are concentrated at ISU and seen as signature strengths or are gaining momentum based on new initiatives:

- **Cybersecurity** is recognized as a signature research and education area within the ISU School of Engineering. ISU has offered undergraduate and graduate courses in information assurance since 1995 and the University has one of the largest programs in the nation. The graduate programs in cybersecurity are offered both on- and off-campus (online) and include both master's and PhD level degree options. ISU is offering a new undergraduate engineering degree in cybersecurity, one of just three programs nationally where cyber education is coupled with computer engineering which provides deep knowledge and understanding that cuts across both hardware and software and has direct relevancy for the cyber-physical nature of Manufacturing 4.0 applications including IIoT, embedded systems, and industrial controls.

  Cyber-related research applications and strengths at ISU have been particularly focused around power grid applications, working with the Department of Energy including with Pacific Northwest National Laboratory (PNNL) and others in this space.

  Notably, by early in 2020 ISU had mobilized a public-private coalition including the Iowa Economic Development Authority and several leading Iowa manufacturers to apply for a major DOE cyber test bed proposal to create the Institute for Cyber in Advanced Manufacturing with an IIoT emphasis. While the team did not ultimately win the award, this shows the interest among multiple stakeholders for leveraging the University's cyber expertise in the 4.0 realm.

- **The Bioeconomy Institute (BEI)** represents ISU's national prominence and strategic investments in biofuels and bioenergy research and development—merging the University's leading strengths in both agriculture and engineering. The Institute works to advance the use of biorenewable resources (biomass) as sustainable feedstocks to produce fuels, energy, chemicals, and materials as alternatives to petroleum and fossil sources of carbon and energy. Launched in 2002, the BEI has engaged more than 200 faculty and staff; 35 departments in all eight colleges; and industry and federal agencies sponsoring more than $80 million in research in the last five years.[21] Relevant to Manufacturing 4.0, BEI researchers are working on rapid, modular manufacturing solutions, often in partnership with Iowa ag-related companies, as a major area of focus in response to challenges of transporting biomass to refinery facilities and capturing biomass waste such as sawdust and agricultural residues which are very valuable.

- Rural broadband access is critical for Iowa manufacturing to realize the benefits and promise of 4.0-related technology investments. ISU submitted a proposal in early 2020 to the NSF to fund a major rural broadband project. The proposal, titled "AraNet: Wireless Living Lab for Smart and Connected Rural Communities," was submitted to the national Platforms for Advanced Wireless Research (PAWR) program. The project would establish a network enabling

21 ISU Bioeconomy Institute website, see: https://www.biorenew.iastate.edu/about/.

The Iowa Cyber Hub: A Partnership of ISU and Des Moines Area Community College (DMACC) to Protect the Nation through Cyber Education & Training

The Cyber Hub, which started as a pilot project between ISU and DMACC, is dedicated to improving the cybersecurity posture of Iowa's citizens and its engines of economic growth and development for the state and broader region. Aligned with the goals laid out in the State of Iowa's Cybersecurity Plan, the Hub works to accomplish its goals through a comprehensive set of literacy, training, outreach, and educational programs.

The Iowa Cyber Hub is designed to be the focal point for cybersecurity education, outreach, training, and foster additional interaction between companies and the partner schools through internships, training opportunities, and focused projects. The Hub will facilitate government, industry, and academia working together to increase the cyber workforce.

DMACC is further pursuing a CAE2Y designation (Center for Academic Excellence 2-Year) for the National Cyberwatch Center to promote higher education in cyber defense to prepare a growing number of cybersecurity professionals, and to reduce vulnerabilities in the nation's networks.

trustworthy, ultra-high reliability, and ultra-low latency wireless communication in various public domains but also to include manufacturing.

- The University has research infrastructure with relevancy to Manufacturing 4.0 technologies and capabilities. ISU has a High-Performance Computing facility with petascale systems[22] as a shared large-scale computing institutional resource for research and instruction. In addition, the university has numerous additive manufacturing assets and capabilities.

- ISU participates as a Tier 1 Partner in the National Network for Manufacturing Innovation (NNMI)-Manufacturing USA "MxD" Digital Manufacturing Institute.

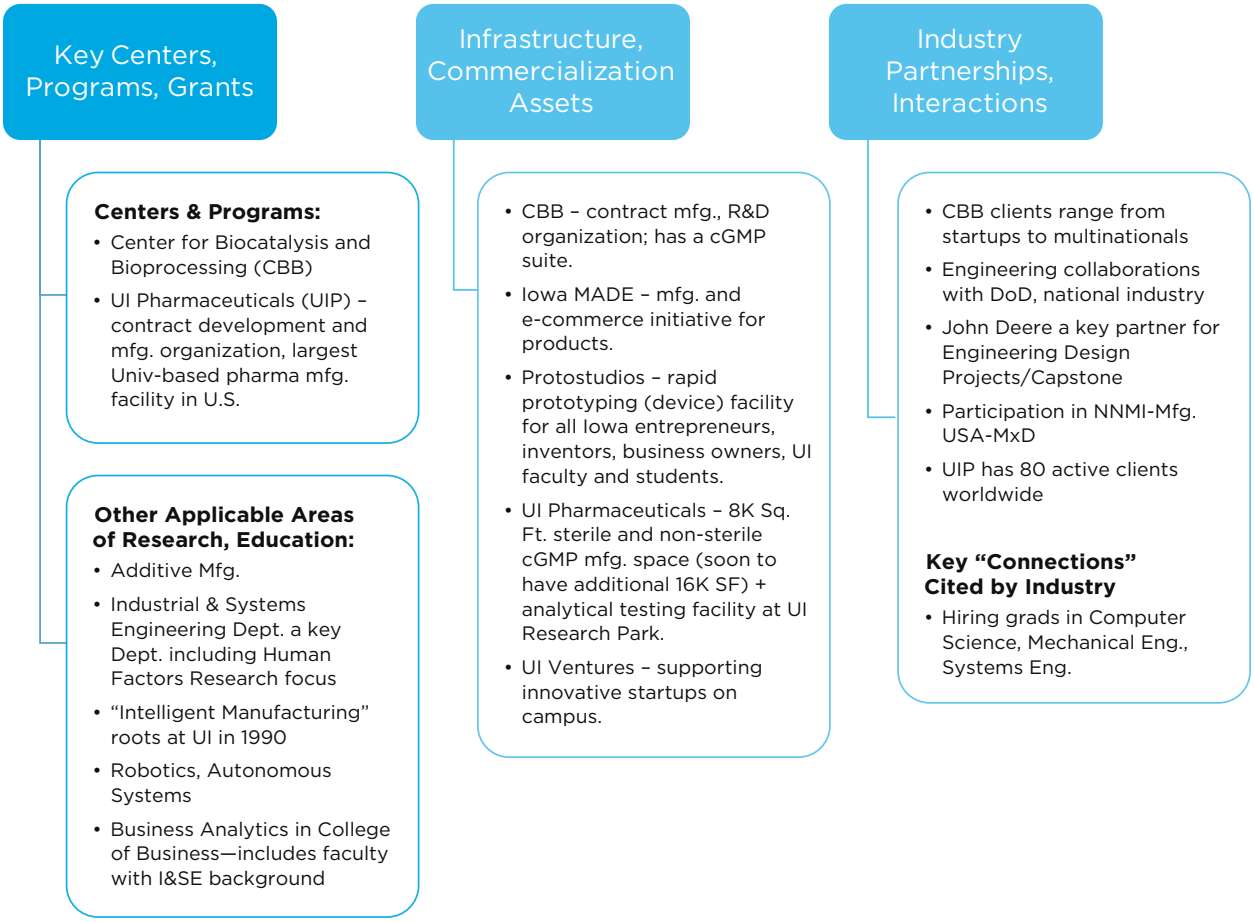
- **Ames Laboratory**, the U.S. Department of Energy's National Laboratory dedicated to creating materials and addressing challenges of national security and resource management, is located in Ames and affiliated with ISU. In 2013, DOE established the Critical Materials Institute (CMI) at the Lab to address domestic shortages of rare-earth and other materials vital to U.S. electronics and energy manufacturing and national security. The research conducted at Ames Lab and the CMI is largely basic in nature, but has implications for manufacturing, particularly in areas such as innovative metal alloys, high-performance magnets, complex materials modeling and simulation, and additive manufacturing.

22 Petascale computing refers to computing systems capable of calculating at least 1015 floating point operations per second, a measure of computer performance (1 petaFLOPS). Petascale computing allowed faster processing of traditional supercomputer applications.

University of Iowa (UI)

The University of Iowa stands out in the Manufacturing 4.0 space with unique contract manufacturing assets, capabilities, and relationships reflecting, in part, its leadership in life sciences and biomedical R&D and education. In addition, UI has prioritized and invested in strategic commercialization initiatives and capabilities such as rapid prototyping. While not as active in specific Manufacturing 4.0-related R&D fields, the University has a large overall research portfolio and combined with its unique capabilities in pharmaceuticals manufacturing and in bioprocessing, UI continues to be a key asset for biosciences manufacturing development—an important national industry strength for Iowa. A summary overview of identified activities and infrastructure is included in Figure 19.

FIGURE 19: SUMMARY PROFILE OF UI'S MANUFACTURING 4.0-RELEVANT ACTIVITIES AND ASSETS



The University of Iowa has world-class facilities that can be leveraged in the manufacturing space, particularly with life sciences-related strengths and applications. These include:

- **The Center for Biocatalysis and Bioprocessing (CBB)** represents a long-standing capability at UI, operating a world-class microbial fermentation and bioprocessing facility that manufactures recombinant proteins and specialty chemicals. The CBB leverages University research strengths in biochemistry and pharmacy and acts as a contract manufacturing and R&D entity, leveraging a staff of 20 professionals to serve a range of organizations from startups to multinational companies including in the pharmaceuticals, food, and other specialty chemicals industries. In 2007, the CBB expanded operations and opened an FDA-regulated Current Good Manufacturing Practice (cGMP) facility, enhancing its capabilities to manufacture drugs in clinical investigations/testing protocols, including biologics (vaccines, biotherapeutics) and GMP-grade reagents.

UI R&D Expenditures in Key Manufacturing 4.0 Fields:

- $10.8M total in 2018
- 9% decline, 2016-18
- Growth seen in Computer Sciences R&D

- **University of Iowa Pharmaceuticals (UIP)** represents a multi-decade history and deep legacy of manufacturing and testing pharmaceutical products, a highly unique capability for a University. The UIP team of approximately 70 experienced pharmaceutical professionals work in 8,000 square feet of sterile and non-sterile cGMP manufacturing space, which is soon to expand by an additional 16,000 square feet with its new, state-of-the-art sterile manufacturing facility coming online. In addition, UIP maintains analytical testing capabilities at the UI Research Park. Contract pharmaceutical services provided by UIP include:

    - Pre-formulation studies
    - Formulation development
    - Clinical supply and commercial manufacturing
    - Analytical method development and validation
    - Quality control and stability testing

UIP performs work for numerous government agencies and is well-positioned to partner with university-based researchers, non-profits, and small startup companies, including producing supplies for clinical trials. UIP has 80 active clients spanning the world and with its recent major facilities and hiring investments is positioned to grow. This unique manufacturing capability leverages sophisticated automation and represents a specialized resource for biopharmaceutical manufacturing and potential for innovative drug development in Iowa.

Strategic investments and emphasis in manufacturing-related commercialization assets and initiatives at UI have included:

- **Protostudios** is a non-profit, state-of-the-art rapid-prototyping facility within the University's Department of Innovation and Economic Development with a mission to help Iowa entrepreneurs,

"UIP is the largest and most experienced university-based FDA-registered pharmaceutical manufacturing facility in the United States manufacturing both sterile and non-sterile products."

-University of Iowa Pharmaceuticals Marketing Materials

inventors, and business owners develop fully functional prototypes of their ideas. This vital function allows for testing, redesigning, determining manufacturing paths, and demonstrating usability to potential investors. Its capabilities include numerous 4.0-related technologies, including: 3D printing and scanning; CNC machining; laser cutting and etching; CAD work; silicon and plastic injection molding; precision micro-welding; and more. To date, Protostudio's emphasis has been largely in the biomedical device and applications space including anatomical analogs, bio-mechanical devices, surgical tools, embedded and IoT electronics.

- **Iowa MADE** is a manufacturing and e-commerce initiative of the University featuring products developed by UI faculty and staff. Products are prototyped and manufactured locally, then sold directly through a web-based platform. A multi-disciplinary student operations team assists with all aspects, gaining first-hand knowledge and experience in bringing a product to market.

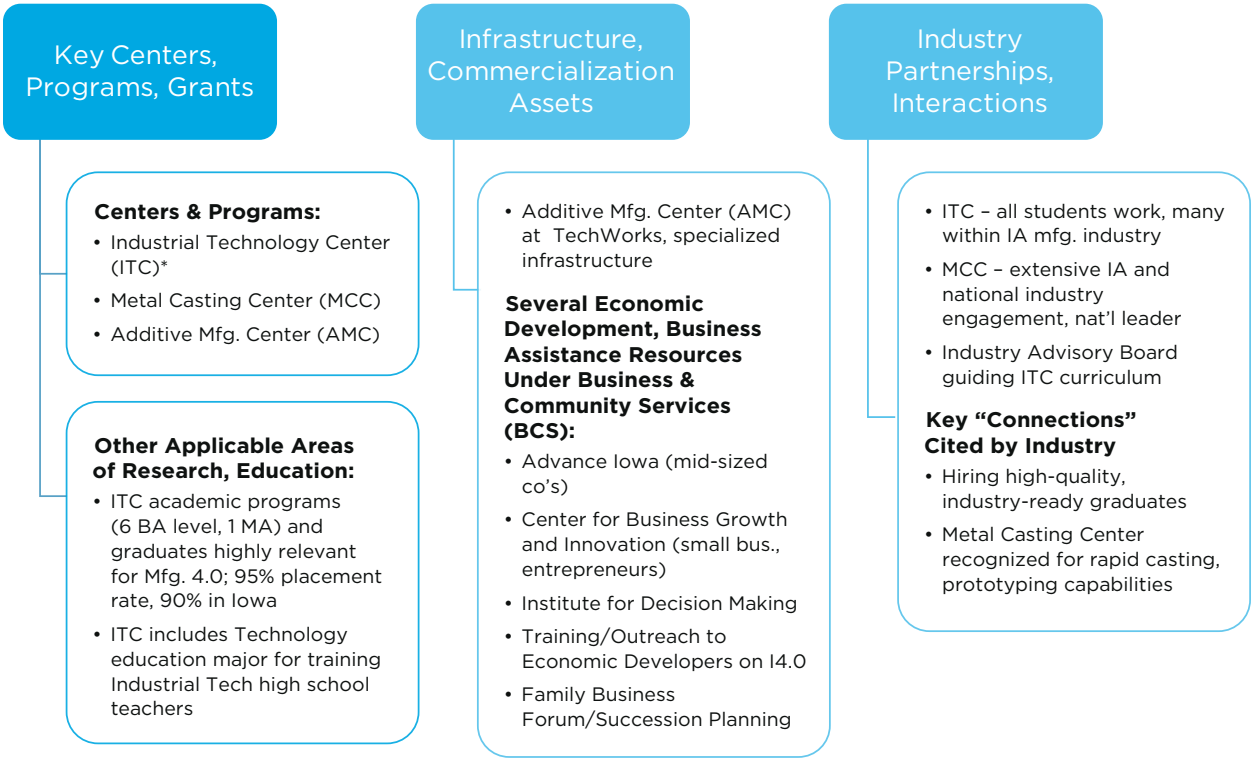
University of Northern Iowa (UNI)

UNI plays a major role in Iowa's manufacturing industry ecosystem through its focused education mission in Industrial Technology where it places 90 percent of its graduates in Iowa's high-demand industrial technology roles. The University further stands out in its world-class Metal Casting Center (MCC) and its affiliated Additive Manufacturing Center (AMC) strategically located at and partnered with TechWorks in Waterloo and leveraging Manufacturing 4.0 technologies. A summary overview of identified activities and infrastructure is included in Figure 20.

UNI R&D Expenditures in Key Manufacturing 4.0 Fields:

- $60K in 2018
- Nearly 8X Growth, 2016-18 (though from very modest base level of $7K)

FIGURE 20: SUMMARY PROFILE OF UNI'S MANUFACTURING 4.0-RELEVANT ACTIVITIES AND ASSETS



**Plans are underway for major ITC facilities and curriculum modernization and expansion (~$44M), significant expansion of enrollment.*

UNI's key centers and programs highly relevant to the manufacturing industry and 4.0 technology adoption and workforce development (not including the AMC, profiled under TechWorks) include:

- **The Department of Technology and the Industrial Technology Center (ITC)** represents a grouping of programs educating and providing hands-on training for students in manufacturing, technology, and construction fields. UNI is the only public university in Iowa with these technology degrees. The Department currently has nearly

UNI's Planned Modernization of the Industrial Technology Center

- **Space: modernizing existing 64,000 GSF; expanding by 45,000 GSF.**
- **Project Cost: $43.9M**

The project will bring the facility into the 21st Century, allowing for tech-heavy labs and better meeting industry needs.

"This project will provide a modern space for our nationally-recognized programs."

-John Fritch, Dean of UNI College of Humanities, Arts, & Sciences

500 students enrolled in varied degree programs, most of which are highly relevant for manufacturing:

- Electrical Engineering Technology
- Graphic Technologies
- Manufacturing Engineering Technology
- Technology & Engineering Education
- Technology Management
- Construction Management
- Graduate Programs—MS in Technology

Department programs are very hands-on and include experiential learning opportunities through labs and internships. Graduates are well-prepared for entry-level manufacturing jobs in functional areas such as process R&D, industrial engineering, production planning and control, materials testing, quality control, production supervision, and more. The programs are highly subscribed and growing, including a large number of transfer students from community and other colleges. Most students work during their degree studies and many are already working for Iowa manufacturers even before graduation. The placement rates for UNI graduates are very high, with 95 percent placed in full-time positions, and 90 percent taking jobs in Iowa.

UNI is in the process of modernizing the ITC to update outdated facilities built in the mid-1970s and to accommodate the high and growing demand for these degree programs. UNI is seeking to use the modernization to better prepare its graduates, including in relevant 4.0 technologies with technology-heavy labs that meet current industry standards, and to better serve Iowa industry. The Department and the ITC will be modernizing curriculum as well, and it is important for the University to consider the trends toward Manufacturing 4.0 in this important inflection point.

- The ITC houses the nationally recognized **Metal Casting Center,** a leading foundry and materials research, education, applied technology, and technical business center where students work with industry partners in a hands-on capacity. The MCC is located at two sites—the ITC on the UNI Campus for materials research and foundry, and the AMC at TechWorks in Waterloo which features extensive and growing additive manufacturing/3D printing capabilities and recently an automated investment casting shell manufacturing cell. The MCC serves more clients than any casting center in North America and is increasingly embedding sensing and leveraging IoT technologies in its operations. The MCC is a key asset for the metals and other manufacturing clusters in Iowa with numerous industry partners and a strategic resource to connect and leverage in the materials and additive manufacturing areas.

Iowa's Community College System

Iowa's 15 community colleges represent an important state and sub-state regional asset in education and applied workforce training, including in the manufacturing space. Community colleges play a key role in translating the direct workforce needs of regional employers, often in "real-time," into education and training courses and degree programs via guidance from regional Industry Advisory Councils and Boards. Iowa's most significant and sizable state workforce and training programs—including the large and impactful state-subsidized "260" workforce training programs for training both new employees (260E program) and existing employees (260F program)—are administered by and primarily through the Community College System.

Iowa's community colleges, as a group, provide at least one educational offering across all nine Industry 4.0 technologies included in CIRAS' concept. Several colleges stand out in providing academic programming across all nine technology areas (Figure 21). Key historical strengths within the Community College system of robotics and automation are being enhanced with significant offerings across most institutions in cybersecurity and additive manufacturing.

FIGURE 21: INDUSTRY 4.0 EDUCATIONAL OFFERINGS/ACADEMIC PROGRAMMING ACROSS IOWA'S COMMUNITY COLLEGES

Iowa Community College	Internet of Things	Cybersecurity	Augmented and Virtual Reality	Big Data	Robotics/ Automation	Additive Mfg./ 3D Printing	Simulation	Systems Integration	Cloud Computing
Des Moines Area Community College	1, 2, 3, 5	1, 2, 3, 5	1, 2	1, 2	1, 2, 3, 5	1, 2	1, 2, 3, 5	1, 2, 3, 4, 5	1, 2, 3, 5
Eastern Iowa Community College	2	1, 2, 3, 5	1, 2, 3	1, 2	1, 2, 3	1, 2, 3, 5	2	2, 3	2
Hawkeye Community College	4	1, 2, 5			1, 2, 3, 4, 5	2	1, 2	4	

Numerical Key of Offering Types
1) Non-Credit Credential
2) Credit Course/Certificate
3) Diploma/Associate's Degree
4) Apprenticeship-Oriented
5) Third Party Credential

Iowa Community College	Internet of Things	Cybersecurity	Augmented and Virtual Reality	Big Data	Robotics/ Automation	Additive Mfg./ 3D Printing	Simulation	Systems Integration	Cloud Computing
Indian Hills Community College		3, 5			3	2			
Iowa Central Community College	1	1, 2, 3, 5		1, 5	2, 3	2	1, 2	2	1
Iowa Lakes Community College	1, 2, 3, 4	1, 2	1, 2, 3	1, 2	1, 2, 3	1, 2	1, 2	1, 2, 3	
Iowa Valley Community College District		1, 2			1, 2, 3	1	1		2
Iowa Western Community College		2, 3			1, 2, 3	2, 3		2	
Kirkwood Community College	2	2	1	1, 2	2, 3	2	1, 2	2	2
North Iowa Area Community College	2	2, 3		2	2, 3, 5	2, 3, 4	2	2, 3, 4	2, 3
Northeast Iowa Community College		1, 2	1	1, 2	1, 2	1, 2			2
Northwest Iowa Community College		2		2	1, 2, 5	1, 2			2
Southeastern Community College	2, 5	1, 2, 3		1, 2	2, 3	2	2	2, 5	2, 5

Numerical Key of Offering Types
1) Non-Credit Credential
2) Credit Course/Certificate
3) Diploma/Associate's Degree
4) Apprenticeship-Oriented
5) Third Party Credential

Iowa Community College	Internet of Things	Cybersecurity	Augmented and Virtual Reality	Big Data	Robotics/ Automation	Additive Mfg./ 3D Printing	Simulation	Systems Integration	Cloud Computing
Southwestern Community College	1	1, 2	1	1	1, 2	1	1, 2	1, 2	1
Western Iowa Tech Community College	2	2, 3	2		1, 2, 3, 4	1, 2			

Numerical Key of Offering Types
1) Non-Credit Credential
2) Credit Course/Certificate
3) Diploma/Associate's Degree
4) Apprenticeship-Oriented
5) Third Party Credential

Source: Information Collected by Iowa Community Colleges, November 2020.

Within its breadth of assets, Iowa has three manufacturing service and support programs with direct strengths to support the state's manufacturers along their Manufacturing 4.0 journey. Within the research and educational capabilities of Iowa's research universities, key world-class R&D strengths exist in several core 4.0 technologies such as cybersecurity, simulation, and additive manufacturing. When considered alongside the state's community college infrastructure, an emerging ecosystem of Industry 4.0-related training and educational opportunities has developed and is currently in place. However, key concerns remain. These Industry 4.0 resources are largely concentrated in Central and Eastern Iowa, reflecting the majority of Iowa's population and manufacturing base. However, given the substantial level of rural-based manufacturing in the state, efforts to bring needed support and Industry 4.0 expertise, education, outreach, and training to the rest of Iowa remain critical.

This page intentionally left blank.

IV. SITUATIONAL ASSESSMENT FOR IOWA MANUFACTURERS AND INDUSTRY 4.0

Industry-Led Strategy Development

The voice of industry has guided the development of the Iowa Manufacturing 4.0 Plan from the outset. Input and feedback from manufacturing leadership through one-on-one interviews, focus groups, and regular meetings with the Advanced Manufacturing Work Group has been vital to understanding the underlying dynamics of the state's manufacturing situation and validating the narrative presented by the quantitative analyses and qualitative inventory of key Iowa assets. This section of the report assesses the situation for Iowa manufacturers primarily with respect to Industry or Manufacturing 4.0 technology adoption and utilization, but also provides further context with respect to broader ecosystem elements and strategic implications. It summarizes both the challenges and barriers to investing in and adopting Manufacturing 4.0 technologies, as well as the opportunities and ideas for strategic interventions to address challenges brought forth by industry leadership.

Themes arising out of the discussions and sessions with Iowa manufacturers as well as key industry stakeholders are organized around the five focus areas or pillars of the Manufacturing 4.0 Plan development set out by IEDA at the beginning of

Industry and Broader Stakeholder Input and Leadership in the Manufacturing 4.0 Plan:

- One-on-One Interviews with Iowa Manufacturing Leaders
- 5 Topic-Specific Focus Groups
- 2 Regional Focus Groups
- Quarterly Presentations and Input from the Advanced Manufacturing Workgroup and the Iowa Innovation Council

Altogether more than 100 Iowans engaged in Strategy development.

this project. These areas have been maintained as an appropriate organizing structure for strategic priorities:

- Manufacturing 4.0 Technology Adoption & Utilization
- Enabling Infrastructure for Digital Technologies
- Improved Supply Chain Linkages
- Accelerating Manufacturing Startups & Scale-Ups
- Ensuring an Effectively Trained Manufacturing 4.0 Workforce

The following sets out the primary issues, challenges, and gaps raised by multiple industry leaders and ideas and opportunities on what would help to elevate the ecosystem by de-risking investments in 4.0 technologies, enabling optimal use and integration of 4.0 investments, re-training and upskilling the workforce, guiding SMEs through the Industry 4.0 journey, and bolstering the startup ecosystem while ensuring Iowa's leading mid-sized and large manufacturers are able to continue to scale up. The ideas and input reflected here, in combination with the results of the additional analyses and assessments undertaken in development of the Manufacturing 4.0 Plan, have been incorporated into the strategies and actions developed and presented in Section V of this report.

Manufacturing 4.0 Technology Adoption & Utilization

Among Iowa manufacturers there is consistent, strong awareness regarding Manufacturing 4.0 technologies and the applications that are needed to enhance their business. State manufacturers have made and implemented numerous 4.0-related investments in recent years, with some larger companies guided by technology "roadmaps" representing longer-term strategies—just one illustration of how the size of company matters in the planning, investment, and execution of 4.0 technology integration. Of the companies engaged during this strategic planning process nearly all have a clear priority list of 4.0 technologies they would invest in next.

Examples of specific technologies adopted and integrated by multiple Iowa manufacturers are overlaid onto a depiction of three major pillars of an Industry 4.0 ecosystem in Figure 22. The technology-specific boxes around the outside of this graphic are color-coded by the extent to which companies are or have implemented (gray), are emerging or in planning for future investments (pink), or they are a mix of implementing and planning (yellow). While this summary is based

"We know our factory has a lot to tell us...and these [Industry 4.0] technologies can enable it."

-Representative from a large Iowa manufacturer

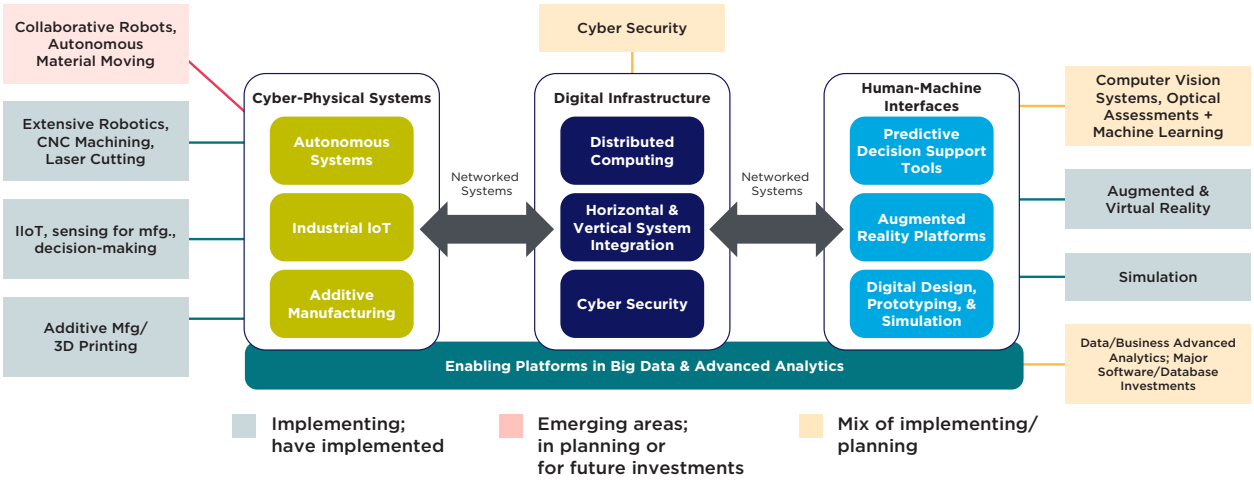
on a limited sample of manufacturing interviews across a blend of small, mid-sized, and large manufacturers, in project Work Group and Council meetings, as well as in focus groups, these findings resonated with stakeholders as an accurate depiction of the technology adoption situation for Iowa manufacturers today. With respect to specific technologies:

- Leading Iowa manufacturers have successfully implemented examples of Industry 4.0 platforms including robotics, IIoT capabilities utilizing sensing technologies, additive manufacturing/3D printing, simulation, and AR/VR technologies for training and other applications. Awareness of the need for adoption and implementation of these technologies among Iowa manufacturers is widespread, but companies are currently distributed across a spectrum of different stages of investment and deployment of these technologies that varies considerably by end market and company size.

- Cybersecurity is the most common and ubiquitous concern among Iowa manufacturers of all sizes and sectors in implementing 4.0 technologies and is what several leaders report "keeps us up at night." Given this chief area of concern it is alarming that so many companies do not yet have in place what they deem to be appropriate levels of security in this increasingly cyber-physical operating environment. Cybersecurity is a more and more universal business need in a non-competitive space where companies can and should collaborate.

- Companies are recognizing that harnessing the full capabilities of Manufacturing 4.0 investments requires attention not only to the types of advanced technologies referenced in the graphic, but more fundamental, cross-cutting platforms in Big Data and advanced analytics to truly access the value of Industry 4.0 solutions. As one manufacturing leader framed it: "We know our factory has a lot to tell us..and these [Industry 4.0] technologies can enable it."

FIGURE 22: TYPES OF INDUSTRY 4.0 TECHNOLOGIES BEING IMPLEMENTED BY IOWA MANUFACTURERS

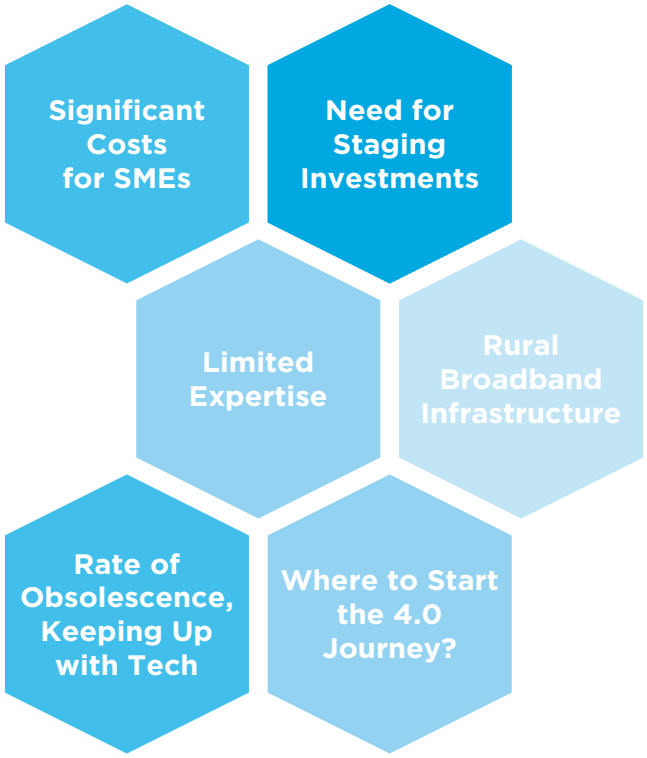


Source: TEConomy Partners, LLC.

There are, however, numerous significant barriers to Manufacturing 4.0 technology adoption and utilization which are summarized in Figure 23 based on conversations and input from Iowa manufacturers. Again, the size of firm matters in key ways—smaller manufacturers often need a starting point, including counseling or consulting regarding how to begin their 4.0 journey. And each of the challenge themes raised in Figure 23, particularly the investment costs and the ability to integrate new technologies into existing processes, systems, and ongoing operations are exacerbated for SMEs relative to their larger counterparts and OEMs. That acknowledged, the 4.0 journey for larger manufacturers is also filled with significant challenges.

Companies of all sizes and industry sectors recognize the shift in workforce and talent demands in a 4.0 environment. They recognize there is limited expertise today and a strong demand for broad-based digital skills training requiring continuing education and the "upskilling" of their existing workforces to optimize these investments. This is discussed in further detail under the workforce and talent strategic priority area.

FIGURE 23: ISSUES, CHALLENGES AND GAPS—CONSISTENT THEMES RAISED BY IOWA MANUFACTURERS REGARDING MANUFACTURING 4.0 TECHNOLOGY ADOPTION AND UTILIZATION



Source: TEConomy Partners, LLC.

CIRAS' biennial Manufacturing Needs Assessment emphasizes and confirms these challenges and the situation for manufacturers and raises several "needs" related to Industry 4.0.[23] Of the seven core needs of Iowa's manufacturers identified by CIRAS' extensive surveying and regional forums, three speak most strongly to the future of Industry 4.0 adoption in the state:

- Transition from awareness to action in Industry 4.0.
- Drive productivity improvements in the manufacturing floor and the office.
- Improve implementation capabilities among manufacturers with 20-99 employees (small enterprises).

"Manufacturers are beginning to embrace the suite of technologies represented by Industry 4.0. From emerging automation tools such as collaborative robots (cobots) to machine connectivity and advanced engineering tools, manufacturers are interested in action. This survey and the forums indicate that foundational tools are in place more and more throughout Iowa.

Manufacturers need to execute on Industry 4.0."

- CIRAS, Iowa Manufacturing Needs Assessment, 2019-2020

Iowa has in place several existing assets working to advance Manufacturing 4.0 technology adoption and utilization, including: CIRAS and its new Digital Manufacturing Lab; the Quad Cities Manufacturing Innovation Hub; and TechWorks' investments and growth in the Cedar Valley. These assets and capabilities represent a strong starting point for Iowa in key technology areas; however, the Innovation Hub and TechWorks are regionally siloed and increased connectivity and collaboration among these organizations and physical assets should be a near-term goal.

What should Iowa do or consider to "de-risk" Industry 4.0 investments and increase adoption particularly among SMEs?

Industry leaders brought forth or were supportive of the following ideas to de-risk investments, and to advance technology adoption and utilization:

- Explore economic development incentives for digital, Manufacturing 4.0 investments;
- Incentivize productivity enhancements for SMEs;
- Incent in-state supply chains and sourcing;
- Accelerate depreciation schedules for Manufacturing 4.0 Investments; and
- Increase usage and availability of CIRAS' Industry 4.0 assessment.

These ideas and input have been incorporated into the strategies and actions developed and presented in further detail in the next section of the report.

23 Iowa State University, Center for Industrial Research and Service (CIRAS), "Iowa Manufacturing Needs Assessment, 2019-20."

Enabling Infrastructure for Digital Technologies

Adopting and integrating the suite of digital Manufacturing 4.0 technologies requires fundamental infrastructure in place to optimize and realize its benefits. Enabling "infrastructure" in this context includes and spans statewide access to fiber and reliable high-speed broadband; the IT backbone and ability to achieve "digital integration" within individual companies; and critical cybersecurity infrastructure required for increasingly interconnected factories in a cyber-physical context. Just as reliable and well-maintained roads, railways, airports, and bridges have been foundational to advanced economies, this modern digital infrastructure is fundamental to advancing a competitive Industry 4.0 economy with high rates of technology adoption.

Digital-centric Industry 4.0 technologies are driving the future of manufacturing. More than half (53 percent) of Iowa's manufacturing employment is found in Iowa's rural (non-metro) areas and span both large companies and suppliers to larger Iowa manufacturers. As manufacturers adopt Industry 4.0 technologies, increased bandwidth, latency requirements, and the ability to manage Big Data and associated advanced analytics will be essential for 4.0 investments and future competitiveness of Iowa manufacturers.

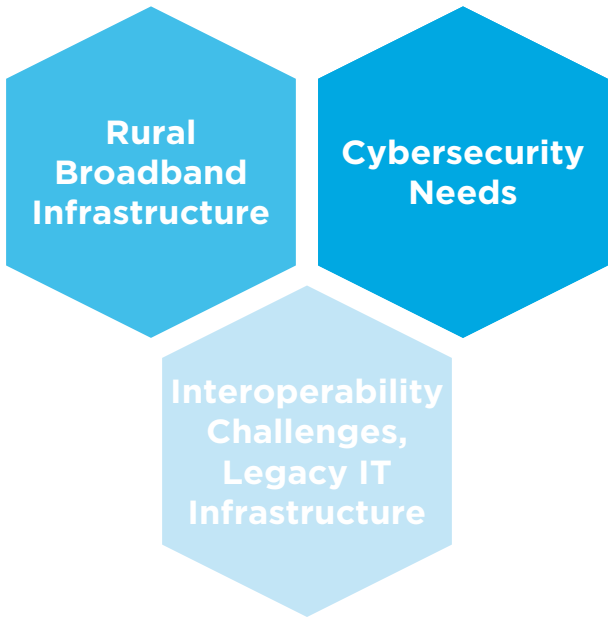
Additionally, operating in a dynamic, connected environment driven by the integration of Industrial Internet of Things (IIoT) sensors and equipment requires navigating an increasingly complex interoperability and data transfer landscape. Manufacturers adopting new Industry 4.0 technologies will find themselves facing a mix of new and legacy infrastructure both within their own businesses as well as in the broader market that must be seamlessly integrated in order to realize the full promise of Industry 4.0 efficiency gains. Interoperability between a broad portfolio of different machines, sensors, and other connected devices presents a significant barrier to investment and deployment that firms must be able to address in order to build out their own infrastructure. Barriers related to protocol and data standards, machine-to-machine connectivity, and back end management of data flows are all critical elements for Iowa to help its manufacturers address through building out supporting infrastructure that can help streamline deployment of new technologies.

Interview and focus group discussions with, and input from Iowa manufacturers and industry stakeholders finds:

- Concerns among rural manufacturers facing instances of broadband outages resulting in significant production downtime; at times personnel are resorting to using mobile phones rather than corporate IT infrastructure. This is a consistent theme and need arising from conversations with rural Iowa manufacturers.
    - Manufacturers implementing 4.0 technologies require the ability to transfer data faster; demand for 5G Networks are on the rise.
- Common, vital needs for cybersecurity solutions, seen as a competitive-neutral area for potential cooperation and collaboration. Iowa manufacturers are highly concerned about vulnerabilities in their digital infrastructure and their ability to fend off cyberattacks.

- Many Iowa manufacturers are working to update their core IT infrastructure to enable Industry 4.0 investments and see a need for resources regarding base-level digitalization and integration.

FIGURE 24: A. ISSUES, CHALLENGES AND GAPS—CONSISTENT THEMES RAISED BY IOWA MANUFACTURERS REGARDING DIGITAL INFRASTRUCTURE



Source: TEConomy Partners, LLC.

What should Iowa do or consider to enhance digital infrastructure?

Industry leaders brought forth or were supportive of the following ideas to enhance Iowa's digital infrastructure to enable and optimize Industry 4.0 investments:

- Prioritize rural fiber and broadband Infrastructure;
- Collaborate in cybersecurity; and
- Consider further investments in proof-of-concept "Innovation Labs," or an expansion of CIRAS' new Digital Manufacturing Lab citing and recognizing the need for remote access, mobile, or additional "nodes" to reach more underserved parts of the state.

These ideas and input have been incorporated into the strategies and actions developed and presented in further detail in the next section of the report.

Improved Supply Chain Linkages

A holistic Manufacturing 4.0 strategy must consider ways in which new technologies are enhancing supply chain dynamics and relationships for more seamless processes, allowing for more customization and flexibility in specific orders, enabling enhanced traceability and security throughout the supply chain, and more. Industry 4.0 technology adoption is often advanced through the requirements and directives of larger manufacturers or OEMs pushed down to SMEs through supply chain relationships. Ensuring Iowa's SMEs understand and are able to meet and integrate key technology requirements is important for maintaining a vibrant manufacturing sector into the future.

In addition to these dynamics, this study has revealed opportunities to consider for growing Iowa manufacturing via better understanding, documenting, and communicating the breadth of Iowa's manufacturing supply chain to better connect with both in- and out-of-state OEMs, particularly amidst the COVID-19 pandemic and considerations around "re-shoring" production. To seize this opportunity will require identifying the state's supply chain strengths and attractiveness, as well as gaps.

Industry interviews have not revealed current formal mandates from or by companies for suppliers to adopt Manufacturing 4.0 technologies. That does not mean the transition is not happening within the industry, however, and there is a sense of urgency emerging among some large manufacturers on the importance of ensuring technology investments and leveraging of 4.0 technologies in their supply chains. These larger manufacturers see opportunities and needs for suppliers to invest in new technology, with the following context:

- Several manufacturers are predicting an increasing need to "trace" their supply chains and using Industry 4.0 technologies to automate tracing and sourcing of components; for example, in the highly regulated medical device manufacturing and defense sectors to ensure secure chain of custody;
- Need for suppliers to "tie into" increasingly customized IT/supply chain systems;
- Cybersecurity "compliance" with integrated systems is another key consideration and real concern for large manufacturers and OEMs working with suppliers.

Given the ongoing adoption and integration of these technologies, Iowa suppliers must prepare for these requirements and changes, particularly within selected industry segments.

FIGURE 25: ISSUES, CHALLENGES AND GAPS—CONSISTENT THEMES RAISED BY IOWA MANUFACTURERS REGARDING IMPROVING SUPPLY CHAIN LINKAGES AND ADVANCING ADOPTION OF 4.0 TECHNOLOGIES IN THE SUPPLY CHAIN

Source: TEConomy Partners, LLC.

What should Iowa do or consider to improve supply chain linkages and enhance Industry 4.0 technology adoption among SME suppliers?

Industry leaders brought forth or were supportive of the following ideas:

- Support the Supplier Integration Lab Concept being advanced at TechWorks;
- Establish an OEM Advisory Council to support SMEs in the 4.0 journey and help them prioritize investments;
- Incent in-state supply chains and sourcing; and
- Better understand and promote Iowa Supply chain dynamics both within and outside the state.

These ideas and input have been incorporated into the strategies and actions developed and presented in further detail in the next section of the report.

Accelerating Manufacturing Startups and Scale-ups

Iowa has been focused and intentional about investments in the startup ecosystem, with resources and a suite of innovation and support programming for emerging companies. These broader entrepreneurial ecosystem mechanisms support key aspects of emerging firms ranging from proof of concept/prototype development, assist companies seeking to leverage federal SBIR/STTR grants, and provide critical operational support through incubators and accelerators that nurture startups at its universities and in key areas such as Insurance, Agtech, and educational technologies or "EdTech." Manufacturing, however, brings unique challenges in the barriers to starting a new physical products company.[24]

Interview and focus group discussions with, and input from Iowa manufacturers and startup ecosystem stakeholders finds:

- The typical high costs associated with starting a manufacturing company (or any physical product company) translate into significant challenges raising funds both from a total amount required and the patience and level of return expected from the investment community.

- Iowa has a gap in its startup ecosystem with respect to management and executive talent and the service providers to take a manufacturing company in its earliest stages and effectively develop, launch, and scale it. This gap extends into assistance with new product introductions—the often-specialized support services required to bring a physical product to market.

- The startup ecosystem for manufacturing in Iowa is lacking connectivity, specifically a "place" or "clearinghouse" for innovative manufacturing startups and potential investors to access information regarding fundraising, company/product development, and educating founders, for example with respect to supply chains.

24 It should be noted that certain non-biologically based startups in the Agtech space would be included in the broader manufacturing concepts described with this Strategy.

FIGURE 26: ISSUES, CHALLENGES AND GAPS—CONSISTENT THEMES RAISED BY IOWA MANUFACTURERS AND STARTUP ECOSYSTEM STAKEHOLDERS REGARDING ACCELERATING MANUFACTURING STARTUPS AND SCALE-UPS

Source: TEConomy Partners, LLC.

What should Iowa do or consider to accelerate manufacturing startups and scale-ups?

Industry leaders brought forth or were supportive of the following ideas:

- Enhance "connectivity" in the manufacturing startup ecosystem, including Iowa's value proposition in manufacturing with respect to:
  - Industry connections
  - Customer discovery
  - Industrial expertise

- Leverage a "clearinghouse" for:
  - Fundraising
  - Company/product development
  - Educating founders especially regarding supply chains

These ideas and input have been incorporated into the strategies and actions developed and presented in further detail in the next section of the report.

Ensuring an Effectively Trained Manufacturing 4.0 Workforce

Implementing Manufacturing 4.0 technologies is fundamentally changing the nature of work and job functions in the modern "smart" factory. To achieve its goals and benefits and compete in this environment, digital and "hybrid" skills are vital, learning must be continuous and lifelong, and preparation for modern manufacturing careers takes on a new context. Iowa's manufacturers embracing digital technologies require existing employees to be regularly and periodically "up-skilled." Workforce development is both a major barrier but also enabler of Manufacturing 4.0 technology implementation, and how quickly and efficiently training and upskilling can occur is a significant factor in how Iowa competes into the future.

Interview and focus group discussions with, and input from Iowa manufacturers finds:

- A broad consensus on the need to invest in digital skills and raise baseline Manufacturing 4.0 knowledge across nearly all occupational groups and levels.

- Among Iowa's small- and mid-sized manufacturers, seeing many instances of IT, Analytics, and/or Technician personnel "wearing multiple hats" with respect to their roles in implementing Industry 4.0 technologies. These individuals often rely on informal training in-house and many don't have advanced degrees. This trend is driven by their valuable knowledge of unique production processes, so employers decide they would prefer to train and grow this talent internally, regardless of an individual's educational or digital training background.

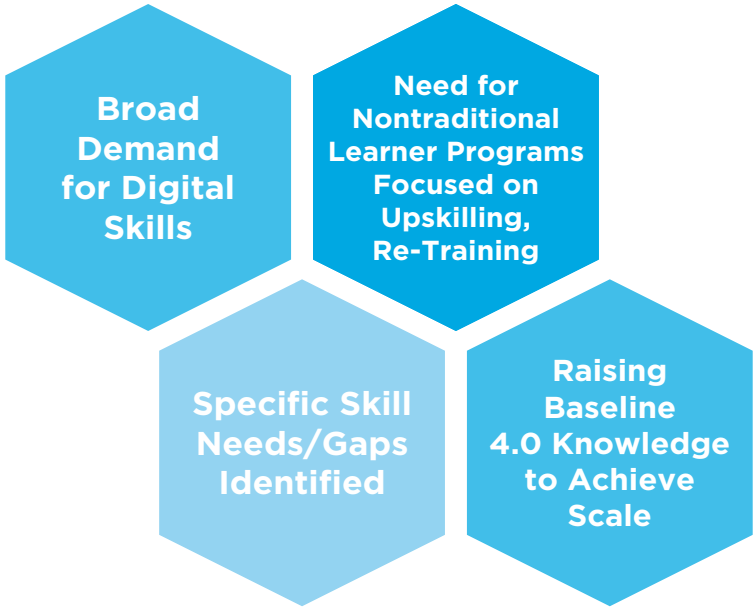
- Concern among some companies that the technical training and expertise available at the state's community colleges—a focal point of much of Iowa's current workforce training/re-training programs—are lacking in Industry 4.0 technologies and advanced analytics.

- Specific Industry/Manufacturing 4.0 skill sets in-demand that were consistently raised by manufacturing leadership include:
    - Embedded electronics and software knowledge and the need for cross-cutting skills, for example, Mechanical Engineers with software expertise;
    - Industrial IoT specialists;
    - Cybersecurity professionals and expertise;
    - Middleware skills to integrate systems in large enterprise environments; and
    - Technical Project Management overseeing cross-functional teams.

- In general, the need for investments in adult or what might be called "nontraditional learner" upskilling programs in areas including IT, digital operations, supply chain management/logistics analytics, and related areas.

Among the Iowa manufacturers engaged in project interviews and focus groups, there is an emerging consensus that implementing Manufacturing 4.0 technologies is not likely to require significant new hires, but instead will require upskilling existing workers.

FIGURE 27: ISSUES, CHALLENGES AND GAPS—CONSISTENT THEMES RAISED BY IOWA MANUFACTURERS REGARDING WORKFORCE AND TALENT NEEDS IN A MANUFACTURING 4.0 ENVIRONMENT



Source: TEConomy Partners, LLC.

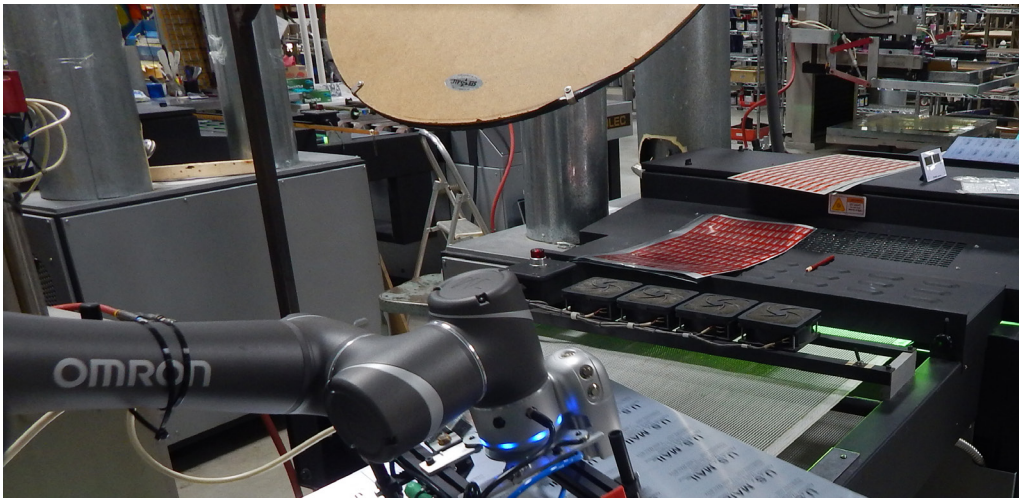
What should Iowa do or consider to meet the challenges of developing an effectively trained Manufacturing 4.0 workforce?

Industry leaders brought forth or were supportive of the following ideas:

- Consider/create new workforce re-training, upskilling program(s) recognizing the need for greater flexibility in training providers;
- Consider micro-credentialing and/or certificate programs to bolster incumbent worker training in areas such as Manufacturing 4.0 introductory course(s)/credential(s) that would include multiple facets such as: the business case and overview, data analytics, cybersecurity, etc.
- Re-frame college and university engineering, IT, data sciences, and other relevant programs for Manufacturing 4.0 curriculum and experiential learning needs.

These ideas and input have been incorporated into the strategies and actions developed and presented in further detail in the next section of the report.

This page intentionally left blank.



V. STRATEGIES AND ACTIONS TO ADVANCE MANUFACTURING 4.0 AND FURTHER ENHANCE IOWA'S MANUFACTURING ECOSYSTEM

This section of the report considers the full set of industry analyses conducted and the situation for Iowa manufacturers across the five strategic priority areas and the input provided on potential strategic interventions to address the issues, challenges, and barriers faced by firms in implementing Manufacturing 4.0 technologies. Detailed here are recommended strategies and actions developed in close consultation with the Advanced Manufacturing Work Group. Also included are examples of programs, initiatives, or investments made in other regions, states, and nations that are either directly relevant to the strategic recommendations made, or represent examples of potential future initiatives Iowa should consider as it implements this strategy and contemplates future investments.

Goal of the Iowa Manufacturing 4.0 Plan:

> *Iowa will become a high-adoption state in Manufacturing 4.0 technologies over the next 5 years, with broad integration and leveraging of advanced, smart manufacturing technologies across its diverse manufacturing base—with respect to both size of firm and industry sector.*

While this strategic plan is primarily focused on advancing and integrating technology adoption and integration among Iowa's manufacturers, it further addresses enhancements in some key elements of the broader manufacturing ecosystem. With an intentional, strategic effort, Iowa will enhance its global manufacturing competitiveness by:

- Adopting Manufacturing 4.0 technologies to increase productivity and to narrow the gap with the national average;
- Re-training and upskilling its manufacturing workforce to address acute workforce shortage issues and to successfully implement the suite of Manufacturing 4.0 technologies;

- Investing in infrastructure for digital technologies to ensure their optimal integration and effectiveness;
- Understanding and improving supply chain linkages throughout the industry; and
- Accelerating the connectivity and opportunities for manufacturing startups and scale-ups.

Key overarching principles have emerged during this strategic planning process and should serve to guide plan development and implementation of the plan. These principles include:

- Leveraging strategic collaborations;
- Increasing the scale of interactions;
- Promoting a sense of urgency for all manufacturers and the state recognizing that global and national competitors are adopting and utilizing Industry 4.0 technologies at rapid rates.

TEConomy has aligned its strategic recommendations with the five strategic priorities or pillars of the Manufacturing 4.0 Plan development set out by IEDA at the beginning of this project.

1. Manufacturing 4.0 Technology Adoption & Utilization
2. Enabling Infrastructure for Digital Technologies
3. Improved Supply Chain Linkages
4. Accelerating Manufacturing Startups & Scale-Ups
5. Ensuring an Effectively Trained Manufacturing 4.0 Workforce

Figure 28 summarizes the full set of strategic recommendations before each are detailed within and across the five strategic priority areas.

FIGURE 28: SUMMARY OF RECOMMENDED STRATEGIES & ACTIONS FOR THE IOWA MANUFACTURING 4.0 PLAN

Strategy #1 Manufacturing 4.0 Tech Adoption & Utilization	**Strategy #2 Enabling Infrastructure for Digital Technologies**	**Strategy #3 Improved Supply Chain Linkages**
Action 1.1: Implement state economic development incentives for Manufacturing 4.0 technology investments and adoption by Iowa manufacturers, including digital investments, allocating a sizable portion of incentives to SMEs.	Action 2.1: Prioritize investments in rural fiber and broadband infrastructure for Iowa's rural manufacturers, aligned with ongoing state investments and initiatives.	Action 3.1: Form an Iowa OEM Advisory Council to advise, counsel, and support supply chain SMEs in adopting Manufacturing 4.0 technologies.
Action 1.2: Accelerate depreciation schedules to support the integration of Manufacturing 4.0 technology investments.	Action 2.2: Support cross-industry and industry-university collaborations and implement company-specific assessments to address critical manufacturing-specific cybersecurity challenges.	Action 3.2: Incent and enhance in-state supply chain connectivity between Iowa's larger manufacturers and OEMs and SMEs.
Action 1.3: Increase usage and availability of CIRAS' Industry 4.0 Assessment tools, counseling, and implementation planning as a key starting point for Iowa manufacturers developing actionable technology adoption plans specific to their company.	Action 2.3: Provide resources to Iowa manufacturing SMEs to help address interoperability challenges in a dynamic Industry 4.0 operating environment.	Action 3.3: Update and leverage existing supply chain mapping tools to better understand and promote the strength of Iowa's supply chain network and identify opportunities to enhance connectivity.
Action 1.4: Advance the knowledge base, expertise, and collaboration among Iowa's economic development professionals and other business support professionals and organizations around the importance of Industry 4.0 and key technologies.		
Action 1.5: Monitor and track Iowa's Manufacturing 4.0 adoption rates regularly via CIRAS surveys and forums, segmented by size of company and industry.		

Strategy #4 Accelerating Manufacturing Startups & Scale-Ups	Strategy #5 Ensuring an Effectively Trained Manufacturing 4.0 Workforce
Action 4.1: Develop and maintain a virtual Manufacturing Startup, Support, and Information Source.	Action 5.1: Restructure funding models for workforce re-training and upskilling program(s) for Iowa's existing manufacturing workforce that are not tied to new job creation.
Action 4.2: Consider personal and potentially corporate incentives (e.g., tax incentives, matching funds, dedicated fund of funds) to generate manufacturing-specific angel or venture investments in new, physical product-based, manufacturing companies located in Iowa.	Action 5.2: Develop and implement Manufacturing 4.0-specific "micro-credentialing," certificate programs, and otherwise applied, "stackable" credentials at Iowa 2- and 4-year institutions to upskill and re-train the incumbent workforce, particularly targeted toward the SME technician workforce and in digital skills and data analytics.
	Action 5.3: Enhance cross-disciplinary undergraduate and graduate level curriculum and programming for "hybrid" Manufacturing 4.0 talent demands across Engineering, IT, and Data Sciences at Iowa's colleges and universities.
	Action 5.4: Target Manufacturing 4.0-related occupations for increased participation in Registered Apprenticeships and Industry Recognized Apprenticeship Programs and invest to lower existing barriers specific to manufacturing.
	Action 5.5: Align and consolidate state-support for achieving the necessary scale in Manufacturing 4.0 training/re-training.

Source: TEConomy Partners, LLC.

1. Manufacturing 4.0 Technology Adoption & Utilization

Rationale: Iowa's manufacturers demonstrate, in general, a strong awareness of Industry/Manufacturing 4.0 technologies and the specific technologies needed to enhance their competitiveness by increasing productivity and addressing acute workforce shortages. A number of Iowa's large manufacturers are implementing digital roadmaps. Further, many of the companies interviewed for this strategy, regardless of size, have made recent investments in Manufacturing 4.0-related technologies. Yet among all size categories, and particularly among the state's SMEs, significant barriers to acquiring and integrating these technologies into existing operations remain. At the core of this first Manufacturing 4.0 strategy is addressing how to "de-risk" significant technology investments and where the public sector and public-private partnerships have roles to play in doing so.

While several of the identified challenges to adoption and utilization are covered in their own strategies (e.g., workforce and talent), and others are embedded within other strategies (e.g., broadband investments within digital infrastructure), the focus of this strategy is primarily with respect to advancing technology adoption by addressing the significant cost barriers associated with these investments; while also bolstering the entry point for Iowa manufacturers beginning this journey.

Throughout this project, most representatives from Iowa manufacturers have emphasized to the project team that state economic development incentives focused on job creation are "outdated." They report that implementing automation and digital 4.0 technologies does not necessarily lead to adding (or reducing) jobs, but they are investing to remain competitive and job-based incentives are outdated. If manufacturers do not invest and improve in their competitiveness, however, their long-term business viability is at risk.

"On a global scale, Iowa is not far ahead (for example vs. Germany) … but in the U.S. on a 0-100 scale, Iowa would be at the 75th percentile."

"We're seeing companies that could really benefit but they're not making the investment."

-Interview comments regarding Iowa's adoption of Mfg. 4.0 technologies

The following actions are recommended for consideration to increase the rate of technology adoption and utilization, particularly among Iowa's small- and mid-sized manufacturing enterprises.

Action 1.1: Implement state economic development incentives for Manufacturing 4.0 technology investments and adoption by Iowa manufacturers, including digital investments, allocating a sizable portion of incentives to SMEs.

- Consider utilizing a flexible incentives "menu" of both tax credits and matching grants deployed selectively by size of firm, need, technology maturity, and other factors. Due to upfront cost and cash flow concerns, matching grants will be more effective in increasing overall adoption rates among SMEs.
    - Consider capping matching grants at a total project cost of $250,000 (where, for example, a 1:1 match would be $125K for each party); and a minimum project cost should be considered, potentially set at $25,000.
    - A variable matching scale/cost-sharing approach should be considered where a higher cost share is provided by state funding for lower-cost investments and vice versa. This would be intended to ensure that smaller manufacturers, typically investing in smaller 4.0 capital expenditures, would generally reap greater benefit.
- Align incentives with array of pre-approved hardware and software technologies specific to Industry/Manufacturing 4.0, including but not limited to those recognized by CIRAS.
- The total project cost should be inclusive of hardware, software, and training components (where applicable).
- Consider company size disbursements for matching grant funds where 80 percent of state funds are allocated to SMEs and 20 percent to large manufacturers.

Action 1.2: Accelerate depreciation schedules to support the integration of Manufacturing 4.0 technology investments.

- Accelerated depreciation schedules allow for an improved capital accounting situation for firms making these investments while also allowing firms to maintain a more viable technology modernization path as new, more improved/enhanced versions become available.

Action 1.3: Increase usage and availability of CIRAS' Industry 4.0 Assessment tool, counseling, and implementation planning as a key starting point for Iowa manufacturers developing actionable technology adoption plans specific to their company.

- Ensure a version(s) of the Assessment is well designed and appropriate for engaging small manufacturers who have an especially great need for a starting point in their Industry 4.0 journey.
- Ensure CIRAS, TechWorks, and the Quad Cities Manufacturing Innovation Hub have appropriate resources to meet with and counsel individual companies. Consider a state and/or OEM-funded pilot program targeting two to three identified small (20-49 employees) manufacturers across two to three important state supply chains to provide useful lessons learned for the broader manufacturing community.
- To reach a greater scale of interactions, conduct regional Industry 4.0 workshops that incorporate introductions and connections to automation, IT, cybersecurity, and other specific technology integrators and providers; leverage use-cases, testimonials, and examples of the return on investment for Industry 4.0 technologies.
- Consider connecting or matchmaking for Iowa-based technology integrators, vendors to work with smaller manufacturers. CIRAS could potentially "pre-qualify" smaller companies in advance to smooth the process, creating a potential "win-win" for both the manufacturer and the vendor.

Incentives Example: Indiana Manufacturing Readiness Grants

In May 2020, the Indiana Economic Development Corporation (IEDC) in partnership with Conexus Indiana announced the Manufacturing Readiness Grant program as part of the broader Economic Activity Stabilization and Enhancement (EASE) program to stimulate manufacturing investments for future growth.* The program makes available $4 million in the form of matching grants up to or equal to the amount of the qualified investment in new equipment and machinery (minimum 1:1 investment match). From the Conexus Indiana website:**

> *"In partnership with the IEDC, Conexus Indiana is now accepting applications for up to $200,000 in matching grants for companies committing to increasing their competitiveness by integrating smart technologies and processes in order to improve capacity, capability, speed and quality. Funding may also be utilized for health care manufacturing technology, providing financial assistance to manufacturers supporting COVID-19 response efforts."*

The stated goal of the program is to:

> *"Expand critical knowledge and lower the barriers to smart manufacturing technology adoption and healthcare manufacturing equipment procurement at a time when Indiana manufacturers are faced with unprecedented challenges."*

In August, 20 awards under the grant program were announced that totaled nearly $2 million. The companies represent a range of product and market focus areas including automotive, aerospace and defense, machinery and construction, furniture, and healthcare and medical.*** Conexus reports they plan to invest more than $8.2 million in technology and equipment.

Among the awardees investment examples relevant for Manufacturing 4.0 technologies and capabilities, particularly software-related investments and 3D printing include:

- Investing in a new, software-based production platform to increase workflow efficiency for its entire workforce.
- Investing in 3D printing in order to streamline tooling and fixture development while reducing lead times.
- Upgrading its production management software in order to streamline customer orders.
- The company is investing in new software to transform their in-plant and mobile business.
- Investing heavily in advanced machining with COBOT automation to increase their capacity while hiring additional employees to manage these advancements in high-tech processing.
- Investing in additive manufacturing to shorten development cycle times.

* See: https://iedc.in.gov/programs/economic-activity-stabilization-and-enhancement/home.

** See: https://www.conexusindiana.com/manufacturing-readiness-grants/.

*** Conexus Indiana and IEDC news release, see: https://www.conexusindiana.com/state-awards-20-manufacturing-readiness-grants-to-indiana-businesses/.

Incentives Example North Dakota's Automation Tax Credit

Part of the state's 21st Century Manufacturing Workforce Incentive program, qualified businesses can claim an income tax credit for purchasing new or used automation and robotic machinery and equipment for the purpose of upgrading or advancing a manufacturing process. The credit is equal to 20 percent of the cost of the approved machinery and equipment, with maximum credits allowed to all taxpayers of $1 million per calendar year and businesses must demonstrate that they have increased average wages, workforce safety, or productivity by at least 5 percent through the use of new automation machinery or systems. The incentive runs from 2019 through 2022 tax years and is targeted such that new investments in automation do not decrease employment.

Action 1.4: Advance the knowledge base, expertise, and collaboration among Iowa's economic development professionals and other business support professionals and organizations around the importance of Industry 4.0 and key technologies.

- Advancing technology adoption requires a broad-based ecosystem approach where awareness and support is provided at multiple levels and economic developers and business service providers understand the importance of investing and integrating these technologies to a competitive manufacturing sector.
- The UNI Institute for Decision Making is leading an initiative in this area and will be piloting Industry 4.0 training for economic developers in late 2020, leveraging federal Economic Development Administration (EDA) University Center funding.
- Work toward enhanced collaboration among manufacturing-related resource partners to address regional silos.

Action 1.5: Monitor and track Iowa's Manufacturing 4.0 adoption rates regularly via CIRAS surveys and forums, segmented by size of company and industry.

- CIRAS' biennial Needs Assessment survey and regional forums has a wide reach among Iowa manufacturers and should be adapted and updated to include key questions regarding technology adoption and utilization going forward.
- Another option could include integrating a key set of Manufacturing 4.0-related questions/ items in the state's Synchronist site-visitation system.

Key Measures to Track Strategy Performance and Outcomes into the Future:

- Manufacturing GDP (value added) growth – overall and by major industry classifications
- Manufacturing productivity (value added per worker) and growth, gaps relative to the U.S.
- Manufacturing 4.0 technology adoption rates (via CIRAS surveys)
- Integration of Manufacturing 4.0 "enabling" occupations

2. Enabling Infrastructure for Digital Technologies

Rationale: Adopting and integrating the suite of digital Manufacturing 4.0 technologies requires fundamental infrastructure in place to optimize and realize its benefits. Enabling "infrastructure" in this context includes and spans statewide access to fiber and reliable high-speed broadband; the IT backbone and ability to achieve "digital integration" within individual companies; and critical cybersecurity infrastructure required for increasingly interconnected factories in a cyber-physical context. Just as reliable and well-maintained roads, railways, airports, and bridges have been foundational to advanced economies, this modern digital infrastructure is fundamental to advancing a competitive Industry 4.0 economy with high rates of technology adoption.

This strategy recognizes the ongoing efforts in Iowa designed to address some of these needs, particularly with respect to advancing rural broadband infrastructure including from the State's Office of the CIO, grant funding and outreach efforts at ISU, and other initiatives. Fundamental to this strategy, however, is the imperative to allow Iowa manufacturers a "seat at the table" in these discussions and initiatives, ensuring their voice and specific needs and requirements are heard and addressed.

The following actions are recommended for consideration to ensure Iowa has the appropriate enabling infrastructure in place to realize and optimize the potential of Industry 4.0 investments.

Action 2.1: Prioritize investments in rural fiber and broadband infrastructure for Iowa's rural manufacturers, aligned with ongoing state investments and initiatives.

- Align with specific recommendations arising out of the Governor's Economic Recovery Advisory Board and ensure manufacturers have input into these infrastructure investments. These recommendations include the following standards:
    - Enhanced Mobile Broadband: individual user experience data download and upload rates of 100 Mbps (as a minimum target, note that target may still be too slow for significant industrial applications/usage); and
    - Ultra-Reliable and Low Latency Communications: decreasing end-to-end latency speeds to 5 ms or less.

Action 2.2: Support cross-industry and industry-university collaborations and implement company-specific assessments to address critical manufacturing-specific cybersecurity challenges.

- Cybersecurity is a critical yet non-competitive area ripe for collaborations.
- Engage and leverage strengths of ISU to assist manufacturers in meeting challenges of an increasingly cyber-physical manufacturing environment.
- In conjunction with CIRAS, ISU, and other subject matter experts, develop a multi-faceted cybersecurity risk assessment for Iowa's SMEs to better understand their cybersecurity vulnerabilities now and as they further pursue additional automation and the adoption of Industry 4.0 technologies. Leverage expertise to enhance capabilities to address identified vulnerabilities.

Future Considerations for Iowa, International Example from Germany: Mittelstand Digital SME Competence Centers

Germany was among the first global manufacturing economies to embrace the transition to Industry 4.0 models at large scale, where a multi-pronged national effort led by the Federal Ministry for Economic Affairs and Energy (BMWi) to aid SMEs in integrating Industry 4.0 tools and practices was deployed. One of the signature initiatives developed as a result of the national Industry 4.0 strategy were the Mittelstand 4.0 Competence Centers consisting of 26 Industry 4.0-focused centers scattered throughout Germany, providing information and digitalization support to SMEs free of change.

The centers provide expert knowledge, use cases, and networking targeted specifically at widespread adoption of Industry 4.0 technologies among SMEs with the goal of closing the investment and knowledge gap between smaller firms and large manufacturers to boost national competitiveness and resilience. Each center represents a different consortium consisting of regional public and private organizations with projects funded through BMWi, with various centers focused on specific technology platforms and models ranging from 3D printing to autonomous logistics. Centers offer a number of assets to help aid in consulting SMEs such as technology adoption with demonstration and test environments, model Industry 4.0 production lines, access to technology integration services, and mobile solutions labs.

Just one example of the program's success is the case study of MOLLE GmbH, a packaging company which worked with one of the competence centers to transition from traditional manufacturing practices to integration of Industry 4.0 models. The center helped the company to develop a phased digitization strategy that first fit all production machines with digital interfaces that feed data to analytics tools, then implanted a transition to ERP software, and finally consulted with retrofitting legacy analog machinery to fully digitize an existing production facility at scale.

Action 2.3: Provide resources to Iowa manufacturing SMEs to help address interoperability challenges in a dynamic Industry 4.0 operating environment.

- In conjunction with CIRAS and other subject matter experts, develop an interoperability assessment framework to help Iowa manufacturers better anticipate and evaluate potential challenges in integrating new machinery and services into their existing operations. The assessment tool could be administered through a "help desk" outreach service that leverages subject matter experts to guide Iowa manufacturers through thinking about how to best approach interoperability and connectivity solutions based on the assessment framework.
- Convene a working group to develop a public knowledge base of best practice solutions in enabling digital infrastructure for Iowa manufacturers across key connectivity and interoperability layers including machine-to-machine (M2M) interoperability, authentication and data transfer protocols, and cloud-based services.
- Provide resources to Iowa manufacturing SMEs regarding Industrial Internet of Things (IIoT) data/protocol standards.
- Ensure resources are integrated into a single Manufacturing 4.0 Landing Hub for aggregating this and other knowledge base items recommended here and elsewhere in the strategy.

Key Measures to Track Strategy Performance and Outcomes into the Future:

- Measuring broadband and latency speeds at a sample of rural manufacturing operations across the state annually.
- Share of manufacturers that have undertaken cybersecurity assessments.
- Share of manufacturers compliant with cybersecurity standards (e.g., DoD's Cybersecurity Maturity Model Certification "CMMC"—would leverage ISU, CIRAS, other experts to advise on appropriate standards).

Example of Addressing Interoperability Challenges/Standards: MTConnect Institute

Interoperability between digital machinery, software, and systems from different suppliers bought at different times is a key challenge for companies implementing Industry 4.0 ecosystems. The MTConnect Standard is designed to allow more streamlined use of common data structures for scaling digital systems architecture through providing a common, non-proprietary semantic data framework that enables machine-generated data to be leveraged towards holistic Industry 4.0 applications. MTConnect is supported by a not-for-profit standards development institute, whose membership is made up of over 400 companies and research organizations in various manufacturing subsectors spanning automotive to medical device companies. Standards are available on over 50K devices, and the institute notes that "in practice, MTConnect is widely used for factory floor monitoring, OEE calculation, predictive analytics or maintenance, manufacturing cell integration, scheduling and routing, and ERP integration."*

Increasing awareness and adoption of Industry 4.0-aligned interoperability standards amongst Iowa manufacturers can help play a role in bridging the gap from legacy machinery and siloed digital assets to a fully enabled Industry 4.0 environment in the coming years.

* mtconnect.org.

3. Improved Supply Chain Linkages

Rationale: A holistic Manufacturing 4.0 strategy must consider ways in which new technologies are enhancing supply chain dynamics and relationships for more seamless processes, allowing for more customization and flexibility in specific orders, enabling enhanced traceability and security throughout the supply chain, and more. Industry 4.0 technology adoption is often advanced through the requirements and directives of larger manufacturers or OEMs pushed down to SMEs through supply chain relationships. Ensuring Iowa's SMEs understand and are able to meet and integrate key technology requirements is important for maintaining a vibrant manufacturing sector into the future.

In addition to these dynamics, this study has revealed opportunities to consider for growing Iowa manufacturing via better understanding, documenting, and communicating the breadth of Iowa's manufacturing supply chain to better connect with both in- and out-of-state OEMs, particularly amidst the COVID-19 pandemic and considerations around "re-shoring" production. To seize this opportunity will require identifying the state's supply chain strengths and attractiveness, as well as gaps.

Iowa is already planning to invest in Manufacturing 4.0 supply chain integration through investments in TechWorks and a focus on Deere & Company's suppliers. This is a key initiative and example in improving supply chain linkages and this strategy should align with and seek to leverage the ongoing investments in the Cedar Valley.

The following actions are recommended for consideration to improve Iowa's supply chain linkages in a Manufacturing 4.0 environment as well as more broadly for growth opportunities.

Action 3.1: Form an Iowa OEM Advisory Council to advise, counsel, and support supply chain SMEs in adopting Manufacturing 4.0 technologies.

- Consider forming as an active working group connecting the Advanced Manufacturing Work Group to SMEs on the adoption path or as a specific Joint Committee managed by IEDA, CIRAS, and TechWorks.
- The Council should help prioritize 4.0 technology areas for adoption and integration most important for effectively meeting the needs of OEMs and provide a support system for helping to turn advice into action.
- Closely related is providing support for, and leveraging, the Supplier Integration Lab initiative being advanced at TechWorks.

Action 3.2: Incent and enhance in-state supply chain connectivity between Iowa's larger manufacturers and OEMs and SMEs.

- Consider look-through, single factor corporate income tax reform for companies supplying to larger OEMs using Iowa-made products in Iowa manufacturing facilities.

Action 3.3: Update and leverage existing supply chain mapping tools to better understand and promote the strength of Iowa's supply chain network and identify opportunities to enhance connectivity.

- Consider commissioning updates or a new study by faculty from Iowa's three research universities.
- Leverage existing mapping tools established by the Iowa Department of Transportation and the Quad Cities Manufacturing Innovation Hub.

Key Measures to Track Strategy Performance and Outcomes into the Future:

- Iowa small- and mid-sized manufacturers' participation in OEM Advisory Council.
- Working with the major Iowa OEMs and large manufacturers to track the number and "health" of in-state suppliers.

Michigan: Automation Alley's "Industry 4.0 Supplier Reboot"

As a part of Michigan's broader nonprofit World Economic Forum Advanced Manufacturing Hub (AMHUB), the organization offers a "Supplier Reboot" workshop involving a full-day, tailored seminar targeted at groups of up to 80 individuals representing the supplier base for specific companies. Automation Alley organizes and generates content for the workshops based around Industry 4.0 topics such as cloud computing, augmented/virtual reality, automation and robotics systems, factory cybersecurity, compliance and quality control, and data analytics and digital twin applications among many others. The workshop also offers personalized Industry 4.0 assessments across a variety of different company and supplier dimensions, as well as the opportunity to learn directly from existing Automation Alley companies about Industry 4.0 innovation and adoption case studies.

The aim of the program is to increase awareness and upskilling amongst supplier bases using best practices for integrating Industry 4.0 technologies and processes, with the long-term goal of organically growing a critical mass of in-state suppliers that are actively engaged in implementing Industry 4.0 frameworks along an integrated supply chain.

Companies such as Raytheon and Rheinmetall have recently used the program to host supplier days in the Detroit area targeted at increasing Industry 4.0 awareness and integration among local suppliers to aid in major upcoming defense systems manufacturing work.

4. Accelerating Manufacturing Startups & Scale-Ups

Rationale: Manufacturing is a leading driver of the Iowa economy and a vibrant and robust industry cluster is characterized not only by strong innovation and growth among existing manufacturers but also the ability to generate new startups, and to enable them to scale. Moreover, the flexibility in product development and sourcing that Industry 4.0 technologies enable, also make the establishment of a physical footprint (and the jobs associated with it) potentially more challenging from an economic development perspective. Considering the importance of manufacturing to the Iowa economy, the state needs to excel in supporting manufacturing companies at all stages of their lifecycles.

The following actions are recommended for consideration to meet the challenges of better connecting and advancing the startup and scale-up ecosystem for manufacturing in Iowa.

Action 4.1: Develop and maintain a virtual Manufacturing Startup, Support, and Information Source.

- Given the breadth of needs and geographic expanse of the state, consider the creation of an on-line and interactive website where entrepreneurs can seek assistance with their physical product ideas, service providers can post and market their qualifications and expertise areas, and the Iowa investment community could examine potential opportunities for investments with a strong Iowa connection.
- This website should become a conduit by which universities, other public sector providers, and even OEMs/larger firms could make available to both entrepreneurs and existing manufacturers certain assets, equipment, and expertise on a contract basis. Integrate this resource with existing manufacturing- and small business-supporting websites and resources, including:
  - Iowa Source Link—helping small businesses grow and succeed in Iowa; and
  - Iowamfg.com—a resource site for Iowa manufacturers.
- This website should also be structured to include a virtual help desk function for Iowa's existing manufacturers to seek consultants, vendors, or other assistance for their Industry 4.0 adoption and implementation efforts.

Action 4.2: Consider personal and potentially corporate incentives (e.g., tax incentives, matching funds, dedicated fund of funds) to generate manufacturing-specific angel or venture investments in new, physical product-based, manufacturing companies located in Iowa.

- Developing a more significant source of Iowa-based, patient, and knowledgeable manufacturing-specific investment capital that is willing to invest in continuing Iowa's proud manufacturing legacy, would set Iowa apart from its regional peers.
- Such incentives could also provide a connection for retiring leadership and other high net worth individuals from Iowa's anchor manufacturers to engage the next generation of Iowa's manufacturing base.

Key Measures to Track Strategy Performance and Outcomes into the Future:

- Track the number of Iowa-based manufacturing startups each year and their trajectory (revenue, employment growth) over the first three to five years of business.
- Track the number and dollar amounts of Angel and VC investments in startup and emerging Iowa manufacturers.
- Track the number and dollar amounts of federal SBIR/STTR awards in startup and emerging Iowa manufacturers.

Micro-credentialing and the Role of Continuing Education in Upskilling the Industry 4.0 Talent Base

The landscape of postsecondary education is changing with the emergence of new credentials that are designed to promote continuous learning and allow working professionals to add certifications and credentialing to their resume in a rapidly changing technology environment, and without the need for completing an entire degree program. These modular programs, dubbed "micro-credentials," involve small, individual learning units that provide value-added skills and have the ability to combine (or "stack") into broader, cohesive qualifications over time. Micro-credentials often focus on highly applied skills and technologies that are relevant to current industry needs and represent the space between single courses and full degrees.

The spectrum of micro-credentialing includes a variety of terms and options, such as:

- **Academic Certificates:** Academic certificates recognizing the completion of an organized learning activity awarded by an academic institution. These may or may not confer academic credits toward degree programs.
- **Professional/Industrial Certificates:** certificates awarded by professional bodies, industries or product vendors following completion of an examination.
- **Digital Badges:** Virtual representations of completion of learning units that are shared to show accomplishment of certain skills/knowledge, which may or may not be related to an academic program of study. Some programs allow combinations of badges, or "stacks," to grant certificates or credentialing.

Micro-credentials "have expanded their scale considerably, as a consequence of a rising demand for upskilling and reskilling, as well as a sharp reduction in the unit cost of provision made possible by digitalization." Higher education institutions, businesses and other institutions are actively offering alternative credentials that help learners acquire new skills, update their existing skills and signal the competencies they already have.* This is especially true in manufacturing industries, where a lack of qualified talent can relegate new technologies such as industrial robotics to ineffective, niche roles rather than broad enablers of productivity. Despite a focus on increasing STEM talent within manufacturing industries over the last decade, many companies are still reactionary in addressing workforce skills gaps and find themselves needing to quickly augment their workers' skill sets after the fact when a new automation, robotic, or data-driven system is installed on the production line. Manufacturers also often face challenges in upskilling existing workforces through formal degree-based programs which take significant time and capital investment and risk being out of date by the time that talent can fully utilize new skills.

Micro-credentialing attempts to address these programs through a modular, flexible, and responsive framework in order to generate skilled workers in short time frames. Although still in their early adoption phase, a variety of institutions are advancing micro-credentialing programs that are attempting to bridge the gap towards broader industry recognition of these credentials and focusing on ongoing skills-based learning for manufacturing workers. Several high-profile examples include:

- **MIT Smart Manufacturing Certificate,** consisting of a highly accessible set of 10 modules focusing on introduction to smart manufacturing, manufacturing processes, data modeling, sensors, and data analysis. The program is designed for plant managers working in manufacturing and design and manufacturing engineers seeking to learn about data and modeling in a manufacturing environment.

- **Purdue University Micro-credentialing and Badge Programs,** which offer a "Design for Security" Cybersecurity Digital Badge program that focuses on companies that produce cyber or cyber-physical systems and their components as well as a Data Intelligence Micro-credential that is designed to provide applicants with exposure to the analytical methods and tools used by organizations.

- **Yaskawa Academy Digital Badges,** an example of an industry-driven effort to develop micro-credentialing in partnership with Intelitek, a developer of manufacturing workforce training solutions, that expands traditional in-person industrial robotics controller certification training on Yaskawa Motoman systems to include a mix of hands-on and virtual learning that grants "digital badges" in robotic systems integration and operation.

* Organisation for Economic Co-operation and Development, "The Emergence of Alternative Credentials," March 2020.

5. Ensuring an Effectively Trained Manufacturing 4.0 Workforce: Meeting the Workforce Development & Upskilling Challenge

Rationale: Implementing Manufacturing 4.0 technologies is fundamentally changing the nature of work and job functions in the modern "smart" factory. To achieve its goals and benefits and compete in this environment, digital and "hybrid" skills are vital, learning must be continuous and lifelong, and preparation for modern manufacturing careers takes on a new context. Iowa's manufacturers embracing digital technologies require existing employees to be regularly and periodically "up-skilled." Workforce development is both a major barrier but also enabler of Manufacturing 4.0 technology implementation, and how quickly and efficiently training and upskilling can occur is a significant factor in how Iowa competes into the future.

Iowa has in place an existing suite of workforce training programs and initiatives. This strategy is not designed to replace these existing programs; but rather seeks to allocate new resources to be more targeted to the unique workforce re-training and upskilling needs of a robust Manufacturing 4.0 environment as a high priority for Iowa to remain competitive.

Ensuring Iowa has the appropriate flexibility in workforce training and upskilling is critical across a full talent development pipeline that runs from K-12, through 2-year and 4-year postsecondary, apprenticeships and increasingly important incumbent worker training. Today, the majority of Iowa's core and highly subscribed "260" worker training programming is tied to the creation of new jobs and the state's community colleges work with the employer to understand and develop a plan for which the community college and its partners deliver training. The most typical arrangements are either company-led training (arranged by the company and could include in-house instructors, community college instructors, Regents Universities, or private contractors) or community college delivered training. In the last decade, however, Iowa manufacturers' use of the Industrial New Jobs Training Program (260E) has been declining and incumbent worker re-training and upskilling is expected to take on new importance.[25]

Among the Iowa manufacturers engaged in project interviews and focus groups, there is an emerging consensus that implementing Manufacturing 4.0 technologies is not likely to require significant new hires, but instead will require upskilling existing workers, and therefore necessitates reconsidering the new jobs requirements rooted in much of today's state economic development incentives. At the same time, solving the aforementioned workforce demands of a smart manufacturing environment requires education and training solutions across multiple levels. Iowa should, therefore, consider adding to its existing workforce training construct if it is to meet the challenges associated with Manufacturing 4.0.

25 Over the most recent decade, from 2011-2019, the use of the 260E program by manufacturers has averaged 29 companies/establishments per year, down from the annual average usage over the 2002-2010 period of 42.

It is important to recognize that Iowa has been a leader in workforce and talent development initiatives on several fronts—advancing apprenticeships, funding internships, and introducing K-12 students to the breadth of opportunities in advanced manufacturing and "STEM" careers through initiatives such as Future Ready Iowa. But to meet the workforce and talent challenge for a competitive Manufacturing 4.0 future, the public and private sectors must collaborate to ensure it is intentionally embedded in each level of the talent pipeline and with a unique focus on upskilling and re-training.

Over the last decade, states are increasingly investing in workforce training and development, at a time when federal workforce spending declined, and unemployment rates continued to fall to historic lows and companies have been desperate for skilled workers.[26] For context, in a recent study C2ER has found the five leading states in terms of workforce development spending had 3-year average spending ranging from $91 million to $152 million annually. And while three of these states are coastal (NY, NJ, CA), included among the top 5 are one Midwestern state (MN) and one Southern state (AL).[27]

The following actions are recommended for consideration to meet the challenges of competing in an increasingly digital, smart manufacturing environment that has major implications for workforce demands.

Action 5.1: Restructure funding models for workforce re-training and upskilling program(s) for Iowa's existing manufacturing workforce that are not tied to new job creation.

- To effectively re-train and upskill Iowa's existing workforce for a Manufacturing 4.0 environment requires a breadth of training providers and options for employers beyond and in addition to the state's community colleges where existing training efforts are concentrated.
- Restructuring funding models should include examining ways in which to leverage established workforce training programs, such as the 260F program which provides training for existing employees.

Action 5.2: Develop and implement Manufacturing 4.0-specific "micro-credentialing," certificate programs, and otherwise applied, "stackable" credentials at Iowa 2- and 4-year institutions to upskill and re-train the incumbent workforce, particularly targeted toward the SME technician workforce and in digital skills and data analytics.

- Intended to align with Action 5.1 as a primary source for worker re-training.
- Create Introductory Manufacturing 4.0 courses and credentials that provide instruction and leverage case studies, site visits, etc. around Manufacturing 4.0 overview, data analytics, cybersecurity, and other key topics. Important to enable digital educational access, where possible, to provide programming across the state and maximize reach relative to startup costs.

26 The Council for Community and Economic Research (C2ER), "State Investment in Workforce Development on the Rise," October 2019.
27 Ibid.

- Develop and promote industry-driven and industry-recognized, portable credentials that incentivize workers to participate and that utilize an industry board/council for developing, standardizing, and approving credentials.

Action 5.3: Enhance cross-disciplinary undergraduate and graduate level curriculum and programming for "hybrid" Manufacturing 4.0 talent demands across engineering, IT, and data sciences at Iowa's colleges and universities.

- Engage Iowa manufacturers in industry Advisory Councils, capstone courses, as guest lecturers, in joint faculty appointments, internships and other capacities to inform and maintain relevant current and future Industry 4.0 skill demands.
- Embed multi-disciplinary Manufacturing 4.0-specific curricula within existing degree programs (e.g., Mechanical Engineering + Embedded Electronic Systems; Computer Sciences + Data Sciences; Industrial Technology + Advanced Analytics).
- Develop Post-Baccalaureate and Post-Master's Manufacturing 4.0 Certificate program(s) targeted toward both current postsecondary students and alumni in key degree fields (e.g., Engineering, IT, Data Sciences, Business) who are considering or even transitioning into a career in manufacturing.

Action 5.4: Target Manufacturing 4.0-related occupations for increased participation in Registered Apprenticeships and Industry Recognized Apprenticeship Programs and invest to lower existing barriers specific to manufacturing.

- Invest and partner with both Iowa manufacturers and training providers to lower barriers that include lack of support for nontraditional learning times at colleges and universities for incumbent workers; investing in Industry 4.0-relevant equipment and software for training; and work toward greater scale where occupations allow for greater than 1:1 apprentice oversight.

Action 5.5: Align and consolidate state-support for achieving the necessary scale in Manufacturing 4.0 training/re-training.

- Going forward, it is critical to monitor and gauge the demand for Manufacturing 4.0 training/re-training, likely through regular industry and training provider surveys, to consider whether it is appropriate to develop and concentrate resources and expertise into a signature Manufacturing 4.0 "Training Hub" with strategic facilities investments.
- Organize and consolidate state workforce development initiatives for scaling up the Manufacturing 4.0 workforce and aligning closely with employers. Iowa manufacturers report being confused when seeking training options and attempting to navigate workforce training programs that are delivered across multiple state agencies. Iowa should consider consolidating Workforce programming under Iowa Workforce Development (IWD).
- Provide state support to help underwrite the costs of providing statewide access to workshop and training events, allowing efforts developed in one region to be more seamlessly provided

in other areas of the state, to avoid duplication of effort and achieve greater scale and efficiency.

- Work with CIRAS, TechWorks, and the Quad Cities Innovation Hub collaboratively to fund participation and engage a broad range of manufacturing stakeholders in training workshops, seminars, etc. including efforts to:
  - "Train the Trainer" involving outside experts working with high school and postsecondary educators, community college and other customized training providers, and corporate training professionals to enhance the Industry 4.0 knowledge base and relevancy across the state.
  - Advance the knowledge base and expertise of Iowa's economic development and other business support professionals and organizations around the importance of Industry 4.0 and key technologies (aligned with Strategy 1, Action 1.4).

Key Measures to Track Strategy Performance and Outcomes into the Future:

- Once established, track participation and growth in manufacturing-specific workforce re-training and upskilling programs and numbers of awards in new 4.0 specific credentials, by size of firm; once a baseline is set, establish annual goals in growing participation.
- Integration of Manufacturing 4.0 "enabling" occupations across the Iowa manufacturing industry.

CONCLUSION

The importance of Iowa's manufacturing industry is clear—the sector makes an outsized contribution to the state economy in terms of employment, output, and innovation activity. Simply put, manufacturing has always mattered to Iowa and it continues to, perhaps more than ever. The challenge for Iowa is maintaining its competitive position globally while adopting and integrating the technologies and corresponding benefits of Industry 4.0 to enhance productivity, to keep pace with the nation in the growth and value of its manufacturing output, and to meet the challenges posed by acute workforce shortages.

This plan represents a call to action for Iowa's manufacturers, state leaders, resource providers, economic developers, and state agencies to work together to support its manufacturers' transitioning to Industry 4.0 technologies and to maintain a vibrant manufacturing base through strategies that will drive and ensure competitiveness in the state's manufacturing sector. As Iowa works to implement these strategies, it will continue to look toward the Advanced Manufacturing Work Group, the Iowa Innovation Council and manufacturing leaders to ensure the implementation of these strategies are industry-driven and supported by continuous collaboration among all partners and stakeholders involved in this important work.

APPENDIX

Defining the Major Manufacturing Industry Subsectors for Iowa

NAICS Code	NAICS Description
Ag/Construction Equipment and Other Heavy Machinery	
326211	Tire Manufacturing (except Retreading)
326212	Tire Retreading
333111	Farm Machinery and Equipment Manufacturing
333112	Lawn and Garden Tractor and Home Lawn and Garden Equipment Manufacturing
333120	Construction Machinery Manufacturing
333612	Speed Changer, Industrial High-Speed Drive, and Gear Manufacturing
333618	Other Engine Equipment Manufacturing
333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing
336120	Heavy Duty Truck Manufacturing
336211	Motor Vehicle Body Manufacturing
336212	Truck Trailer Manufacturing
336992	Military Armored Vehicle, Tank, and Tank Component Manufacturing
Automation & General Industrial Machinery	
332911	Industrial Valve Manufacturing
332912	Fluid Power Valve and Hose Fitting Manufacturing
332919	Other Metal Valve and Pipe Fitting Manufacturing
333411	Air Purification Equipment Manufacturing
333412	Industrial and Commercial Fan and Blower Manufacturing

NAICS Code	NAICS Description
333413	Industrial and Commercial Fan and Blower a nd Air Purification Equipment Manufacturing
333511	Industrial Mold Manufacturing
333512	Machine Tool (Metal Cutting Types) Manufacturing
333513	Machine Tool (Metal Forming Types) Manufacturing
333514	Special Die and Tool, Die Set, Jig, and Fixture Manufacturing
333515	Cutting Tool and Machine Tool Accessory Manufacturing
333516	Rolling Mill Machinery and Equipment Manufacturing
333517	Machine Tool Manufacturing
333518	Other Metalworking Machinery Manufacturing
333519	Rolling Mill and Other Metalworking Machinery Manufacturing
333911	Pump and Pumping Equipment Manufacturing
333912	Air and Gas Compressor Manufacturing
333913	Measuring and Dispensing Pump Manufacturing
333914	Measuring, Dispensing, and Other Pumping Equipment Manufacturing
333922	Conveyor and Conveying Equipment Manufacturing
333992	Welding and Soldering Equipment Manufacturing
333994	Industrial Process Furnace and Oven Manufacturing
333995	Fluid Power Cylinder and Actuator Manufacturing
333996	Fluid Power Pump and Motor Manufacturing
333999	All Other Miscellaneous General Purpose Machinery Manufacturing
334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables
335312	Motor and Generator Manufacturing
335313	Switchgear and Switchboard Apparatus Manufacturing
335314	Relay and Industrial Control Manufacturing

NAICS Code	NAICS Description
Avionics & Communications Electronics	
334511	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing
336411	Aircraft Manufacturing
336412	Aircraft Engine and Engine Parts Manufacturing
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing
336414	Guided Missile and Space Vehicle Manufacturing
336415	Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts Manufacturing
336419	Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing
Bioscience Manufacturing	
311221	Wet Corn Milling
311222	Soybean Processing
311223	Other Oilseed Processing
311224	Soybean and Other Oilseed Processing
325193	Ethyl Alcohol Manufacturing
325221	Cellulosic Organic Fiber Manufacturing
325311	Nitrogenous Fertilizer Manufacturing
325312	Phosphatic Fertilizer Manufacturing
325314	Fertilizer (Mixing Only) Manufacturing
325320	Pesticide and Other Agricultural Chemical Manufacturing
325411	Medicinal and Botanical Manufacturing
325412	Pharmaceutical Preparation Manufacturing
325413	In-Vitro Diagnostic Substance Manufacturing
325414	Biological Product (except Diagnostic) Manufacturing
334510	Electromedical and Electrotherapeutic Apparatus Manufacturing
334516	Analytical Laboratory Instrument Manufacturing

NAICS Code	NAICS Description
334517	Irradiation Apparatus Manufacturing
339112	Surgical and Medical Instrument Manufacturing
339113	Surgical Appliance and Supplies Manufacturing
339114	Dental Equipment and Supplies Manufacturing
Building, Construction, and Furniture Products	
321113	Sawmills
321114	Wood Preservation
321211	Hardwood Veneer and Plywood Manufacturing
321212	Softwood Veneer and Plywood Manufacturing
321213	Engineered Wood Member (except Truss) Manufacturing
321214	Truss Manufacturing
321219	Reconstituted Wood Product Manufacturing
321911	Wood Window and Door Manufacturing
321912	Cut Stock, Resawing Lumber, and Planing
321918	Other Millwork (including Flooring)
324122	Asphalt Shingle and Coating Materials Manufacturing
326122	Plastics Pipe and Pipe Fitting Manufacturing
326191	Plastics Plumbing Fixture Manufacturing
326192	Resilient Floor Covering Manufacturing
327120	Clay Building Material and Refractories Manufacturing
327121	Brick and Structural Clay Tile Manufacturing
327122	Ceramic Wall and Floor Tile Manufacturing
327123	Other Structural Clay Product Manufacturing
327211	Flat Glass Manufacturing
327215	Glass Product Manufacturing Made of Purchased Glass
327310	Cement Manufacturing

NAICS Code	NAICS Description
327320	Ready-Mix Concrete Manufacturing
327331	Concrete Block and Brick Manufacturing
327332	Concrete Pipe Manufacturing
327390	Other Concrete Product Manufacturing
327420	Gypsum Product Manufacturing
327991	Cut Stone and Stone Product Manufacturing
332311	Prefabricated Metal Building and Component Manufacturing
332312	Fabricated Structural Metal Manufacturing
332321	Metal Window and Door Manufacturing
332323	Ornamental and Architectural Metal Work Manufacturing
332913	Plumbing Fixture Fitting and Trim Manufacturing
335121	Residential Electric Lighting Fixture Manufacturing
335122	Commercial, Industrial, and Institutional Electric Lighting Fixture Manufacturing
337110	Wood Kitchen Cabinet and Countertop Manufacturing
337121	Upholstered Household Furniture Manufacturing
337122	Nonupholstered Wood Household Furniture Manufacturing
337124	Metal Household Furniture Manufacturing
337125	Household Furniture (except Wood and Metal) Manufacturing
337127	Institutional Furniture Manufacturing
337129	Wood Television, Radio, and Sewing Machine Cabinet Manufacturing
337211	Wood Office Furniture Manufacturing
337212	Custom Architectural Woodwork and Millwork Manufacturing
337214	Office Furniture (except Wood) Manufacturing
337215	Showcase, Partition, Shelving, and Locker Manufacturing
337910	Mattress Manufacturing
337920	Blind and Shade Manufacturing

NAICS Code	NAICS Description
Consumer Motor Vehicles and Parts	
336111	Automobile Manufacturing
336112	Light Truck and Utility Vehicle Manufacturing
336213	Motor Home Manufacturing
336214	Travel Trailer and Camper Manufacturing
336310	Motor Vehicle Gasoline Engine and Engine Parts Manufacturing
336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing
336312	Gasoline Engine and Engine Parts Manufacturing
336320	Motor Vehicle Electrical and Electronic Equipment Manufacturing
336321	Vehicular Lighting Equipment Manufacturing
336322	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing
336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing
336340	Motor Vehicle Brake System Manufacturing
336350	Motor Vehicle Transmission and Power Train Parts Manufacturing
336360	Motor Vehicle Seating and Interior Trim Manufacturing
336370	Motor Vehicle Metal Stamping
336390	Other Motor Vehicle Parts Manufacturing
336391	Motor Vehicle Air-Conditioning Manufacturing
336399	All Other Motor Vehicle Parts Manufacturing
Food Production	
311111	Dog and Cat Food Manufacturing
311119	Other Animal Food Manufacturing
311211	Flour Milling
311212	Rice Milling
311213	Malt Manufacturing
311225	Fats and Oils Refining and Blending

NAICS Code	NAICS Description
311230	Breakfast Cereal Manufacturing
311311	Sugarcane Mills
311312	Cane Sugar Refining
311313	Beet Sugar Manufacturing
311314	Cane Sugar Manufacturing
311320	Chocolate and Confectionery Manufacturing from Cacao Beans
311330	Confectionery Manufacturing from Purchased Chocolate
311340	Nonchocolate Confectionery Manufacturing
311351	Chocolate and Confectionery Manufacturing from Cacao Beans
311352	Confectionery Manufacturing from Purchased Chocolate
311411	Frozen Fruit, Juice, and Vegetable Manufacturing
311412	Frozen Specialty Food Manufacturing
311421	Fruit and Vegetable Canning
311422	Specialty Canning
311423	Dried and Dehydrated Food Manufacturing
311511	Fluid Milk Manufacturing
311512	Creamery Butter Manufacturing
311513	Cheese Manufacturing
311514	Dry, Condensed, and Evaporated Dairy Product Manufacturing
311520	Ice Cream and Frozen Dessert Manufacturing
311611	Animal (except Poultry) Slaughtering
311612	Meat Processed from Carcasses
311613	Rendering and Meat Byproduct Processing
311615	Poultry Processing
311710	Seafood Product Preparation and Packaging
311711	Seafood Canning

NAICS Code	NAICS Description
311712	Fresh and Frozen Seafood Processing
311811	Retail Bakeries
311812	Commercial Bakeries
311813	Frozen Cakes, Pies, and Other Pastries Manufacturing
311821	Cookie and Cracker Manufacturing
311822	Flour Mixes and Dough Manufacturing from Purchased Flour
311823	Dry Pasta Manufacturing
311824	Dry Pasta, Dough, and Flour Mixes Manufacturing from Purchased Flour
311830	Tortilla Manufacturing
311911	Roasted Nuts and Peanut Butter Manufacturing
311919	Other Snack Food Manufacturing
311920	Coffee and Tea Manufacturing
311930	Flavoring Syrup and Concentrate Manufacturing
311941	Mayonnaise, Dressing, and Other Prepared Sauce Manufacturing
311942	Spice and Extract Manufacturing
311991	Perishable Prepared Food Manufacturing
311999	All Other Miscellaneous Food Manufacturing
312111	Soft Drink Manufacturing
312112	Bottled Water Manufacturing
312113	Ice Manufacturing
312120	Breweries
312130	Wineries
312140	Distilleries
322130	Paperboard Mills
322211	Corrugated and Solid Fiber Box Manufacturing
322212	Folding Paperboard Box Manufacturing

NAICS Code	NAICS Description
322213	Setup Paperboard Box Manufacturing
322214	Fiber Can, Tube, Drum, and Similar Products Manufacturing
322215	Nonfolding Sanitary Food Container Manufacturing
322219	Other Paperboard Container Manufacturing
322220	Paper Bag and Coated and Treated Paper Manufacturing
322221	Coated and Laminated Packaging Paper Manufacturing
322222	Coated and Laminated Paper Manufacturing
322223	Coated Paper Bag and Pouch Manufacturing
322224	Uncoated Paper and Multiwall Bag Manufacturing
322225	Laminated Aluminum Foil Manufacturing for Flexible Packaging Uses
322226	Surface-Coated Paperboard Manufacturing
326111	Plastics Bag and Pouch Manufacturing
326112	Plastics Packaging Film and Sheet (including Laminated) Manufacturing
326140	Polystyrene Foam Product Manufacturing
326160	Plastics Bottle Manufacturing
327213	Glass Container Manufacturing
332431	Metal Can Manufacturing
333241	Food Product Machinery Manufacturing
333294	Food Product Machinery Manufacturing
333993	Packaging Machinery Manufacturing
Other Fabricated Metals Manufacturing	
332111	Iron and Steel Forging
332112	Nonferrous Forging
332114	Custom Roll Forming
332115	Crown and Closure Manufacturing
332116	Metal Stamping

NAICS Code	NAICS Description
332117	Powder Metallurgy Part Manufacturing
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)
332211	Cutlery and Flatware (except Precious) Manufacturing
332212	Hand and Edge Tool Manufacturing
332213	Saw Blade and Handsaw Manufacturing
332214	Kitchen Utensil, Pot, and Pan Manufacturing
332215	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing
332216	Saw Blade and Handtool Manufacturing
332313	Plate Work Manufacturing
332322	Sheet Metal Work Manufacturing
332410	Power Boiler and Heat Exchanger Manufacturing
332420	Metal Tank (Heavy Gauge) Manufacturing
332439	Other Metal Container Manufacturing
332510	Hardware Manufacturing
332611	Spring (Heavy Gauge) Manufacturing
332612	Spring (Light Gauge) Manufacturing
332613	Spring Manufacturing
332618	Other Fabricated Wire Product Manufacturing
332710	Machine Shops
332721	Precision Turned Product Manufacturing
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing
332811	Metal Heat Treating
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring
332991	Ball and Roller Bearing Manufacturing

NAICS Code	NAICS Description
332992	Small Arms Ammunition Manufacturing
332993	Ammunition (except Small Arms) Manufacturing
332994	Small Arms, Ordnance, and Ordnance Accessories Manufacturing
332995	Other Ordnance and Accessories Manufacturing
332996	Fabricated Pipe and Pipe Fitting Manufacturing
332997	Industrial Pattern Manufacturing
332998	Enameled Iron and Metal Sanitary Ware Manufacturing
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing
Primary Metals Manufacturing	
331110	Iron and Steel Mills and Ferroalloy Manufacturing
331111	Iron and Steel Mills
331112	Electrometallurgical Ferroalloy Product Manufacturing
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
331221	Rolled Steel Shape Manufacturing
331222	Steel Wire Drawing
331311	Alumina Refining
331312	Primary Aluminum Production
331313	Alumina Refining and Primary Aluminum Production
331314	Secondary Smelting and Alloying of Aluminum
331315	Aluminum Sheet, Plate, and Foil Manufacturing
331316	Aluminum Extruded Product Manufacturing
331318	Other Aluminum Rolling, Drawing, and Extruding
331319	Other Aluminum Rolling and Drawing
331410	Nonferrous Metal (except Aluminum) Smelting and Refining
331411	Primary Smelting and Refining of Copper
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)

NAICS Code	NAICS Description
331420	Copper Rolling, Drawing, Extruding, and Alloying
331421	Copper Rolling, Drawing, and Extruding
331422	Copper Wire (except Mechanical) Drawing
331423	Secondary Smelting, Refining, and Alloying of Copper
331491	Nonferrous Metal (except Copper and Aluminum) Rolling, Drawing, and Extruding
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)
331511	Iron Foundries
331512	Steel Investment Foundries
331513	Steel Foundries (except Investment)
331521	Aluminum Die-Casting Foundries
331522	Nonferrous (except Aluminum) Die-Casting Foundries
331523	Nonferrous Metal Die-Casting Foundries
331524	Aluminum Foundries (except Die-Casting)
331525	Copper Foundries (except Die-Casting)
331528	Other Nonferrous Foundries (except Die-Casting)
331529	Other Nonferrous Metal Foundries (except Die-Casting)
Miscellaneous Manufacturing NEC	
This subsector includes all other manufacturing NAICS codes "not elsewhere classified" (NEC).	

Manufacturing Patent Analysis: Supporting Tables

TABLE A-2: IOWA MANUFACTURING-RELATED PATENTS BY TECHNOLOGY AREA (APPLICATIONS AND AWARDED), 2015-2019

Technology Area	Iowa-Invented Applications	Iowa-Invented Awarded	Total Iowa-Invented Apps & Awarded
Finished Products	343	584	927
Engineering (Design & Systems)	**227**	**600**	**827**
Sensors & Instrumentation	**101**	**424**	**525**
Vehicles	106	294	400
Construction	81	197	278
Electronics	19	175	194
Tools, Machining, & Materials	56	78	134
Processes	50	71	121
Handling, Packaging, & Storage	20	90	110
Information Technology & Digital Systems	8	94	102
Communications Systems	4	90	94
Data Processing & Analytics	22	67	89
Networking Systems	6	79	85
Chemistry	16	36	52
Other Tech Areas	9	42	51
Mining	14	25	39
Metallurgy	4	8	12
Total	1,086	2,954	4,040

Note: Bold, shaded patent classes indicate technology areas closely aligned with Industry 4.0.
Source: TEConomy analysis of Clarivate Analytics' Derwent Innovation patent analysis database.

TABLE A-3: IOWA MANUFACTURING-RELATED PATENTS BY ASSIGNEE COMPANY (APPLICATIONS AND AWARDED), 2015-2019 (30 OR MORE PATENT APPLICATIONS AND/OR AWARDS)

Iowa Company (those with 30 or more combined applications and awards)	**Iowa-Invented Applications**	**Iowa-Invented Awarded**	**Total Iowa-Invented Apps & Awarded**
Deere & Company	432	812	1,244
Rockwell Collins Inc.	9	576	585
Fisher Controls International LLC	92	242	334
Delavan Inc	68	80	148
Vermeer Manufacturing Company	56	84	140
CNH Industrial America LLC	23	94	117
Whirlpool Corporation	15	76	91
Kinze Manufacturing Inc.	24	55	79
Rite-Hite Holding Corporation	6	67	73
Musco Corporation	5	42	47
Unverferth Manufacturing Company Inc.	6	32	38
Kemin Industries Inc.	20	18	38
Intermec Inc.	4	32	36
Bridgestone Bandag LLC	16	16	32
AGCO Corporation	12	19	31
Pella Corporation	15	16	31

Source: TEConomy analysis of Clarivate Analytics' Derwent Innovation patent analysis database.


TECONOMY
PARTNERS LLC