The Future is Now, Realizing the Promise of Industry 4.0:

A Strategic Plan to Ensure a Competitive Future for Manufacturing in Maryland

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EXECUTIVE SUMMARY

Manufacturing in Maryland is an often-overlooked sector contributing to Maryland's leading advanced industrial base. While manufacturing is not as highly concentrated in Maryland as in other states, the industry is a foundational pillar of the state's economy that consistently generates high-paying, family-sustaining jobs, drives wealth generation and economic growth through intensive exports, and adds high value through innovative product development. State manufacturers serve diverse global markets in food and agribusiness, protect the nation and serve strategic interests in aerospace and defense systems, improve quality of life in biopharmaceutical and vaccine production, and build homes by delivering high-quality wood products. These are just some of the areas in which more than one hundred thousand Marylanders contribute their skills and expertise each day across each region in the state.

For Maryland manufacturing to remain competitive and continue to drive outsized economic and innovation returns for the state and its residents, the industry must be prepared to embrace a digital future. Manufacturers globally are both preparing for and already implementing a digital transformation toward "smart" manufacturing that will have vast implications for industry competitiveness. This transformation is so significant that some have heralded its arrival as the Fourth Industrial Revolution, or "Industry 4.0." While the earlier 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.

Maryland's Manufacturing Industry Represents:

- 109,000 jobs across all regions with avg. wages of nearly $84,000
- 4,170 business establishments
- $27.6 Billion in GSP
- $9.1 Billion in employee compensation
- $39.8 Billion in annual exports
- 7 diverse clusters, markets served
- Major innovation driver: accounts for 10% of GSP but 75% of industrial R&D

Source: TEConomy Partners' analysis of Emsi, 2021.2 data sets.

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. Recognizing the stakes, the Maryland Manufacturing Extension Partnership, or MD MEP, has commissioned this strategic plan to guide and advance both the near- and longer-term competitiveness and growth of Maryland manufacturing against this backdrop of intensive digitization.

SETTING THE CONTEXT:
AN IMPACTFUL INDUSTRY FOR MARYLAND HAS STABILIZED, BUT COMPETITIVE CHALLENGES REMAIN

Manufacturing in Maryland contributes nearly $28 billion to the state's Gross State Product (GSP) and comprises a highly diverse subset of industry clusters. The clusters illustrate the breadth of products manufactured across the state and the varied global markets served, including:

- **Aerospace & Defense Systems**
- **Food & Beverage**
- **Life Sciences**
- **Polymers & Related Products**
- **Precision Manufacturing**
- **Printing & Packaging**
- **Wood Products**

Manufacturing is active across each of Maryland's four geographic regions. Its footprint, like the state's population, is largest in Central Maryland (57% of all jobs) but extends outward in all directions. Although Eastern and Western Maryland have lower employment levels, manufacturing represents a somewhat greater share and importance to their overall economies, as illustrated by employment concentrations closer to national averages (location quotients closer to 1.0). Each region contributes its own unique companies, innovations, and key products to the markets it serves.

While manufacturing is an important economic driver across the state, manufacturing is less concentrated in Maryland relative to the national average. But what Maryland may lack in the overall size or concentration of its manufacturing base relative to other states, it makes up for by punching above its weight in terms of worker productivity and industrial research and development.

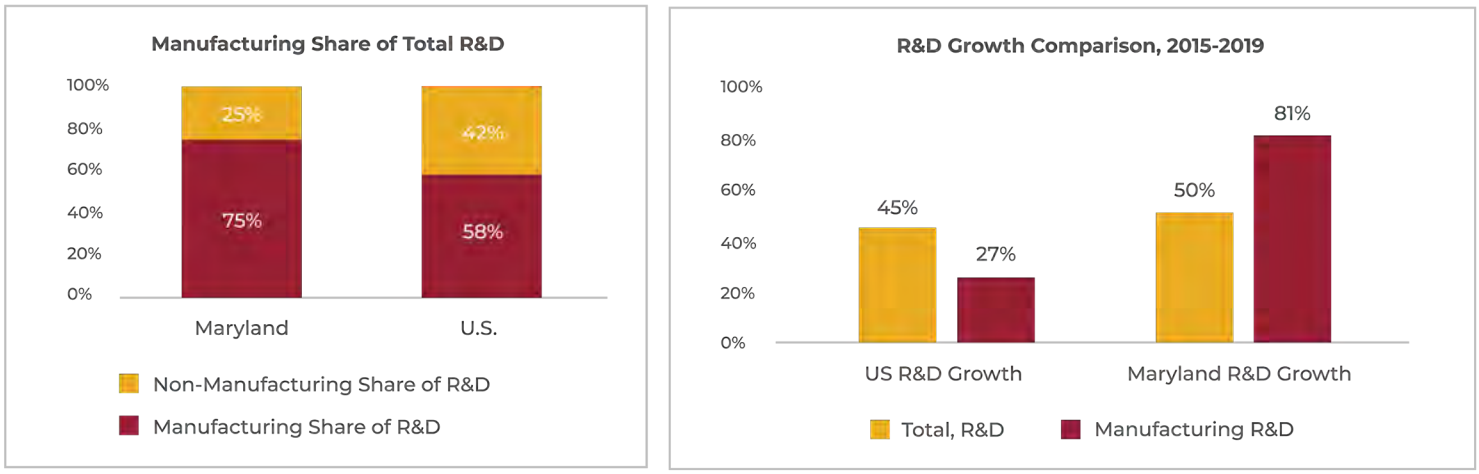
On average, Maryland manufacturing workers produced more than $250,000 in value-added activity per worker in 2020. High value-added per worker is a measure of productivity in manufacturing, along with enhanced quality and features of products being produced, and therefore is highly dependent on the successful deployment of technology. In recent years, Maryland has not only surpassed the level of productivity seen nationally (nearly $191,000), but has grown at a faster rate than the nation. This is further evident in manufacturing accounting for 10% of GSP in Maryland while utilizing just 5% of the state's labor force. Across Maryland's diverse manufacturing base, all of its clusters, with the exception of printing and packaging, have average productivity levels exceeding the national average. So, while Maryland is undersized in manufacturing employment, it stands out in manufacturing productivity across its diverse industry base.

At $3.2 billion, Maryland manufacturers account for three-quarters of the state's annual total industrial R&D expenditures, led by the life sciences and aerospace and defense clusters. Industrial R&D investment is one key metric of innovation activity and often provides an additional glimpse at Industry 4.0 potential, as innovative firms are much more likely to adopt or consider digital automation solutions.

Maryland Manufacturing plays an outsized role as an innovation engine for the state—the sector represents 10% of GSP but accounts for 75% of industrial research and development ($3.2 Billion).

As shown in Figure ES-1, Maryland's industry R&D base found in manufacturing is both a higher share than the national average and is also growing much faster than the national average.

Figures ES-1: Manufacturing Share of Total Industrial R&D and Recent Growth, Maryland and U.S., 2019



Source: TEConomy analysis of National Science Foundation, Business R&D Survey data, 2015 & 2019 (most recent year available).

In the academic R&D space, Maryland represents a leading state in science and engineering R&D, and many of these activities are concentrated in key fields relevant for Industry 4.0. In fields most closely relevant for Industry 4.0 solutions development, Maryland's $1.32 billion in 2020 R&D expenditures is highly concentrated and "specialized"—representing 28% of University R&D in Maryland compared to 11% across the nation overall.[1] R&D activities in these fields are growing as well and outpacing the nation since 2015. Maryland universities represent an important and leading source of both innovation and talent development relevant for Industry 4.0 adoption, and collaborations and partnerships with Maryland's manufacturing community are critical for seizing a competitive edge.

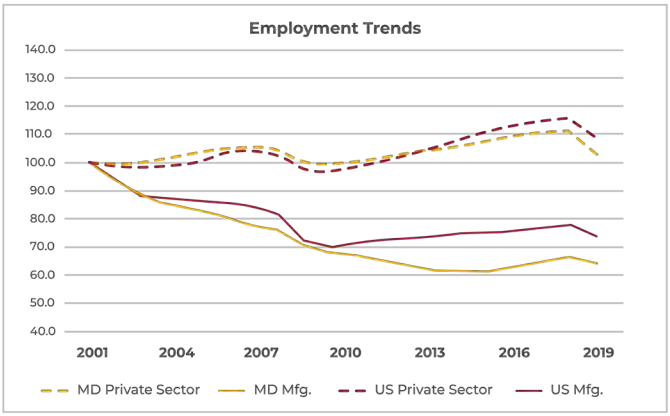
Maryland's ability to compete based on higher productivity and industry R&D is generating positive results in recent years, and offsets the state's higher costs of doing business in manufacturing:

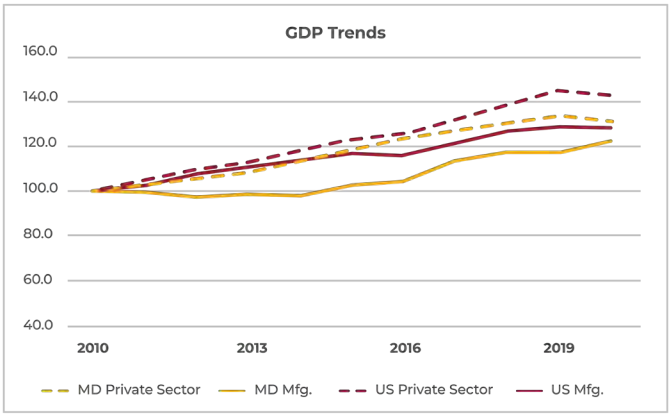
- **Maryland has slightly outpaced U.S. manufacturing employment and GDP growth since 2015, but this recent trend is a stabilization of the industry following years of steeper employment declines and lagging output growth for the state** (see Figure ES-2). Over the last two decades, Maryland manufacturing has struggled with lagging GSP growth and steady, rapid declines in its employment base. While industry employment has stabilized and GSP growth has increased its pace in recent years, the industry has clearly faced longer-term competitiveness challenges and contraction—a key context as to why Industry 4.0 adoption will matter for state competitiveness.

- **This growth in manufacturing is found broadly across the state's diverse manufacturing base.** Five of the seven manufacturing industry clusters found in Maryland have grown in employment since 2015, and four of those five experienced double-digit growth rates despite the inclusion of the challenging 2020 COVID-19 year.

[1]Relevant fields identified by TEConomy include electrical, electronic, and communications engineering; computer and information sciences; mechanical engineering; mathematics and statistics; and industrial and manufacturing engineering.

Figures ES-2: Maryland Manufacturing has Seen Long-Term Competitiveness Challenges that it has Recently Reversed—Manufacturing Employment & GSP Average Annual Growth Trends, 2001-20, 2010-20





Source: TEConomy Partners' analysis of Emsi Q2 2021 data set.

Maryland manufacturing has effectively stabilized in recent years, but its longer-term competitive challenges cannot be ignored. The state industry has seen many years of declining employment and lagging output growth. And for a state sector that competes on its productivity and innovation edge, the current and impending digitization wave in the form of Industry 4.0 must be a key pillar and focus for the industry to effectively compete into the future.

HOW IS MARYLAND POSITIONED FOR INDUSTRY/MANUFACTURING 4.0?

Industry 4.0 has significant implications for Maryland's competitive advantages in productivity and innovative product development. The essence of Industry 4.0 is a transformational change in the manufacturing production process, as well as in product design and development, through the digitization of manufacturing activities. Maryland cannot afford to fall behind or be excluded from the national leaders in Industry 4.0, as it risks the state's competitive edge in sustaining growth in manufacturing across its diverse base.

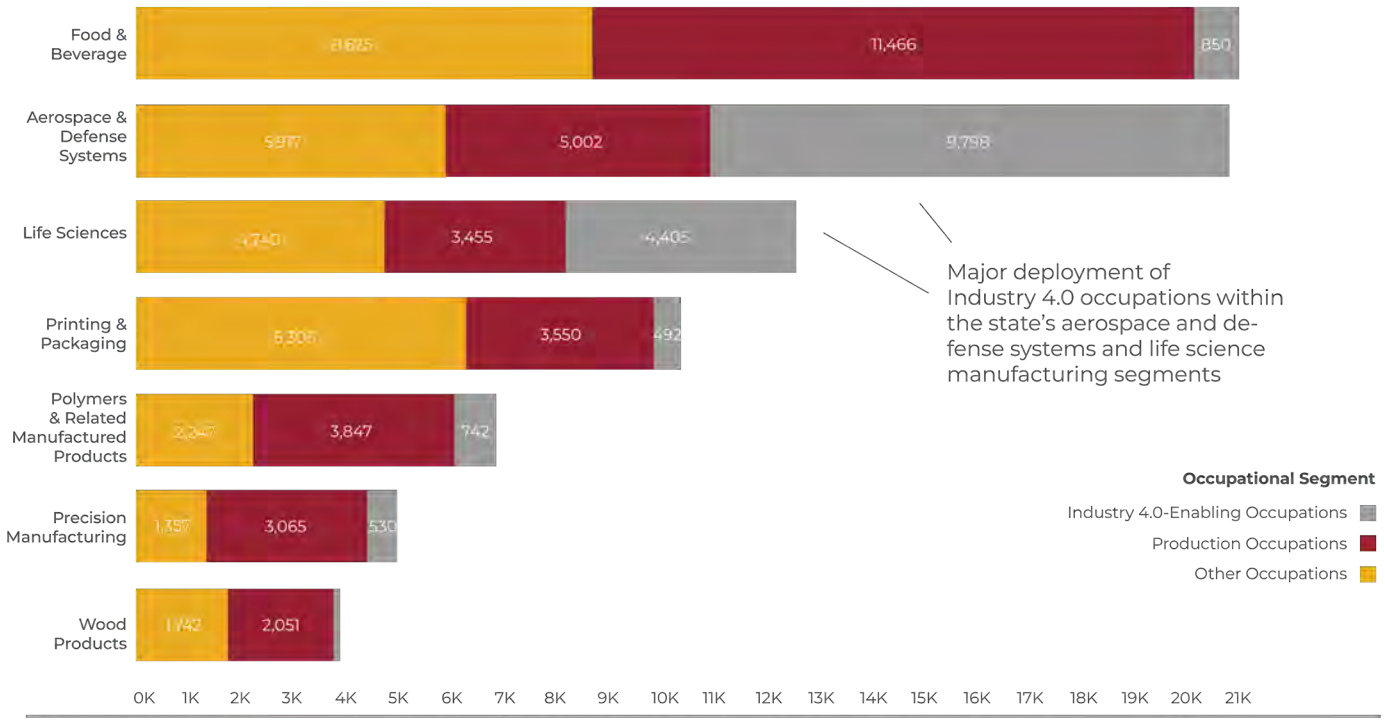
A series of quantitative analyses, combined with situational interviews and group discussions with manufacturing leaders and other industry stakeholders, finds that Maryland has assets to leverage in adopting Industry 4.0 technologies; however, like other manufacturing ecosystems, it faces significant challenges and barriers.

Maryland's manufacturing workforce is particularly concentrated in what can be referred to as an *Industry 4.0-enabling* workforce—a set of occupational groups and roles spanning computer and data sciences to engineers and technicians critical for assessing, designing, implementing, and deploying digital technologies and resulting data streams for smart automation. **Maryland's Industry 4.0-enabling occupational employment share of its overall manufacturing industry is significantly higher than that of the nation's—21% of the sector's workforce versus 13% of the nation's.** Although this represents a smaller share of manufacturing relative to the industry's large production workforce, these one-in-five workers have grown their share of the industry's workforce at roughly twice the rate of the nation's since 2015.

Not all manufacturing clusters, however, are well-positioned with respect to this critical workforce—among the seven, two stand well above their counterparts, both in Maryland and nationally, in their concentration and deployment of Industry 4.0-enabling talent: 1) aerospace and defense systems and 2) life sciences (Figure ES-3). Aerospace and defense systems is reliant on engineering talent (37% of Industry 4.0-related employment) but is still driven by a well-distributed mix of additional Industry 4.0-enabling occupations, ranging from computing and IT to business analytics. Life sciences, on the other hand, leverages a large scientific workforce (38% of Industry 4.0-related employment) and represents a unique context, as most manufacturing industries have lower concentrations of scientific occupations relative to traditional engineering.

Maryland has an overall competitive advantage in its enabling talent situation—but is it a tale of two "tiers," with aerospace and defense and life sciences well-positioned to adopt and integrate Industry 4.0, while other clusters struggle? Although not all sectors can expect the same level of adoption, it will be important to "lift all boats" among clusters when considering strategic interventions and support.

Figure ES-3: Industry 4.0-Enabling Occupational Employment within Maryland's Manufacturing Clusters, 2020



Maryland Employment in Manufacturing Industries, 2020

Source: TEConomy analysis of industry staffing patterns data from Emsi (Emsi Release 2021.2).

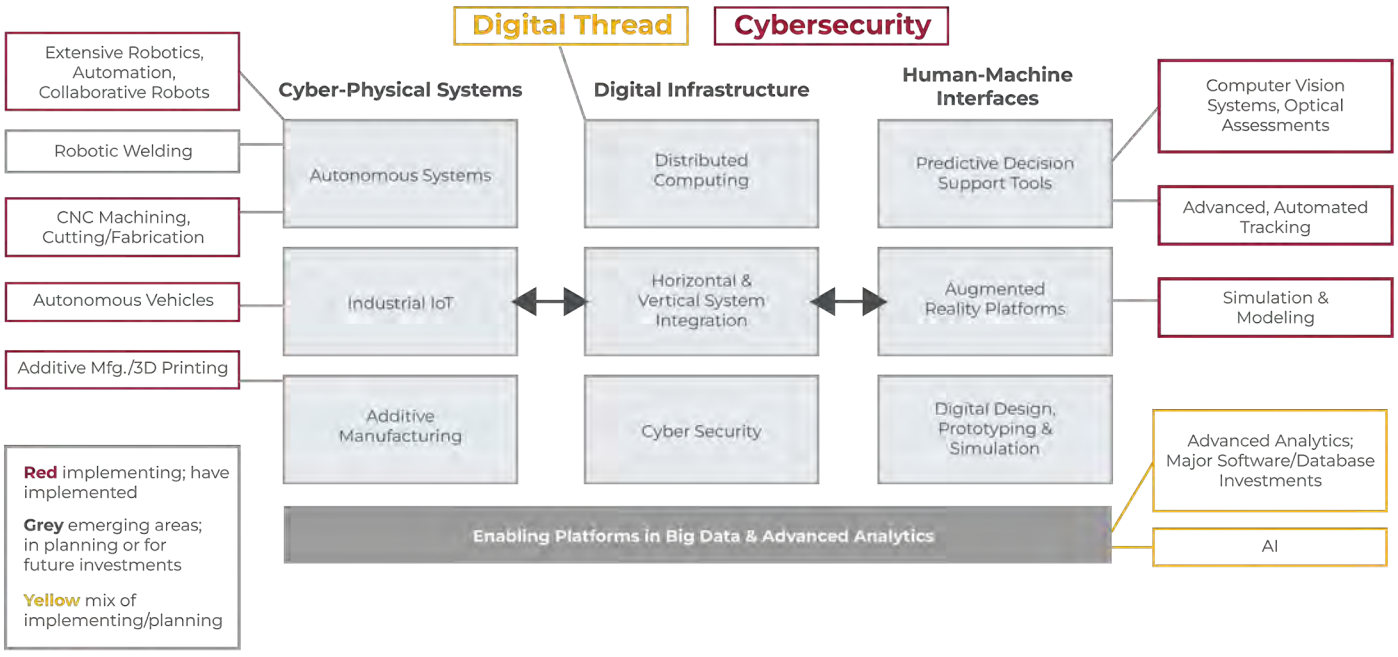
The challenge for Maryland will be the inevitable strain on the supply of this skilled workforce critical for Manufacturing 4.0 adoption. Manufacturers face an especially competitive and challenging workforce landscape in attracting and retaining Industry 4.0-enabling jobs due to the combined challenges of limited supply; high demand from, and competition with, other tech-driven industries for talent; and relatively large cohorts of existing workers likely to require "up-skilling."

The Situation for Industry 4.0 Technology Adoption/Integration in Maryland: Primarily Discrete Implementation, Companies Point to Several Consistent Challenges, Barriers

Maryland manufacturing leaders are adopting and integrating numerous technologies and capabilities squarely in the digital automation and Industry 4.0 context; however, this adoption, particularly among small- and mid-sized manufacturers or enterprises (SME) manufacturers, is most often discrete and not more broadly integrated to realize the full capabilities and data-driven insights of a 4.0 environment. Interviews indicate a generally low adoption rate of integrated industry automation and 4.0 technologies and suggest that Maryland is lagging behind as a state. Maryland manufacturing SMEs today typically use discrete individual technologies (e.g., a 3D printer, virtual reality simulation, robotic welding equipment) but are not yet implementing multi-technology, digitally integrated systems that harness the full potential of Industry 4.0 advances and data-driven insights.

Figure ES-4 maps the types of Industry 4.0 technologies being adopted in Maryland today and in the near future. It is important to note that these technologies are pulled from interviews with state manufacturers, and therefore are not an exhaustive survey or inventory of Maryland manufacturing. The technologies and capabilities mapped to the outer edges of Figure 4 were assigned a color based on the implementation status described by the companies interviewed.

Figure ES-4: Types of Industry 4.0 Technologies Being Adopted/Integrated in Maryland Today and in Near-Future (Based on Maryland Manufacturing Interviews, Not an Exhaustive Inventory)



Source: TEConomy Partners, LLC.

Common Barriers & Challenges to Industry 4.0 Technology Adoption

At the crux of this strategic planning effort, and one of its primary objectives, is assisting Maryland manufacturers in addressing major challenges and barriers to increased technology adoption—effectively answering, how do we help to "de-risk" technology adoption, particularly for SME manufacturers? It is therefore important to consider the consistent themes raised regarding these barriers (Figure ES-5):

Maryland SME manufacturers have few resources to leverage to start the Industry 4.0 journey. Companies interviewed cited a general lack of resources and expertise to help them know where to start and what is most appropriate for their firm. A major theme in these discussions centered around firms' interest in and need to test, pilot, and demonstrate 4.0-related technologies before making individual investments or trying to implement digital solutions at scale.

The significant costs associated with digital technology investments and their integration with legacy IT systems represents another major hurdle, particularly for SMEs, but also for large manufacturers. And although pricing a particular piece of equipment or software package may be relatively easy, more challenging for firms working to understand the big picture is understanding the return on that investment. A key resource for manufacturers currently lacking in Maryland is a database or repository of Industry 4.0 "use cases"—real-world examples and experiences of manufacturers that are implementing technologies and driving them to scale—to help their counterparts understand the ROI and payback on digital investments.

Implementing Industry 4.0 technologies has major implications for the industry's workforce, both in terms of incumbents and new hires. Maryland manufacturers are experiencing a broad-based need for employees with enhanced digital skills, as well as for additional IT specialists, data scientists, and professional engineers, technicians, and scientists who have hybrid expertise. This hybrid expertise takes the form of mechanical engineers who are, as one manufacturer emphasized, "both mechanically and tech competent," such as industrial engineers with some data sciences knowledge and expertise. Thus, there are needs for both education and training resources to upskill the existing manufacturing workforce that are flexible and very focused, while continuing to generate the core talent that maps to "enabling" roles.

Enabling 4.0 tech adoption by addressing foundational technologies and technology infrastructure for interoperability and systems integration. A dynamic Industry 4.0 operating environment is not simply "plug and play;" it requires addressing the integration of new machinery and services into existing operations. Often, manufacturers face the challenge of integrating new smart solutions in an environment where numerous legacy software systems and hardware components must now communicate with each other, send data, and connect with cloud-based services.

Figure ES-5: Major Barriers Identified by Maryland Manufacturers to Adopting Industry 4.0 Technologies

RECOMMENDED STRATEGIES AND ACTIONS TO ENSURE A COMPETITIVE FUTURE FOR MARYLAND MANUFACTURING

The key findings from this effort, including those from both the baseline quantitative and situational analyses, point to four strategic priorities on which to organize and focus the recommended strategies and actions of the Plan. These include:

1. **Establishing resources for starting the Industry 4.0 journey for Maryland manufacturers.**
2. **Addressing the barriers and challenges to Industry 4.0 technology adoption and integration.**
3. **Strengthening intra-state supply chain connections.**
4. **Seizing emerging manufacturing industry and market opportunities.**

Combined, these strategic priorities are aligned with the overall project goals and objectives and draw from the key findings. A set of recommended strategies and actions are aligned with each priority area for the state and its manufacturing leaders and stakeholders to consider, and are summarized in Figure ES-6.

Figure ES-6: Summary of Recommended Strategies and Actions to Ensure a Competitive Future for Maryland Manufacturing

1. Establishing resources for starting the Industry 4.0 journey for Maryland manufacturers.

Action 1.1: Offer Manufacturing 4.0-specific assessments and facilitation for Maryland SMEs.

Action 1.2: Invest in and support a Maryland Manufacturing 4.0 Tech Demonstration and Training Lab primarily targeted toward SMEs.

Action 1.3: Catalogue and showcase "Use Cases" in communicating the ROI and the journey for other manufacturers that have successfully implemented Industry 4.0 technologies and to assist in making the business case for investments.

Action 1.4: Provide assessment and informational resources for systems integration and addressing interoperability challenges.

Action 1.5: Implement regular survey efforts to gauge progress on Industry 4.0 adoption among Maryland SMEs.

2. Addressing the barriers and challenges to Industry 4.0 technology adoption and integration.

Action 2.1: Develop and deploy a state incentives program—The Maryland Manufacturing Innovation Fund — to de-risk and address cost challenges for SMEs to invest in digital, Manufacturing 4.0 Technologies.

Action 2.2: Build awareness among Maryland manufacturers of existing state incentives and programs, particularly those which are applicable to Industry 4.0 investments and workforce and talent development.

Action 2.3: Advance broad-based assistance and strategic partnerships in addressing cybersecurity threats to manufacturers.

Action 2.4: Support both upskilling and broad-based training of Maryland's Manufacturing workforce — both among incumbent workers and across the education pipeline—at an appropriate scale for impending rise of Industry 4.0.

3. Strengthening intra-state supply chain connections.

Action 3.1: Develop Maryland supply chain mapping and directory resources for targeted manufacturing clusters.

Action 3.2: Incent, promote in-state supply chain connections, sourcing, purchasing

Action 3.3: Proactively pursue potential "reshoring" opportunities in targeted industries.

4. Seizing emerging manufacturing industry and market opportunities.

Action 4.1: Increase engagement between MD MEP and the Maryland life sciences cluster leveraging strategic partnerships and collaborations with life sciences-focused state organizations and strategic life sciences assets.

Action 4.2: Identify and seize Federal procurement opportunities for Maryland manufacturers.

It is envisioned that MD MEP will play a lead role in many of these strategic interventions, but effective partnerships are vital for implementation, as many recommendations require collaboration with state government agencies (e.g., Departments of Commerce and Labor), Maryland research universities and community colleges, industry associations, and others across the ecosystem.

What was once considered futuristic digital transformation is now very much in the forefront for global manufacturing competitiveness. For Maryland manufacturers considering Industry 4.0 solutions—the future is now.

INTRODUCTION: A FOUNDATION OF MARYLAND'S ECONOMY PREPARES FOR DIGITAL TRANSFORMATION

Maryland's economic and innovation reputation in areas such as IT and cyber, leading-edge life sciences research, and its extensive federal government complex typically overshadow its rich history in, and the outsized innovation contributions from, manufacturing. Manufacturing in Maryland is an often-overlooked sector contributing to Maryland's leading advanced industrial base. While it is true that manufacturing is not highly concentrated in Maryland as in other states, what is often missed is that manufacturing in Maryland has long represented a foundational pillar and significant contributor to the state economy in the form of high-paying, family-sustaining jobs, wealth generation and economic growth through exports and innovative product development. State manufacturers serve global markets in food and agribusiness, protect the nation and serve strategic interests in aerospace and defense systems, improve quality of life in biopharmaceutical and vaccine production, and build homes by delivering high-quality wood products. These are just some of the areas in which more than one hundred thousand Marylanders contribute their skills and expertise each day across each region of the state.

As the leading champion for state manufacturers, the Maryland Manufacturing Extension Partnership, or MD MEP, understands these contributions and the strategic importance of the sector and works every day to ensure its competitiveness. MD MEP, which is part of the national network of state MEP programs, is primarily focused on serving small- and mid-sized manufacturers or enterprises (SMEs, defined as having 500 or fewer employees) across all subsectors and markets of the industry. The organization carries out this mission through an array of programs and services designed to enhance the efficiency and profitability of manufacturing operations and ultimately to create jobs and growth opportunities for Maryland. MD MEP considers the broader ecosystem in which its constituent companies operate, as well as their needs that span workforce and talent, technology and innovation, supply chain solutions, continuous process improvements, and overall market growth strategies.

MD MEP Drives Significant Impacts for Maryland Manufacturers

As a result of its engagements with state manufacturers, MD MEP clients report the following impacts since 2013:

- $954M of economic impacts including new sales, savings, and investments
- More than 6,400 jobs created or retained

Source: Maryland MEP.

MD MEP has contributed to and seen encouraging signs of turnaround in Maryland manufacturing in recent years, with strong job and output growth that has outpaced the nation. The industry continues to punch above its weight in productivity and innovation activity, as manufacturing contributes 10% to state GSP and accounts for 75% of its total industrial research and development, while only employing 5% of the state's workforce. But there have been longer-term competitiveness challenges as Maryland has for many years lagged its counterparts nationally in employment and output growth and, like those counterparts, is experiencing a new dynamic of painful labor and supply chain shocks during the COVID-19 pandemic.

Looking forward, a significant transformational change is rapidly unfolding across manufacturing that poses both opportunities and challenges for the long-term competitiveness of Maryland's manufacturing sector. The transformation involves the intensive digitization of manufacturing operations, often referred to as Industry 4.0. The capabilities of Industry 4.0 technologies represent a paradigm shift so significant industry experts have referred to it as the arrival of the "Fourth Industrial Revolution." 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.

Digital industrial technology is transforming the modern global manufacturing sector, with major implications for industry competitiveness. 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.

MD MEP engaged TEConomy Partners, LLC (TEConomy) to develop a Strategic Plan for manufacturing to guide and advance both near- and longer-term competitiveness and growth of Maryland manufacturing that leverage the promise of Industry 4.0 technologies. The organization seeks to inform the state and its industrial leaders and varied stakeholders, as well as its own operations and strategy with the following identified as primary goals and objectives:

- Advance the use and adoption of, and readiness for new and emerging advanced manufacturing and automation technologies, including and primarily those associated with Industry 4.0 among Maryland manufacturers.

- Identify one to two industry and/or market "verticals" associated with supply chain strengths and aligned with strong growth opportunities for Maryland manufacturers for targeting into the future, including for strategic "reshoring" opportunities.

The Plan is organized into four sections: 1) a baseline assessment of the economic trends and positioning of Maryland's manufacturing sector to set the context; 2) an overview of Industry 4.0 technologies and their role in transforming modern manufacturing and how Maryland is positioned to seize the opportunity; 3) a situational assessment that brings forth the voice of industry and drives toward strategic priorities for the sector; and finally, 4) a set of strategic recommendations and specific actions for MD MEP, its stakeholders, and partner organizations to consider for maintaining manufacturing competitiveness into the future.

This strategic planning effort has been overseen and guided by a diverse representation of manufacturing leaders and broader stakeholders participating as part of the project Advisory Committee and prioritizing the voice of industry via one-on-one interviews and group discussions.
Industry or Manufacturing 4.0 (which will be used interchangeably in this report) have primarily been viewed as an aspirational future of "smart" manufacturing, but that future is here, that future is now for Maryland and its competitors across the globe.

I. A BASELINE ASSESSMENT FOR MARYLAND MANUFACTURING: SETTING THE CONTEXT OF THE INDUSTRY'S POSITION, PERFORMANCE, & MAJOR CLUSTERS AND THE NEED FOR INDUSTRY 4.0 ADOPTION TO MAINTAIN COMPETITIVENESS

At the outset, it is important to provide a quantitative "baseline" analysis to set the context of the overall structure, composition, competitive position, and unique existing and emerging strengths of the manufacturing industry in Maryland as we begin to consider the implications of Industry 4.0. This baseline analysis highlights the overall importance to Maryland's economy of its manufacturing industry as a major economic driver that stands out as an outsized leader in statewide productivity and high-value innovation, but also illuminates competitive challenges that must be addressed by adopting transformative technology in the form of Industry 4.0.

MANUFACTURING INDUSTRY ECONOMIC ANALYSIS FINDS AN IMPACTFUL GROWTH SECTOR BUT LONGER-TERM COMPETITIVENESS CHALLENGES

As shown in Figure 1, every day more than 109,000 Marylanders report to more than 4,000 individual manufacturing establishments spanning all regions of the state to produce an impressive array of products and serving diverse global markets. This activity combines to contribute nearly $28 billion to Maryland's GSP—strong value-adding activity reflected by just over $9 billion in total compensation paid to the industry's workforce.

Figure 1: Summary Economic Metrics for Maryland Manufacturing, 2020

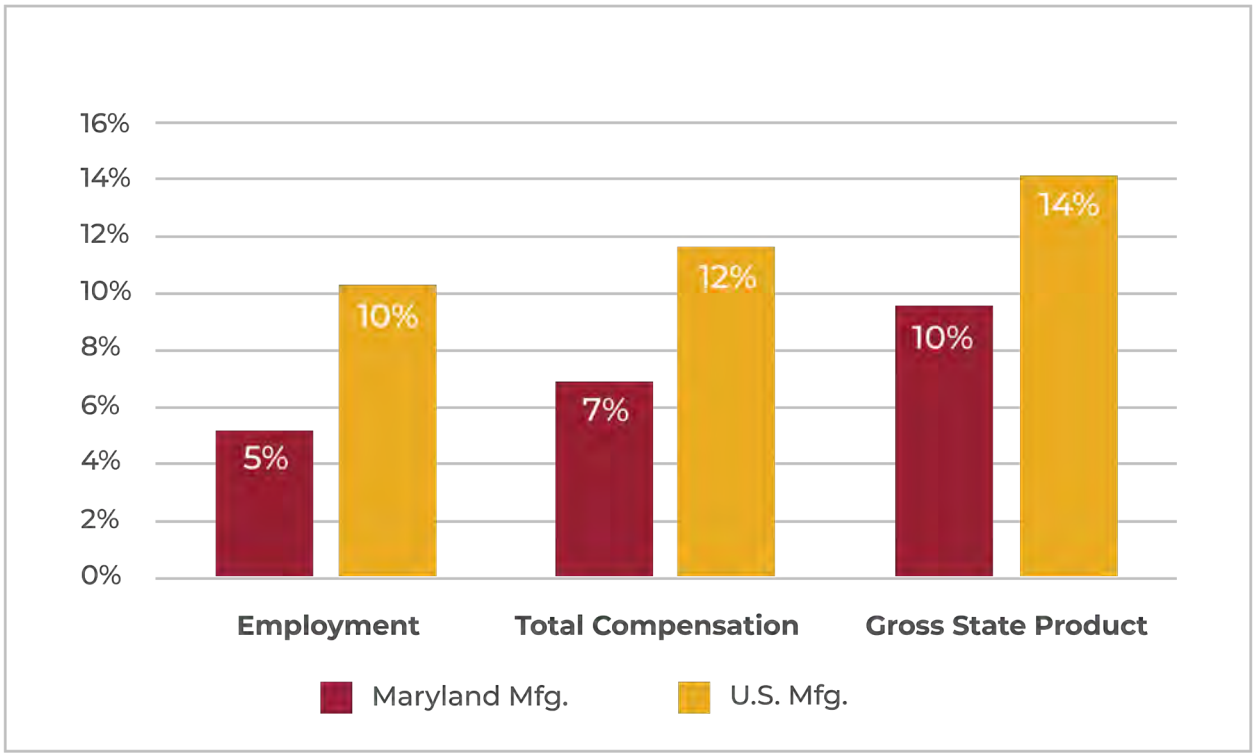
Maryland's Manufacturing Industry Represents:

Source: TEConomy Partners' analysis of Emsi Q2 2021 data set.

While it's an important economic driver in the state, manufacturing is less concentrated in Maryland relative to the national average. This under-concentration is evident across three top-line metrics where Maryland's share of economic activity attributable to manufacturing stands below those seen nationally, specifically with respect to employment, total compensation, and GSP (Figure 2). Manufacturing accounts for 5% of all private sector jobs in Maryland, compared to 10% of jobs nationally, translating into an industry location quotient (LQ) for Maryland of 0.52.[2] This occurs in Maryland, in part, due to the outsized service economy driven by the federal, contracting, and related industrial complex in Central Maryland that leads to dampening the contributions of manufacturing as a share of overall economic activity in the state.

[2] Location quotients (LQs) are a standard measure of the concentration of a particular industry in a state or region relative to the nation. The LQ is the share of total state or regional employment in the particular industry divided by the share of total industry employment in the nation. An LQ greater than 1.0 for a particular industry indicates that the region has a greater relative concentration, whereas an LQ less than 1.0 signifies a relative underrepresentation. An LQ greater than 1.20 denotes employment concentration significantly above the national average. In this analysis, regional specializations are defined by LQs of 1.20 or greater.

Figure 2: Maryland Manufacturing's Share of Key Top-Line Economic Indicators vs. US, 2020

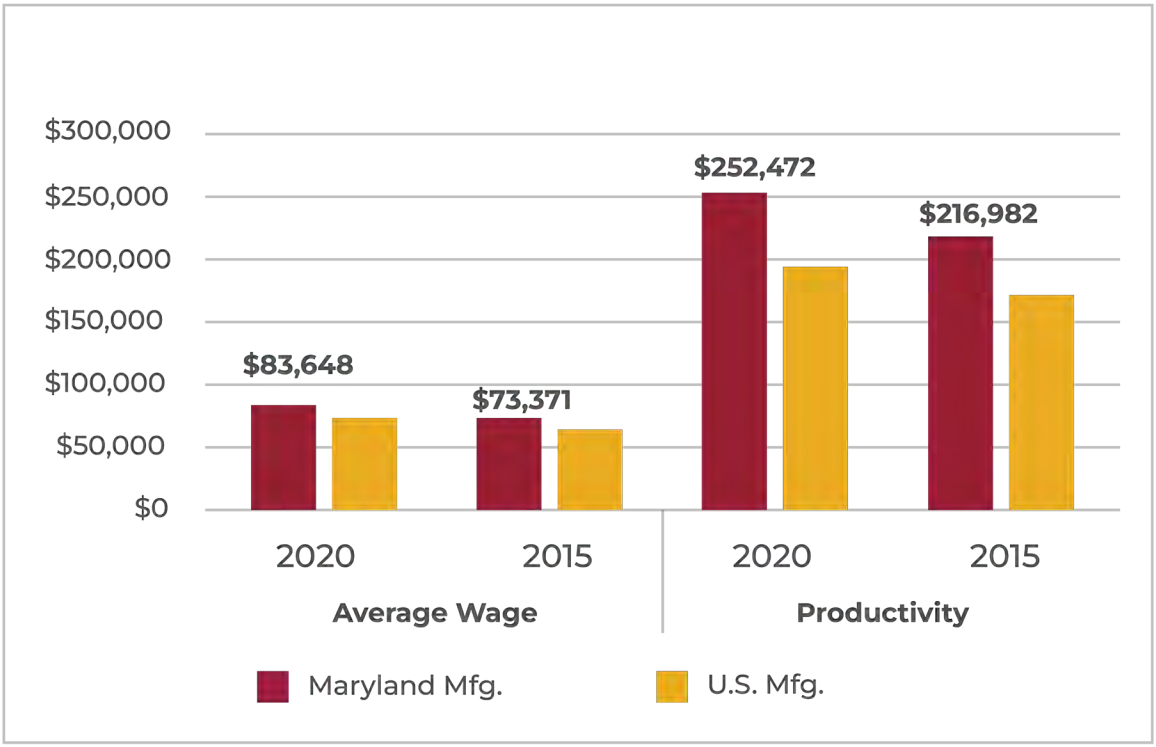


Source: TEConomy Partners' analysis of Emsi Q2 2021 data set.

What Maryland may lack in the overall size or concentration of its manufacturing base relative to other states, it makes up for by punching above its weight in terms of value-adding activity that measures worker productivity. On average, Maryland manufacturing workers produced more than $250,000 in value-added activity per worker in 2020—the key measure of workforce productivity in manufacturing (see Figure 3). In recent years this figure has not only surpassed the level seen nationally (nearly $191,000), but it has grown at a faster rate than the nation. This is further evident in manufacturing accounting for 10% of GSP in Maryland while utilizing just 5% of the state's labor force.

Strong productivity enables Maryland manufacturing industries to pay higher overall wages and remain competitive. Maryland manufacturing workers earn more than both their counterparts nationally and relative to the overall private sector worker in the state. In 2020, manufacturing wages averaged nearly $84,000 in Maryland, compared to $71,000 nationally and $64,000 for the overall Maryland private sector. This situation is obviously beneficial to workers but drives concerns among manufacturers about high labor costs, a concern addressed in the situational assessment to follow.

Figure 3: Maryland Manufacturing's Average Wages and Productivity vs. US, 2020



Source: TEConomy Partners' analysis of Emsi Q2 2021 data set.

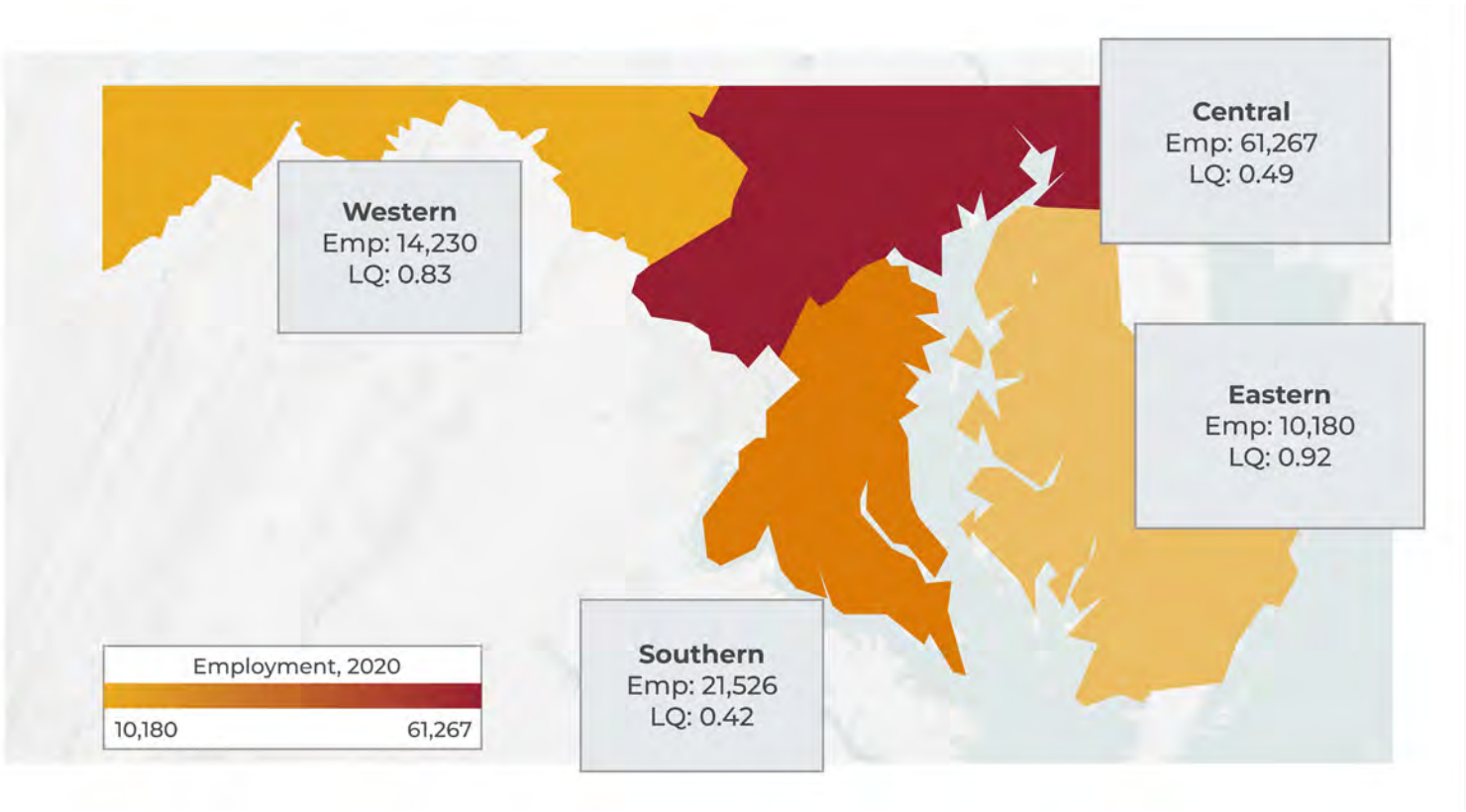
Manufacturing's outsized productivity and importance to the state's economy relative to other industries is illustrated in the context of its role as a "traded" industry, one that exports its products outside of the state, thereby generating net new wealth for Maryland.[3] In 2020, the value of exports generated by state manufacturers reached $39.8 billion.

Manufacturing is active across each of Maryland's four major regions. Its footprint, like the state's population, is largest in Central Maryland (57% of all jobs) but extends outward in all directions (Figure 4). While Eastern and Western Maryland have lower employment levels, manufacturing represents a somewhat greater share and importance to their overall economies, as illustrated by employment concentrations closer to national averages (location quotients closer to 1.0). Each region contributes its own unique companies, innovations, and key products to the markets it serves.

In 2020, the sales value of exports generated by Maryland manufacturers reached $39.8 billion.

[3]As opposed to a "local" or "non-traded" industry that primarily serves local residents and therefore does not generate new wealth for a region, state, or nation. Examples of local or locally traded industries include education, utilities, and most healthcare services.

Figure 4: Manufacturing Employment in Maryland by Region, 2020



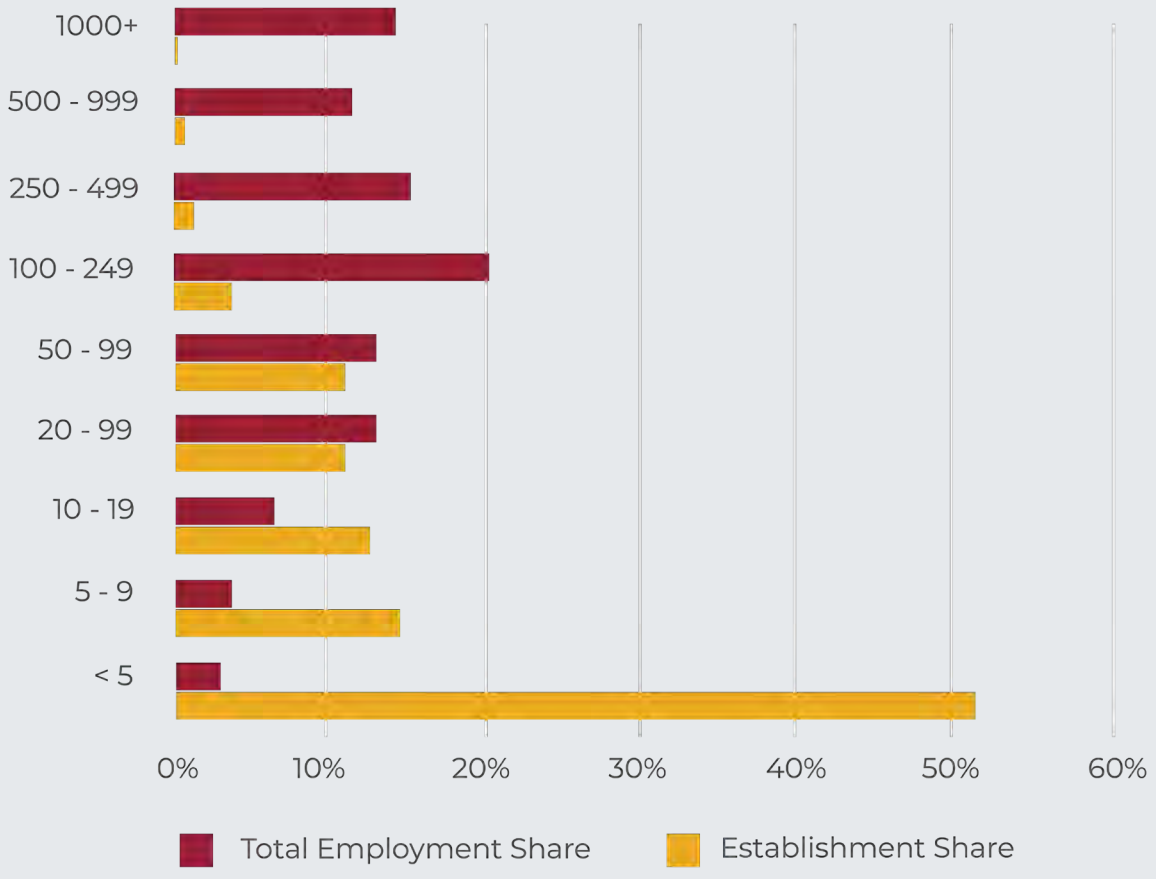
Note: LQ = Location Quotient.

Source: BLS, QCEW data via Emsi (Datarun 21.2); TEConomy analysis.

THE IMPORTANCE OF SMALL- AND MID-SIZED ENTERPRISES (SMEs) IN MARYLAND'S MANUFACTURING SECTOR

Although large manufacturers (those with 500 or more employees) with household names are front of mind for consumers and state residents, more than half of manufacturing firms in Maryland have fewer than five employees and the largest employment totals for firms lie within the 100-249 employee band. Recognizing the important role these firms play within the state and nation's manufacturing ecosystem as local and often rural employers and key suppliers, and the limited resources these firms have, the National Institute of Standards and Technology (NIST) has ensured the MEP Network is focused on primarily serving SMEs. This is not to diminish at all the importance of large manufacturers as significant employers, major exporters, and drivers of demand for SMEs along critical supply chains.

Size Distribution of Maryland's Manufacturing Establishments and Employment, 2020



Source: TEConomy estimates and analysis of U.S. BLS QCEW Employment Size Distribution Data Set, Q1-2020.

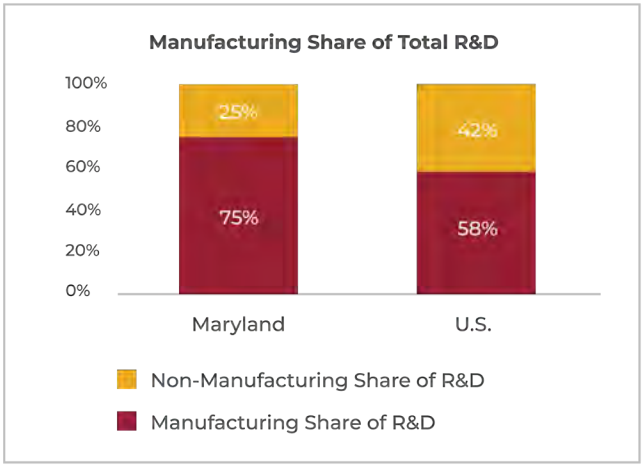
Industrial R&D: Manufacturing is the Predominant Driver for Maryland

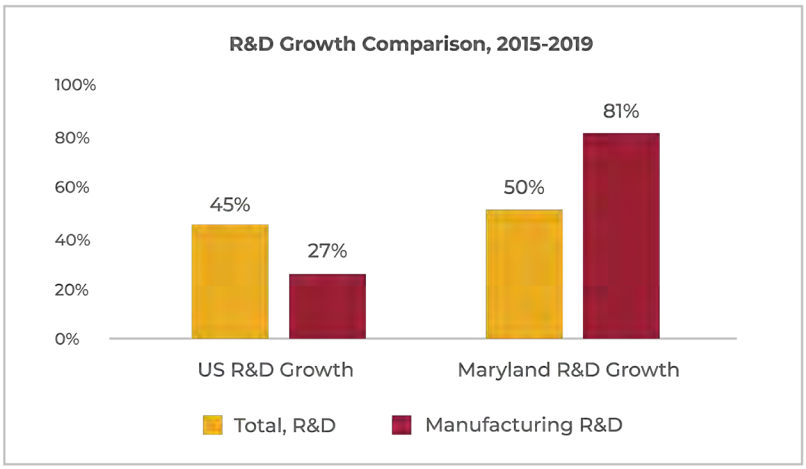
Industrial R&D investment is one key metric of innovation activity and often provides an additional glimpse at Industry 4.0 potential, as innovative firms are much more likely to adopt or consider digital automation solutions. Maryland manufacturers account for three-quarters of the state's total industrial R&D expenditures. While industry R&D survey data have an unfortunate time lag, Maryland manufacturing R&D reached $3.2 billion in 2019. This figure, as well as overall industrial R&D, has grown substantially above US averages since 2015 (Figure 5).

Maryland Manufacturing plays an outsized role as an innovation engine for the state—the sector represents 10% of GSP but accounts for 75% of industrial research and development ($3.2 Billion).

Industrial R&D is most concentrated within large firms, and this is the case in Maryland; however, while 74% of Maryland's total industrial R&D (manufacturing and non-manufacturing combined) occurs in firms with 500 or more employees, this figure is significantly lower than the 87% at the national level. This is good news for Maryland manufacturing, as it signals a strong innovation stance for SMEs and potential for enhanced, innovation-driven growth in a Manufacturing 4.0 environment.

Figure 5: Manufacturing Share of Total Industrial R&D and Recent Growth, Maryland, and U.S., 2019





Source: TEConomy analysis of National Science Foundation, Business R&D Survey data, 2015 & 2019 (most recent year available).

Industrial R&D spans the manufacturing cluster context in Maryland, predictably dominated by the life sciences and aerospace and defense systems. A summary of R&D expenditures, growth and focus areas finds:

Life Sciences Manufacturing

- Reached $1.98 billion in 2019, accounting for 62% of state's manufacturing R&D (47% of Maryland's total industrial R&D)
- Recent (2015-2019) growth dramatically outpaced US (220% to 53%)
- Most of the R&D occurs within pharmaceutical manufacturing ($1.77 billion; 89% of industry cluster total)

Aerospace & Defense Systems Manufacturing

- Reached $550 million in 2019 (down from $760 million in 2018), accounting for 17% of state's manufacturing R&D (compared to 22% nationally)
- Overall cluster R&D levels declined in the recent period (2015-2019), similar to the US overall (-6% to -8%)
- Most of the R&D occurs within aerospace manufacturing ($338 million; 61% of industry cluster total, but down from $520 million in 2018)

Machinery Manufacturing (broad with components captured in other Maryland clusters)

- Reached $182 million in 2019, accounting for 6% of state's manufacturing R&D (slightly above US average)
- Industry R&D levels grew in recent period (2015-2019) exceeding US growth (17% compared to 11% in US)

Polymers & Related Manufactured Products

- Reached $117 million in 2019, accounting for 4% of state's manufacturing R&D (compared to 2% US average)
- Cluster R&D levels declined in recent period (2015-2019) compared to a growth in the US overall (-22% to 4%)

Food Manufacturing

- Reached $50 million in 2019 (down from $58 million in 2018), accounting for 2% of state's manufacturing R&D (similar to US average)
- Cluster R&D levels grew slightly in recent period (2015-2019) compared to a decline in the US overall (4% to -15%)

Academic R&D: Maryland's Research Universities Represent a Key Asset, Potential Partner in Industry 4.0 Solutions Development

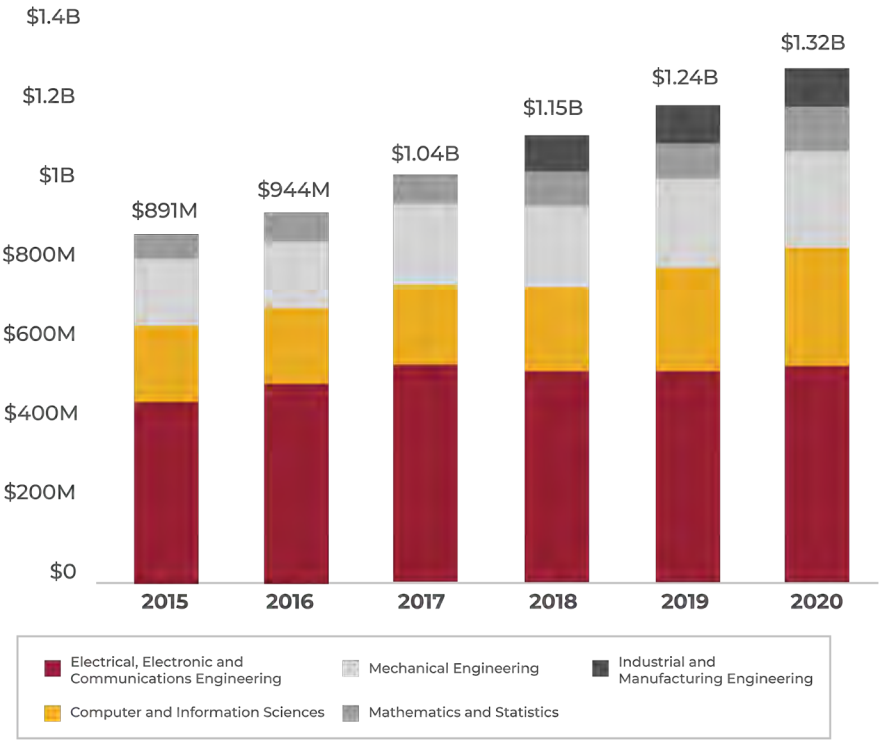
Maryland has a strong reputation in postsecondary education and R&D, and deservedly so as the state ranks fourth among all states in its annual level of science and engineering research expenditures.[4] Maryland is incredibly concentrated in science and engineering or "S&E" R&D as a small state positioned behind only California, New York, and Texas nationally. Led by nation-leading research institutions in Johns Hopkins University and the University of Maryland, College Park and Baltimore County, Maryland institutions conducted nearly $4.7 billion in S&E-related R&D in 2020 alone.

[4] Based on analysis of National Science Foundation (NSF), Higher Education R&D Survey, 2020.

In fields most closely relevant for Industry 4.0 solutions development, Maryland's $1.32 billion in 2020 R&D expenditures is highly concentrated and "specialized"—representing 28% of University R&D in Maryland compared to 11% across the United States. R&D activities in these fields are growing as well and outpacing the nation since 2015 (Figures 6 and 7).

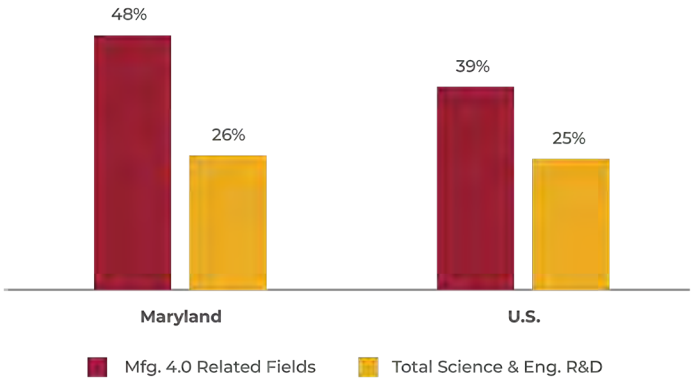
Maryland universities represent an important and leading source of both innovation and talent development relevant for Industry 4.0 adoption, and collaborations and partnerships with Maryland's manufacturing community are critical for seizing a competitive edge.

Figure 6: Maryland University R&D Expenditures in Mfg. 4.0-related Fields, 2015-2020



Source: TEConomy analysis of National Science Foundation, Higher Education R&D Surveys, 2015-2020.

Figure 7: Growth Trend in University R&D, Maryland vs. US, 2015-2020

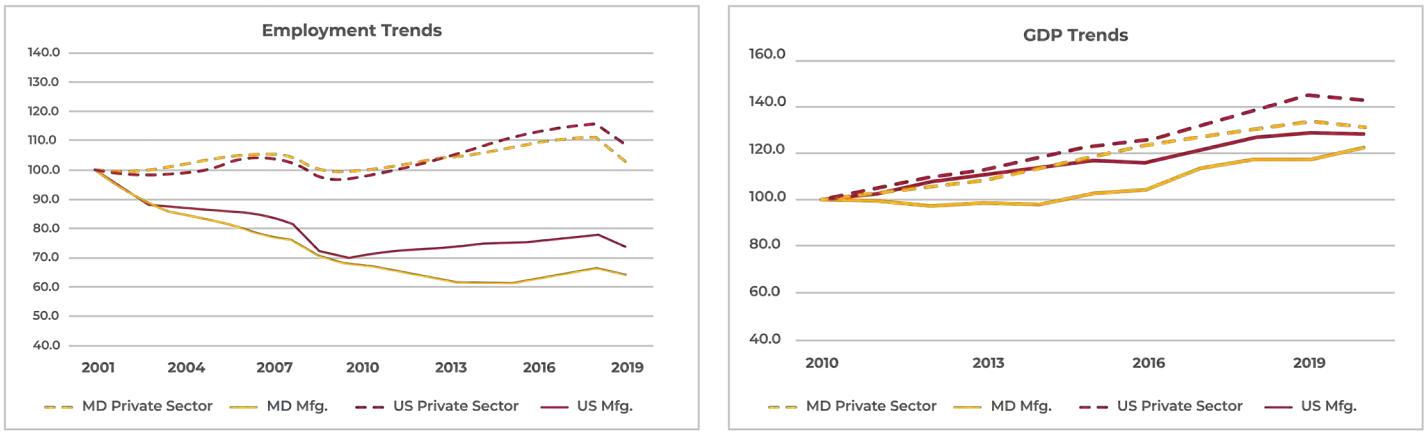


Source: TEConomy analysis of National Science Foundation, Higher Education R&D Survey.

Longer-Term Competitiveness Challenges for Manufacturing

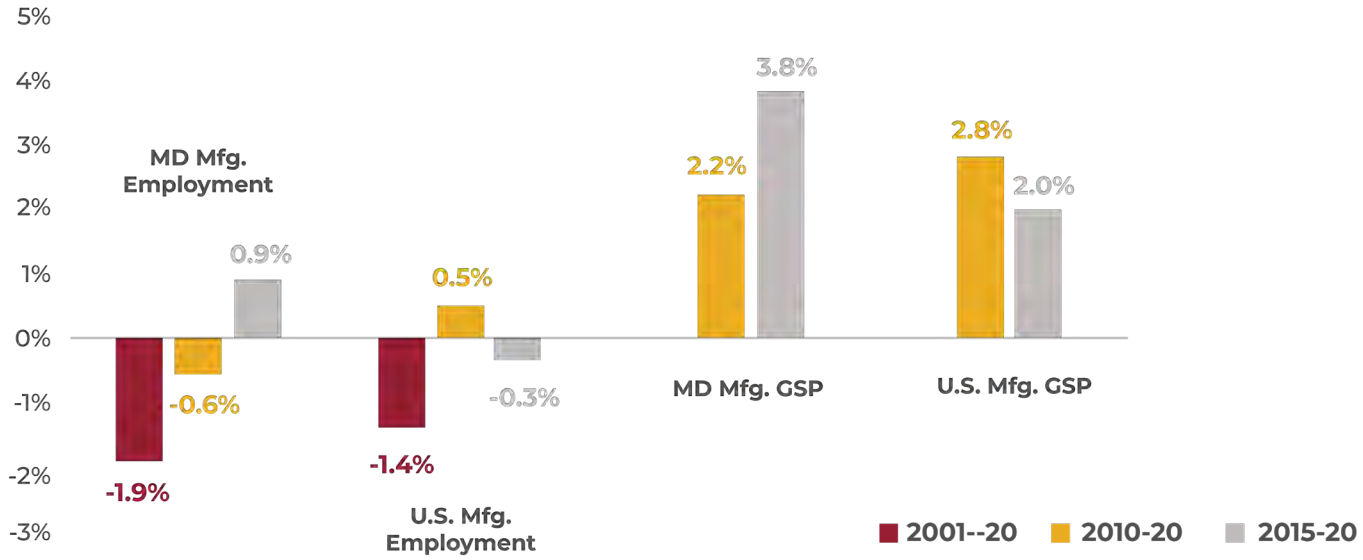
As a consequence of Maryland's higher productivity and R&D in manufacturing, the state has outpaced US manufacturing employment and GDP growth since 2015, but this recent trend is a stabilization of the industry following years of steeper employment declines and lagging output growth for the state (see Figures 8 and 9). Over the last two decades, Maryland manufacturing has struggled with lagging GSP growth and steady, rapid declines in its employment base. While industry employment has stabilized and GSP growth has increased its pace in recent years, the industry has clearly faced longer-term competitiveness challenges and contraction—a key context as to why Industry 4.0 adoption will matter for state competitiveness.

Figure 8: Maryland Manufacturing has Seen Long-Term Competitiveness Challenges That it has Recently Reversed—Manufacturing Employment & GSP Average Annual Growth Trends, 2001-20, 2010-20



Source: TEConomy Partners' analysis of Emsi Q2 2021 data set.

Figure 9: Maryland Manufacturing has Seen Long-Term Competitiveness Challenges That it has Recently Reversed—Manufacturing Employment & GSP Average Annual Growth Trends, 2001-20



Manufacturing is a diversified industry in Maryland with the baseline analysis identifying seven distinct and varied clusters. The clusters illustrate the breadth of products manufactured across the state and numerous global markets served—from cutting-edge aerospace navigation and defense systems to vaccines and cell therapies for cancer patients, to seafood and spices, Maryland manufacturing is truly diverse. Table 1 lists the seven clusters, their key sub-clusters, and examples of the Maryland companies within each. Summary employment metrics and the geographic distribution of each cluster is included in Appendix A to this report.

Table 1: Maryland Manufacturing Industry Clusters–Key Subsectors and Example Companies

Manufacturing Cluster	Key Sub-Clusters (% of Jobs)	Examples of MD Companies
Aerospace & Defense Systems	Navigation, Guidance, & Security Instrumentation (61%) Aerospace (15%) Communications Equipment (14%)	Northrup Grumman Systems Corporation, Lockheed Martin, Raytheon, Boeing, L3Harris, Textron Systems (AAI Corporation), Advanced Thermal Batteries
Food & Beverage	Food (82%) & Beverage (18%) Manufacturing	Perdue Farms, McCormick & Company, Smithfield Foods, Synutra International, Northeast Foods, Ingredion, Inc., Fuchs North America, Eight O'Clock Coffee
Life Sciences	Pharmaceuticals (76%) Medical Devices & Equipment (24%)	Celegene, Orgenesis, AstraZeneca (Medimmune), Emergent Biosolutions, Kite Pharma, Meridian Medical Technologies, Trinity Sterile, Inc., Action Products, Inc.
Polymers & Related Products	Plastic & Rubber Products (75%) Adhesives, Coatings & Paint (25%)	W. L. Gore & Associates, Inc., Berry Plastics, Fawn Industries, Wm. T. Burnett & Co., Tenax Corporation
Precision Manufacturing	Precision Metalworking (55%)	Dixon Valve & Coupling Company; Cambridge International (Rexnord), Kenlee Precision Corporation, Danko Arlington, The Bechdon Company, Inc.; Raloid Corporation
Printing & Packaging	Printing (66%)	Plastipak, Altium Packaging, Spartech, Phoenix Color, Atlas Container Corporation, CCL Label, WebbMason Marketing
Wood Products	Lumber & Building Products (53%)	Shelter Systems, Washington Woodworking, The Taney Corporation, Beachley Furniture Company, Helmut Guenschel, Inc.

Source: TEConomy Partners, LLC.

The employment size, concentration, and recent hiring trend of each cluster is shown in Table 2 and Figure 10. The bubble chart provides a snapshot of the varied size of each cluster (size of each bubble), with food and beverage manufacturing and aerospace and defense systems the two largest clusters approaching 21,000 jobs each. What stands out in recent years is the strong employment growth across a majority of the clusters, with five of seven growing since 2015 and four of those five seeing double-digit growth rates despite the inclusion of the 2020 COVID year.

Like the overall manufacturing industry in Maryland, nearly all of the clusters are under-concentrated in the state relative to national averages. The exception is life sciences, where Maryland has a 6% greater concentration of jobs relative to the United States (LQ of 1.06), a strong concentration though one that is not yet considered to be "specialized" (LQ of 1.2 or greater). The strong growth and under-concentration of the clusters place many of them firmly in the "emerging" category from an industry targeting perspective.

Table 2: Employment Size, Concentration, and Growth Metrics for Maryland Manufacturing Clusters, 2020

Maryland Manufacturing Industry	Employment		
	Totals, 2020	Change, 2015-2020	Concentration (LQ)
Food & Beverage	20,908	17%	0.64
Aerospace Defense Systems	20,740	17%	0.95
Life Sciences	12,604	29%	1.06
Printing & Packaging	10,354	-10%	0.72
Polymers & Related Mfd. Products	6,826	5%	0.53
Precision Manufacturing	4,944	0%	0.28
Wood Products	3,870	12%	0.44

Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2)

Figure 10: Employment Size, Concentration, and Growth Metrics for Maryland Manufacturing Clusters, 2020

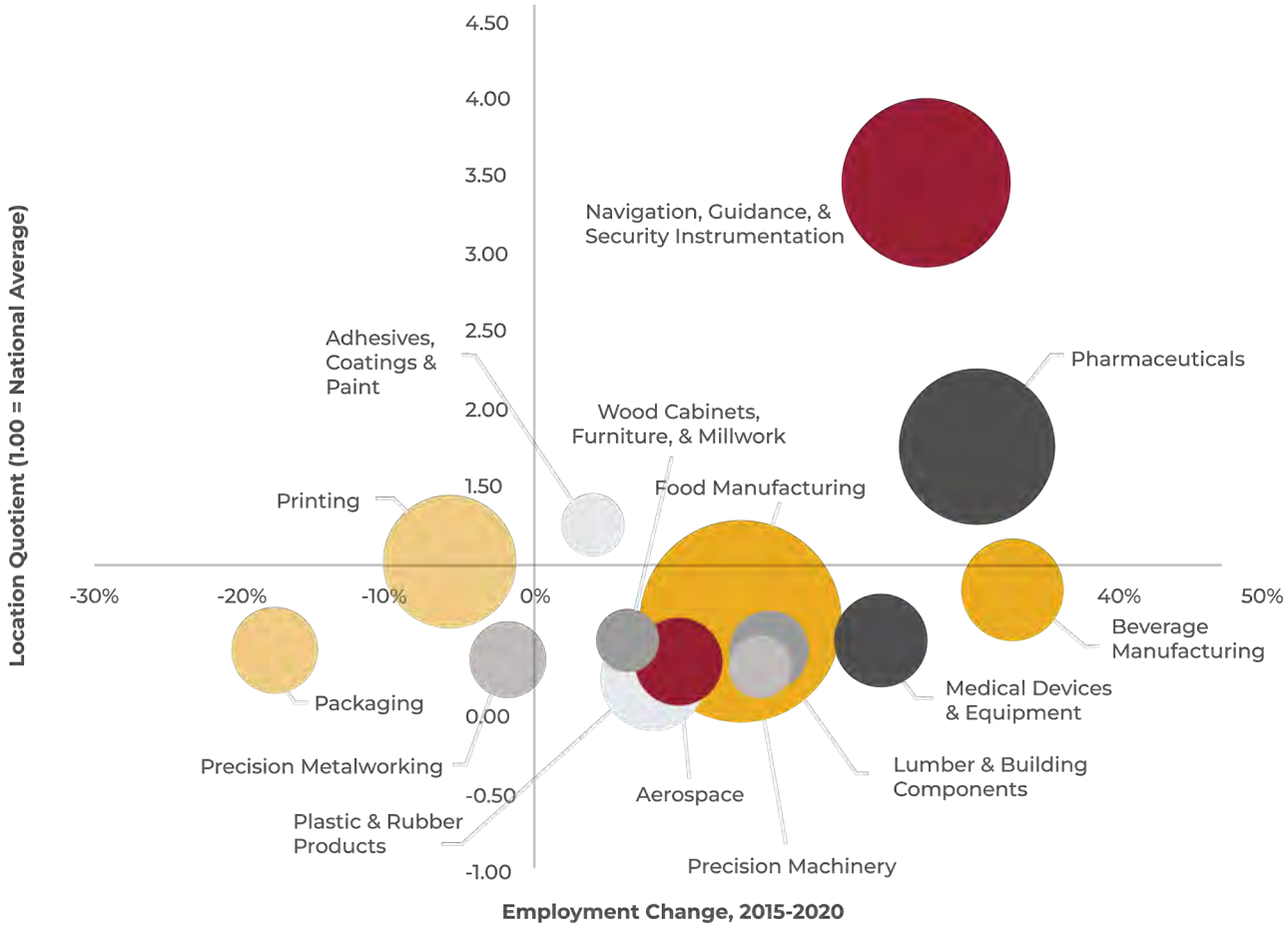
Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2)

Five of the Maryland manufacturing clusters have outpaced their national counterparts in job growth since 2015. All but printing and packaging and polymers and related products have seen stronger net hiring in the 5-year period compared to the national average.

Narrowing the lens and drilling down on the major subclusters driving the overall trends finds three that can be considered current strengths for Maryland—navigation, guidance, and security instrumentation (within aerospace and defense systems); pharmaceutical manufacturing (life sciences); and adhesives, coatings, and paint (polymers and related, see Figure 11). Each of these has a "specialized" concentration of jobs in Maryland relative to the national average and has grown its base since 2015. The rapid growth of the instrumentation and pharmaceuticals sub-clusters is especially impressive given the large size of their existing employment base.
Likewise, food manufacturing has hired at a rapid clip (up 14%) despite its sizable base representing the largest individual sub-cluster.

Even at a quick glance, the color-coded bubbles tell the story at the cluster level with strong recent hiring in life sciences and in food and beverages, aerospace and defense systems, and wood products. Precision manufacturing has seen mixed performance, with net new hires in precision machinery offset by job declines in precision metalworking. The net job losses in printing and packaging have been across both major components.

Figure 11: Employment Size, Concentration, and Growth Metrics for Maryland Manufacturing Clusters, 2020

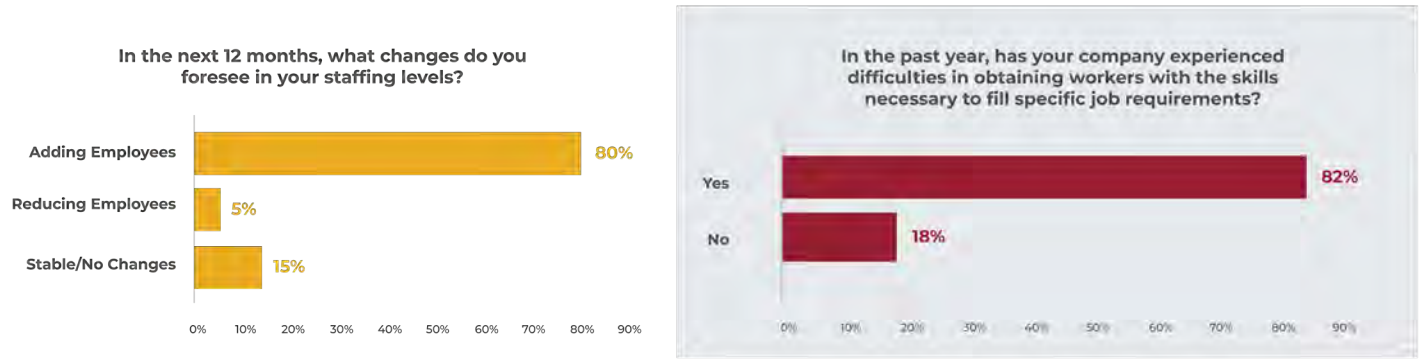


Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2)

Reflecting the strong employment growth of the seven clusters, nearly all of Maryland's subclusters have outpaced job growth nationally (see Appendix A). Based on a 2021 Maryland Department of Commerce survey, this strong overall hiring stance is expected to continue in Maryland in the near term, with 80% of manufacturers reporting plans to add employees in the next 12 months (Figure 12).[5] As will be discussed in the next section of the report, the most common and most challenging issue facing Maryland manufacturers today is around identifying and hiring new talent and workforce—and a key question will be, can state manufacturers continue to hire their way to sustained growth?

[5] The Maryland Department of Commerce surveyed 228 state manufacturers in Summer 2021 on an array of topics regarding their current situation and outlook for the future. Selected results are used to inform this study and are included in different sections of the report. Sample sizes responding to each question vary and are noted for each figure used in this report.

Figure 12: Hiring Outlook for and Challenges Faced by Maryland Manufacturers, 2021



Note: for these questions, the sample sizes were 130 for staffing outlook and 131 for difficulty in hiring.
Source: Maryland Dept. of Commerce, 2021 Maryland Manufacturing Survey.

IMPLICATIONS AND INITIAL INSIGHTS FOR INDUSTRY 4.0 ADOPTION

The baseline analysis poses two significant realities around the importance of Maryland manufacturing adopting Industry 4.0:

- Maryland manufacturing has effectively stabilized in recent years, but its longer-term competitive challenges cannot be ignored. The state industry has seen decades of declining employment and lagging output growth, and Maryland's ability to master Industry 4.0 capabilities may provide an opportunity for sustaining long-term growth.
- At the same time, Industry 4.0 poses significant challenges to Maryland maintaining its existing competitive advantages in productivity and innovative product development. The essence of Industry 4.0 is a transformational change in manufacturing production process and product design and development through the digitization of manufacturing activities. Maryland cannot afford to fall behind or even not be among the national leaders in Industry 4.0 because it risks the state's competitive edge in manufacturing across its diverse base.

Other challenges and threats identified by the baseline assessment include:

- While above-average industry wages reflect strong value-adding activities and benefit workers, they represent a competitiveness challenge for manufacturers trying to compete for talent, a dynamic that will be raised in the situational assessment from discussions with employers.
- Maryland's under-concentrated manufacturing base remains a challenge to retaining, recruiting, and attracting both new firms and talent in the industry looking for career opportunities, supply chain and talent connections.

But opportunities also emerge from the baseline industry assessment, namely that growth opportunities are abundant across the state's manufacturing clusters based on recent trends. The next section of the report will describe Industry 4.0 in greater detail and frame how Maryland is positioned both currently and into the future for technology adoption and integration.

II. WHAT IS INDUSTRY/MANUFACTURING 4.0 AND HOW IS MARYLAND POSITIONED TO SEIZE THE OPPORTUNITY?

A DIGITAL TRANSFORMATION IN MANUFACTURING ENABLING GAME-CHANGING OUTCOMES

Many manufacturers with long-standing industry experience will note that digital technologies in manufacturing are not a new phenomenon, as manufacturers have long made use of robotics and other automation tools and technologies since the 1980s. What has shifted in recent years, as technology development has progressed, is a transformational evolution away from a number of formerly disparate tools and applications used in isolation toward the ability to interconnect in a "smart" manufacturing environment. Today's smart manufacturing, or Industry 4.0 environment, draws from a host of technologies enabling data collection and analysis and real-time communication across and between machines.

The Origins, Terminology of "Industry 4.0"

Originally rooted in Germany's national strategy for adoption of smart manufacturing systems, the term Industry 4.0 (or "Industrie" 4.0, often used interchangeably with the term Manufacturing 4.0 as done in this report) is now widely used to refer to the portfolio of technologies, capabilities, and services that manufacturers are using to shift traditionally labor-intensive production enterprises towards digital and automated operations models.

Industry 4.0 technologies are thus 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. These highly desirable outcomes are enabled by an expansive portfolio of new technologies, capabilities, and services, with several key goals in transitioning operations to Industry 4.0 models shown in Figure 13.[6]

Figure 13: Goals in Transitioning Manufacturing Operations to Industry 4.0 Models

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 & 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

Source: adapted from "Design Principles for Industrie 4.0 Scenarios, 2016."

There are varied concepts and depictions of the range of Industry 4.0 technologies, but framing them using key groupings is more appropriate for understanding the modern industrial setting and full context of their applications. Three key categories of technologies most commonly come together to enable an integrated Industry 4.0 operating environment:

[6] Mario Hermann, Tobias Pentek and Boris Otto, "Design Principles for Industrie 4.0 Scenarios," 2016 49th Hawaii International Conference on System Sciences (HICSS), 2016, pp. 3928-3937, doi: 10.1109/HICSS.2016.488.

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 manufacturing's ongoing digitization.

- Examples include advanced robotics and autonomous systems, additive manufacturing, augmented and virtual reality, digital design and prototyping capabilities, and other cyber-physical systems.

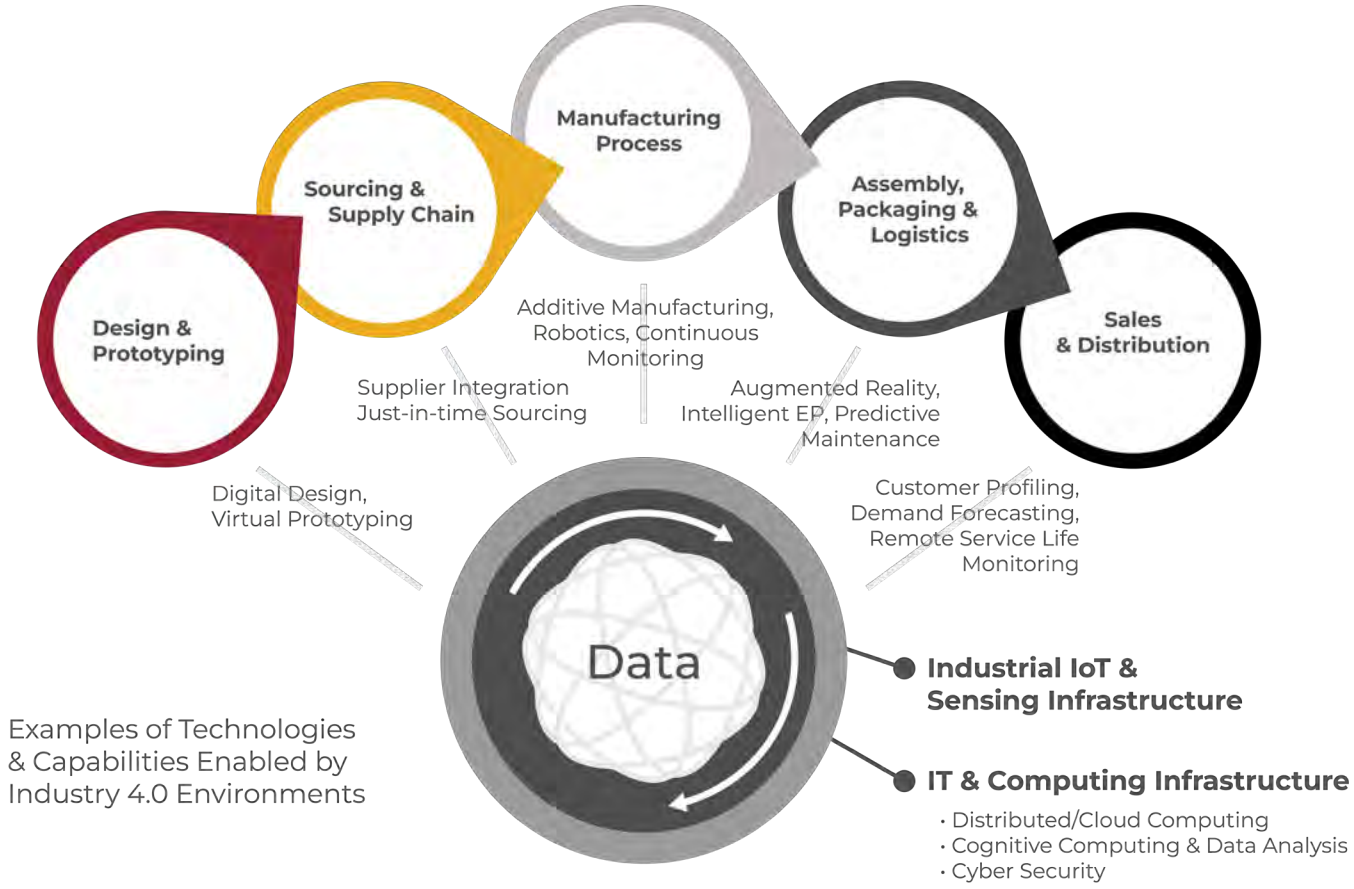
Downstream Industry 4.0 capabilities and services that leverage both of the technology types described above to produce new value-added capabilities for manufacturers, but are not novel technologies in and of themselves.

- 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 will be shown in the situational assessment, Maryland manufacturers are leveraging most all of these discrete individual technologies, though the degree to which they are optimized as a truly integrated system varies considerably and is generally limited based on discussions held with selected manufacturers.

The ultimate goal of an integrated and optimized Industry 4.0-enabled production environment is to leverage the ability to gather, store, manipulate, and fully utilize data generated from manufacturing operations to generate actionable insights. This is an aspirational goal to realize the concept of a "smart" or "intelligent" factory or plant at scale, where a broad suite of 4.0 technologies is deployed to create a positive feedback cycle that allows a manufacturer to be highly adaptive and flexible in real time. For corporate leaders in Industry 4.0 adoption, this capability creates a highly advantageous, uneven playing field against competitors operating in legacy production environments. An illustration of this smart manufacturing model and the insights leveraged through continuous feedback cycles is shown in Figure 14.

Figure 14: A Fully Integrated Industry 4.0 Environment and the Role of Data-Driven Feedback Cycles



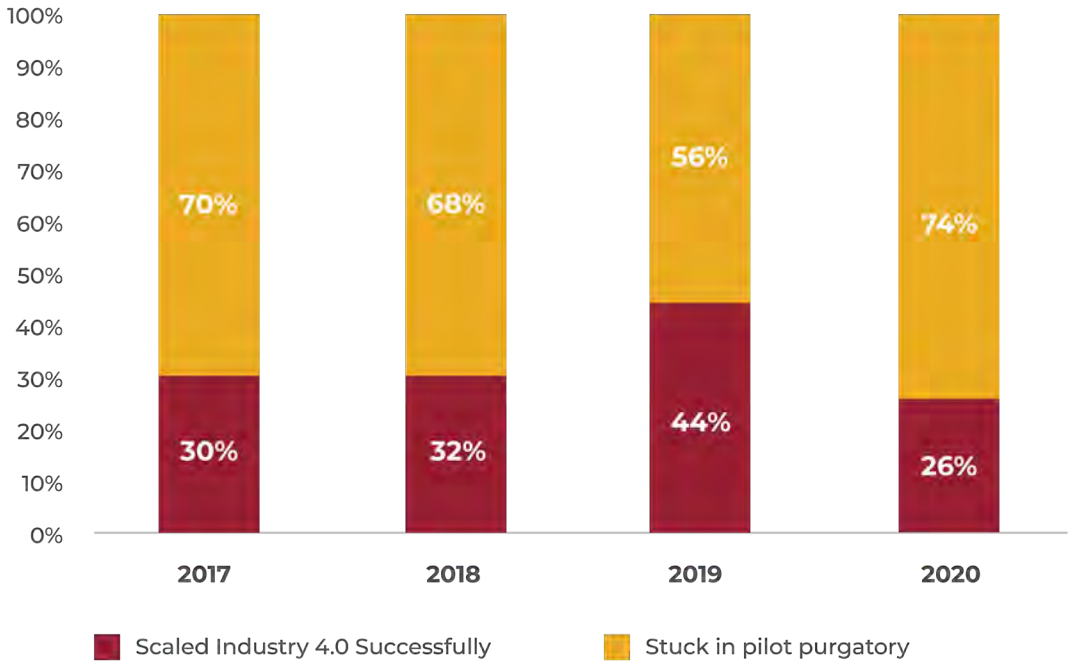
Source: TEConomy Partners, LLC.

GAUGING GLOBAL ADOPTION TODAY AND THE OUTLOOK FOR THE FUTURE

McKinsey & Company has tracked Industry 4.0 adoption in global surveys of manufacturing executives and the degree to which companies are achieving the type of scale and optimization described above along a maturity scale. Response summaries from their latest four surveys are shown in Figure 15.[7] And while the share reporting that they had successfully scaled Industry 4.0 was down considerably in 2020, they report two likely causes—one, the bar for successful scaling has risen amid real tests during crises caused by COVID-19; and two, "battle testing" platforms during a pandemic may have revealed implementation once thought to have reached scale not yet fully realized. Regardless, the surveys continue to show a significant share of firms investing in Industry 4.0 and a rising share prior to 2020.

[7] McKinsey & Company. (2021, January). "COVID-19: An Inflection Point for Industry 4.0."

Figure 15: Manufacturing Survey Respondents Reporting Successfully Scaling Industry 4.0 (Shares)



Source: McKinsey & Company.

The general upward growth pattern of adoption at scale of Industry 4.0 technologies is reinforced by a recent survey conducted by SME and Plataine in 2020 that found major acceleration in recent years—with 84% of global manufacturing respondents currently implementing digital strategies compared to only 27% in 2018.[8] While not the threshold of "successfully scaling," this finding clearly illustrates the growing adoption among manufacturers. The Industry 4.0 opportunity has grown to significant market size—the International Society of Automation recently reporting the global Industry 4.0 market was valued at $81.7 billion in 2020, with a projected compound annual growth rate (CAGR) of 20% through 2027.[9]

[8] SME & Plataine, Trends in Global Digital Manufacturing Survey, 2020.

[9] International Society of Automation, "Rising Demand for Industry 4.0 Due to Adoption of Artificial Intelligence in Manufacturing Sector," September 2021

COVID-19 PANDEMIC HAS ACCELERATED URGENCY ON RESILIENT OPERATIONS ENABLED BY INDUSTRY 4.0 SOLUTIONS

Prior to the pandemic there was plenty of momentum behind transformative Industry 4.0 technology adoption, but the trend is accelerating based on the challenges arising from COVID-19. McKinsey & Company, in a recent survey of global manufacturers, finds manufacturing leaders calling on Industry 4.0 solutions to address critical supply chain and workforce challenges seen in the depths of the pandemic—39% implemented a "nerve center" approach to "increase end-to-end supply-chain transparency," and about one quarter were fast-tracking automation initiatives to respond to worker shortages.[1]

Further, McKinsey & Company has found:
"Recent evidence shows that the move towards digital transformation is gaining momentum across virtually all sectors. In fact, in a survey of more than 400 global manufacturing companies, 94 percent of respondents indicated that Industry 4.0 helped them to keep their operations running during the crisis, and 56 percent said the digital transformation they undertook was essential to their pandemic responses. Conversely, for those companies that hadn't scaled—or even begun—their digital transformation, the past year has served as a serious wake-up call to review operational strategies and refocus on Industry 4.0 capabilities." [2]

[1] See: https://www.mckinsey.com/business-functions/operations/our-insights/industry-40-reimagining-manufacturing-operations-after-covid-19

[2] See: https://www.mckinsey.com/business-functions/operations/our-insights/operations-blog/industry-40-adoption-with-the-right-focus

Table 3 considers each of Maryland's seven manufacturing clusters and likely or potential areas of importance in terms of Industry 4.0 technologies and applications.

Table 3: Examples of Key Potential Manufacturing 4.0 Technologies and Applications for Maryland's Manufacturing Clusters

MD Manufacturing Cluster	Examples of Potential Manufacturing 4.0 Technologies of Importance
Aerospace & Defense Systems	• Digital twin and simulation modeling for aircraft and defense platforms for use in digital design and evaluating interoperability challenges for systems integrators • Real-time monitoring of field usage, maintenance, and wear of manufactured parts/systems to enable JIT manufacturing of replacements and adaptive design improvements – relies on embedded instrumentation within products/systems to provide data • Additive manufacturing for customized production runs, usage of novel hybrid feedstock materials • Digital supply chain management for seamless integration into trusted/verified supplier networks • Dedicated cybersecurity operations centers (CSOC) for continuous threat monitoring that addresses security requirements of customers (particularly federal government)

MD Manufacturing Cluster	Examples of Potential Manufacturing 4.0 Technologies of Importance
Food & Beverage	• Data lakes/repositories capturing production, storage, and transportation environment data throughout processing to enable downstream applications • Predictive AI and ML modeling applications that leverage environmental, ingredient, and processing variables across the product journey from initial harvest and processing to packaging in order to optimize product quality and cost savings • Digital traceability, enabled by technologies like distributed ledger systems, that use decentralized metadata tracking to quickly address traceability issues such as food safety • IoT-enabled industrial food and beverage production equipment, e.g., filling and depositor machines that integrate improved sensors for monitoring product quality and local connectivity for sharing data
Life Sciences	• Bioinformatics and materials informatics tools for optimizing production processes and enabling adaptive manufacturing models for precision medicine (with smaller lot sizes, potentially as small as single patient) • Continuous manufacturing approaches (continuous mixing, blending, coatings, etc.) that leverage end-to-end (E2E) systems as opposed to batch runs to optimize run times and automate therapeutics production within flexible, modular production cells • Bioprocessing automation enabled through standardized communications protocols, supervisory control systems, and combinations of linked, modular processing equipment such as bioreactors • 3D printing and novel biomaterials for highly personalized medical device production • Digital integration of laboratory information management systems, clinical deployment data, and supply chain information (i.e., cold chain) for use in regulatory compliance systems and software (Quality 4.0 for life sciences)
Polymers & Related Products	• Digital supply chain integration of upstream materials suppliers as well as customer design tools for highly customized production runs – scaled production of individualized parts • Feedstock materials production for additive manufacturing applications (3D printing), and eventual implementation of 4D printing • IIoT-enabled processing machinery and quality management systems to ensure consistent operating conditions and product output
Precision Manufacturing	• Robotic production cells for use in precision tasks, e.g., robotic welding. • Metal printing technologies for advanced designs (e.g., metal powder bed fusion). • Advanced CNC machinery employing technologies such as laser cutting, tactile manipulation, imaging sensors, etc. that work in conjunction with electronic design automation software. • Materials use life simulation (e.g., stress and wear patterns).
Printing & Packaging	• Packaging automation systems (e.g., automated palleting, labeling, etc.) and industrial automated ground vehicle (AGV)/autonomous mobile robot (AMR) systems • Hybrid packaging machinery (e.g., corrugation plus RPET) for improved packing options • New location and localization systems for real-time tracking of packaging and incorporation of embedded tracking/tracing media withing packaging • "Smart" packaging materials that react to environmental stimuli such as temperature or acceleration • Cyber-physical security solutions to enable secure logistics facilities and distribution
Wood Products	• Adaptive response for wood processing machinery (e.g., dynamic cutting speed in sawmill machinery based on wood properties) • Computer vision applications for analyzing wood characteristics (e.g., defect detection, log shape, board dimensions) • AI/ML applications for wood quality characterization defect prediction • Computer-aided design (CAD) for Mass Timber applications

With this framing context in hand, the assessment now turns to Maryland manufacturing and how it is positioned to adopt and integrate Industry 4.0.

MARYLAND'S MANUFACTURING 4.0-ENABLING WORKFORCE: A COMPETITIVE ADVANTAGE, BUT POTENTIALLY A TALE OF TWO TIERS?

To implement and realize the potential of Industry 4.0 technologies and fully leverage the capabilities of an integrated digital transformation, manufacturers must have the right mix of skilled talent across the organization. A workforce and talent analysis uses several data sets and approaches for understanding the current employment situation and demand dynamics for Maryland manufacturers, including industry "staffing patterns" of occupational employment across the state sector, as well as recent job postings of Maryland manufacturers. The analyses yield insights into Maryland's current situation and to inform strategy development.

TEConomy has developed a concept of an "Industry 4.0-enabling" workforce spanning a broad spectrum of key roles and occupations that range from computer and data sciences to business services. Individuals employed in these roles represent those assessing, designing, implementing, and deploying digital technologies and resulting data streams for smart automation. 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 4.

Table 4: Industry/Manufacturing 4.0-Enabling Occupational Segments and Example Occupations

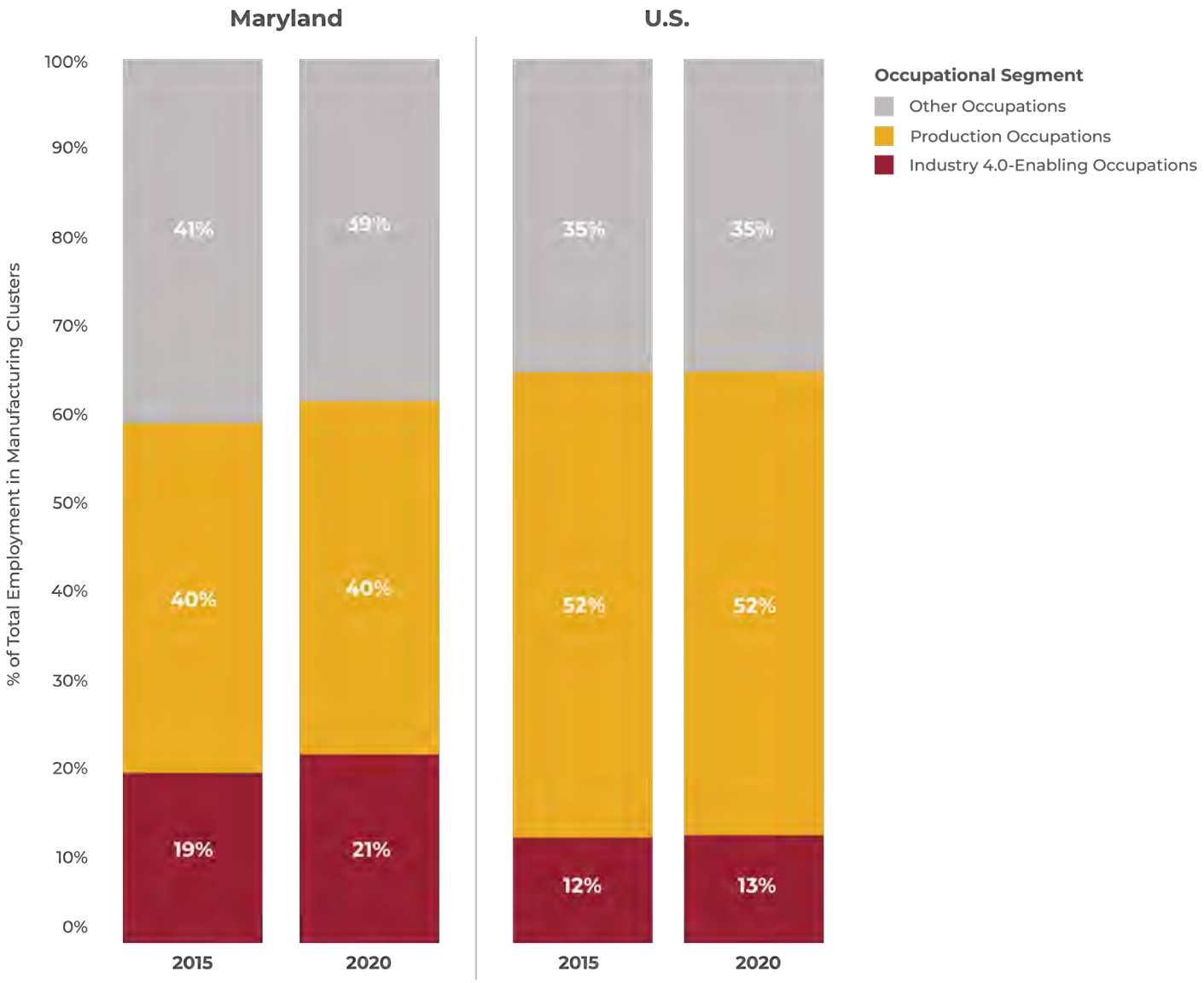
Industry 4.0-Enabling Occupational Segments	Example Occupations in Segment
Business Analytics	Management Analysts, Market Research Analysts
Computer Hardware & Networking	Information Security Analysts, Network and Computer Systems Administrators
Computer Software	Software Developers, Applications, Computer 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

Source: TEConomy Partners, LLC.

Maryland's Industry 4.0-enabling occupational employment share of its overall manufacturing industry is significantly higher than that of the nation's—21% of the sector's workforce versus 13% for the nation (Figure 16). While a smaller share of manufacturing relative to the industry's large production workforce, these one-in-five workers total nearly 17,000 and have grown their share of the industry's workforce at roughly twice the rate as the nation since 2015. Maryland also has a higher share than the United States of other types of non-production occupations such as business support and sales.

While less concentrated as a proportion of the state's manufacturing workforce relative to the nation, production workforces will still play a key role in supporting manufacturing operations. With targeted retraining and reskilling efforts, these roles can successfully transition to new occupational segments over time in an Industry 4.0 environment.

Figure 16: Industry 4.0-Enabling Occupational Employment in the Maryland and US Manufacturing Sector, 2015 and 2020



Source: TEConomy analysis of industry staffing patterns data from Emsi (Emsi Release 2021.2).

Among the enabling occupational workforce the role of engineers across manufacturing stands out as the largest individual segment, but Maryland's manufacturing industries still have a less engineering-intensive profile than the United States overall (Figure 17). This is true for engineering technicians as well. Trend data and job postings, however, find a major hiring push for engineers among manufacturers—the sector has increased its employment of engineers by 22% since 2015, compared to 10% growth within the industry nationally.[10] Engineers are tied with computer software professionals as having the largest share of job postings among the "enabling" workforce—nearly 10% of manufacturing job postings over the last 3.5 years are for engineers.

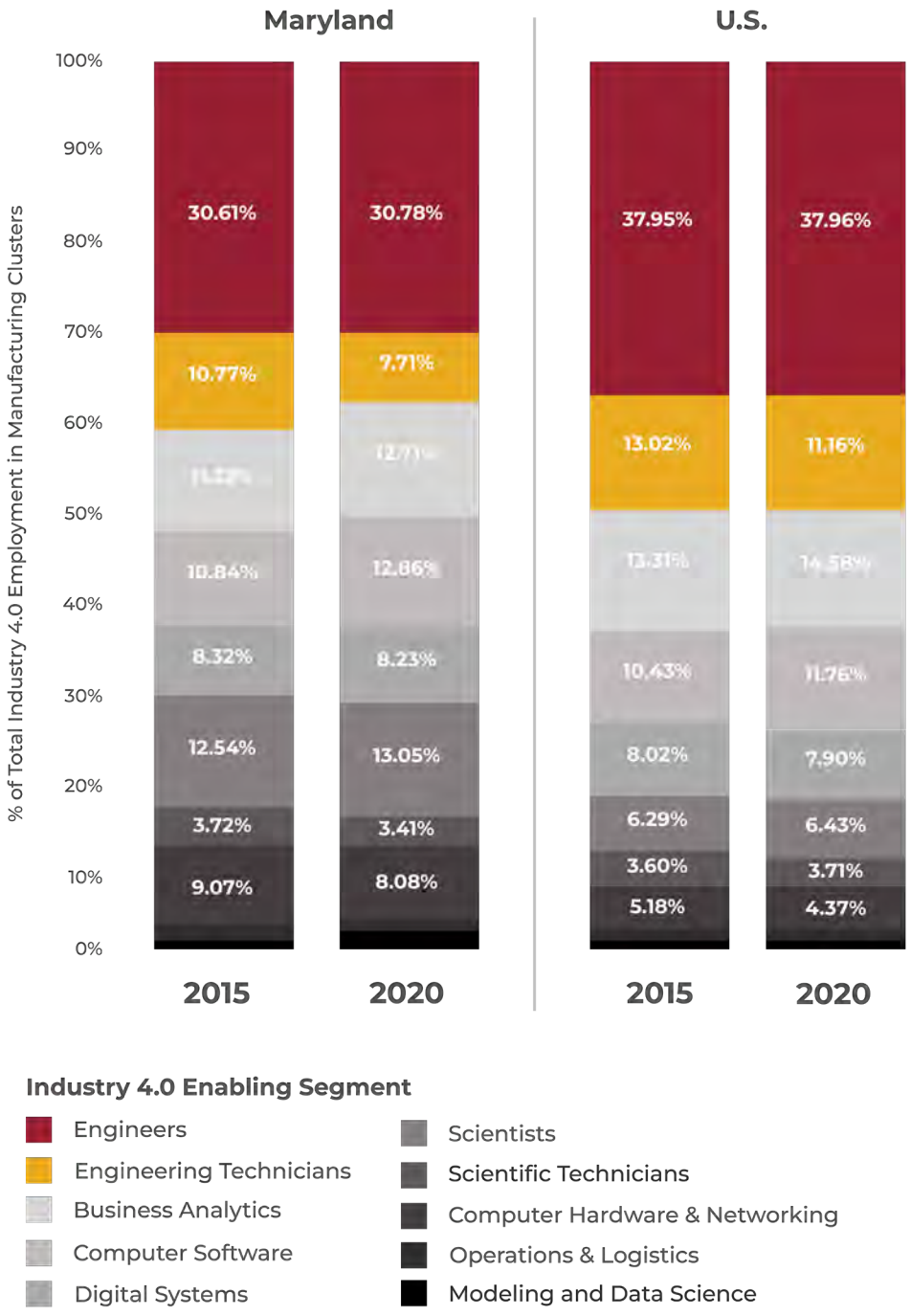
Where Maryland manufacturing does stand out today is in its significantly higher deployment of computer software, hardware, and networking occupations. Along with engineering, the demand for software talent is especially high, with Maryland manufacturers increasing their software workforce by 44% since 2015 compared to a 24% increase nationally. One in ten manufacturing industry job postings is for software professionals in Maryland compared to just 5% nationally.

Maryland also stands out in its scientific workforce, reflecting the concentration and growth of jobs in life sciences manufacturing. The life sciences are among the most R&D- and innovation-intensive sectors globally and employ a very scientific and STEM-intensive workforce. Maryland manufacturers are not standing still, hiring scientists at a rapid rate since 2015 (up 26% in Maryland vs. 12% nationally).

Although it stands at a small base today, a critical and rapidly growing 4.0-enabling segment of the manufacturing workforce is in modeling and data science positions—those spanning math, statistics, and advanced analytics and crucial for making actionable the intelligence generated out of massive data streams in a highly digitized operating environment. These professionals make up a small share of the industry's workforce, but hiring has been on a tear with Maryland manufacturers increasing their data sciences workforce by 74% versus 19% growth nationally.

[10] For growth trend comparisons vs. the U.S. in Industry 4.0-enabling occupational groupings, see Appendix B.

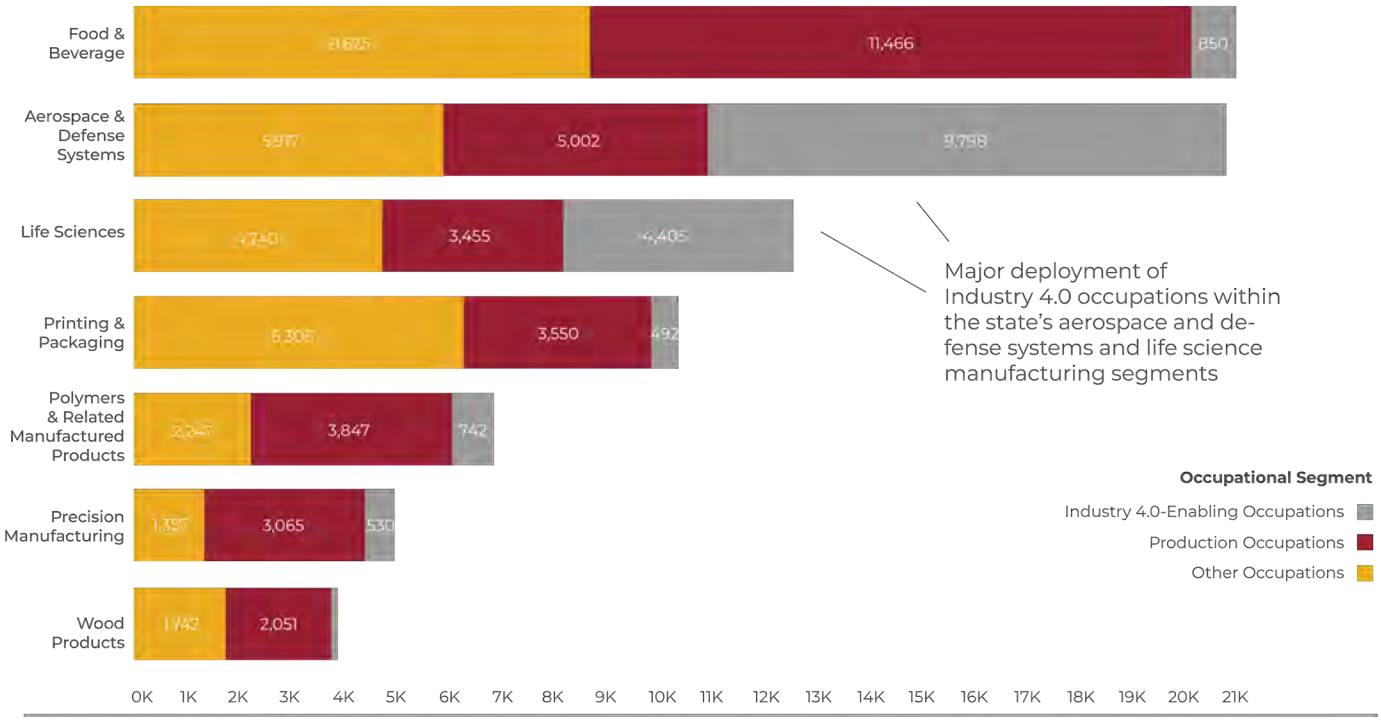
Figure 17: Detailed Industry 4.0-Enabling Occupational Employment in the Maryland and US Manufacturing Sector, 2015 and 2020



Source: TEConomy analysis of industry staffing patterns data from Emsi (Emsi Release 2021.2)

Among the seven manufacturing clusters, two stand well above their counterparts both in Maryland and nationally in their concentration and deployment of Industry 4.0-enabling talent—aerospace and defense systems and life sciences (Figures 18 and 19). Aerospace and defense systems is reliant on engineering talent (37% of Industry 4.0-related employment) but is still driven by a well-distributed mix of additional Industry 4.0-enabling occupations ranging from computing and IT to business analytics. Life sciences, on the other hand, leverages a large scientific workforce (38% of Industry 4.0-related employment) and represents a unique context, as most manufacturing industries have lower concentrations of scientific occupations relative to traditional engineering.

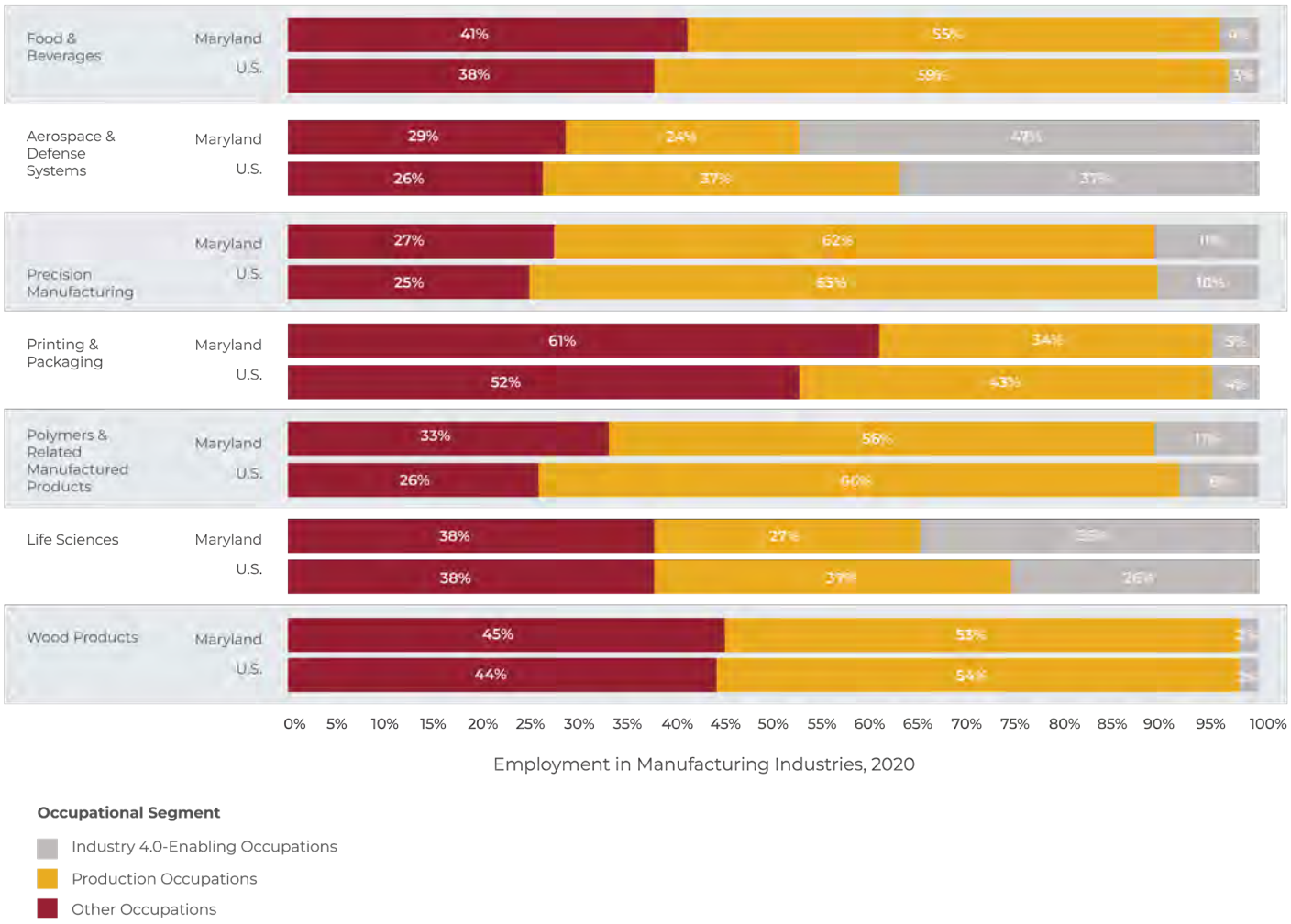
Figure 18: Industry 4.0-Enabling Occupational Employment within Maryland's Manufacturing Clusters, 2020



Maryland Employment in Manufacturing Industries, 2020

Source: TEConomy analysis of industry staffing patterns data from Emsi (Emsi Release 2021.2).

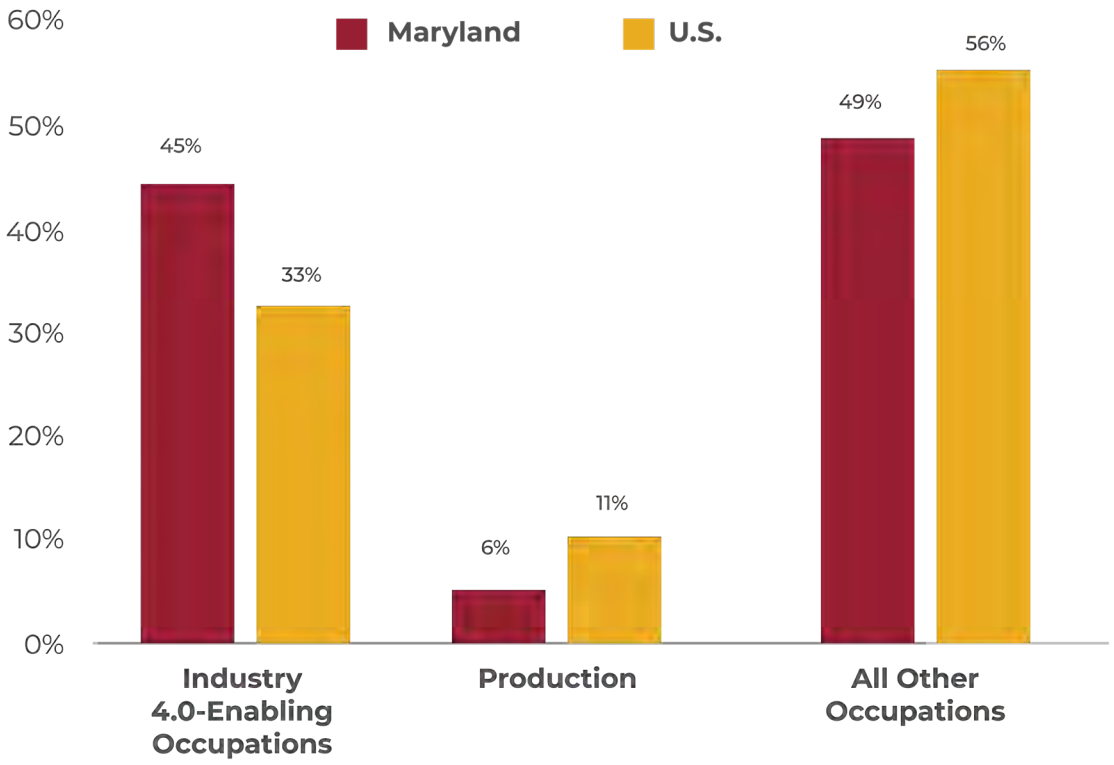
Figure 19: Industry 4.0-Enabling Occupational Employment in Maryland's Manufacturing Clusters, 2020



Source: TEConomy analysis of industry staffing patterns data from Emsi (Emsi Release 2021.2).

Maryland manufacturing is clearly ramping up hiring in these key enabling fields—nearly every manufacturing cluster experienced growth in Industry 4.0-enabling workforce in Maryland that outpaced US growth except for printing and packaging.[11] These professions are dominating industry job postings—while Industry 4.0-enabling occupations make up 21% of the manufacturing workforce, they comprise 45% of industry job postings the last 3.5 years (Figure 20).

Figure 20: Share of Maryland Manufacturing Job Postings by Major Occupational Group, 2018–July 2021



Source: TEConomy Partners' analysis of Emsi, JPA Database, Q3 2021.

Industry 4.0-enabling professions are dominating Maryland manufacturing job postings—while these occupations make up 21% of the manufacturing workforce, they comprise 45% of industry job postings the last 3.5 years.

[11] Ibid.

The challenge for Maryland will be the inevitable strain on the supply of this skilled workforce critical for Manufacturing 4.0 adoption. 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."

Maryland has an overall competitive advantage in its enabling talent situation—but is it a tale of two "tiers," with aerospace and defense and life sciences well-positioned to adopt and integrate Industry 4.0 while other clusters struggle? Although not all sectors can expect the same level of adoption, it will be important to "lift all boats" among clusters when considering strategic interventions and support.

INNOVATION SCAN: PATENT ACTIVITIES

An additional perspective on manufacturing innovation comes through trend and other analysis of intellectual property (IP) generation in the form of patent awards to firms with in-state manufacturing operations. The level of patenting tied to these "assignees" indicates the types of innovative products and processes that will potentially require new Industry 4.0 solutions and services. It also allows for a scan of potential technologies and tools developed as specific Industry 4.0 solutions.

A total of 21,650 patent award and application records were assigned to Maryland individuals and organizations over the 2015 to 2020 period. To identify key manufacturing-related assignees with in-state manufacturing plants or other production-associated sites, we focused on those entities with 10 or more patents over the time period. **This analysis identified at least 4,955, or nearly one in four, Maryland-assigned patent records that are associated with leading manufacturing companies.**

Companies with Maryland manufacturing locations are generating IP across a diversity of industry verticals—more than 70 corporate assignees had at least 10 patents from 2015 through 2020. Table 5 shows those companies with more than 40 assigned applications and awards and Table 6 shows the technology and market focuses that span defense systems sensing, networking hardware, specialty compounds (high performance materials, cosmetics, etc.), biopharmaceuticals, and medical devices.

What the patent analysis has not uncovered is a focus of firms on developing and deploying Industry 4.0-specific technologies, tools, and applications—though admittedly, when developed in-house for production process applications these digital technologies and trade secrets are often not patented. The strategic focus, therefore, is largely on promoting adoption and deployment among Maryland firms rather than a strategy to serve the globe from a solutions development perspective.

Table 5: Patenting by Leading Maryland Manufacturers: Key Companies, 2015-2020

Primary Patent Assignee	MD-Assigned Applications	MD-Assigned Awards	Total MD-Assigned Apps & Awards
Lockheed Martin Corporation	204	1,026	1,230
Ciena Corporation	119	613	732
Hughes Network Systems	75	325	400
Under Armour Inc	149	177	326
Northrop Grumman Systems Corporation	39	181	220
MedImmune	106	72	178
Senseonics Incorporated	58	49	107
MesoScale Technologies	52	44	96
Infinera Corporation	18	72	90
Macrogenics Inc.	38	48	86
Noxell Corporation	28	53	81
WR Grace & Co-Conn	21	55	76
United Therapeutics Corporation	26	46	72
Black & Decker Inc.	1	62	63
Evapco Inc.	27	26	53
Supernus Pharmaceuticals Inc.	18	32	50
Vorbeck Materials Corp	23	25	48
Qiagen Sciences	21	23	44

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

From a patent perspective, the broadly defined aerospace and defense industry cluster captures a significant portion of Maryland's industry patent portfolio, with four of the top five manufacturers(i.e., Lockheed, Ciena, Hughes, and Northrop Grumman), from that cluster accounting for 52% of all manufacturing company patents.

Technology classifications on patent records can be leveraged to assess the types of innovative products and processes local companies are investing in and to understand forward-looking implications for Industry 4.0 deployment. Leading technology areas associated with manufacturing companies in the state include:

- Optoelectronic systems and related communication components
- Diagnostic medical devices
- Biologic therapeutics and biomarker detection technologies (assays, etc.)
- Networking systems and hardware

Table 6: Patenting by Leading Maryland Manufacturers: Key Technology Areas, 2015-20

Technology Area	MD-Assigned Applications	MD-Assigned Awards	Total MD-Assigned Apps & Awards
Optical communications transmitters	21	175	196
Immunoglobulins [IGs], e.g. monoclonal or polyclonal antibodies	99	92	191
Radio transmission systems	26	122	148
Diagnostic medical devices	64	48	112
Biopharmaceuticals	43	48	91
Optical multiplex systems	16	69	85
Diagnostic biomarker detection and sample analysis	50	33	83
Therapeutic antigens and antibodies	29	52	81
Networking: Arrangements for maintenance or administration or management of packet switching networks	18	60	78
Measuring or testing processes involving enzymes, nucleic acids, or microorganisms	26	48	74
Magnetic sensing systems	24	47	71
Networking: Routing or path finding of packets in data switching networks	13	53	66
Selecting arrangements for multiplex systems	4	52	56
Cosmetics or similar toilet preparations	23	30	53
Traffic regulation in packet switching networks	12	40	52
Optical hardware elements and couplings	10	41	51
Arrangements for monitoring or testing packet switching networks	6	40	46
Constructional details common to different types of electric apparatus	4	38	42
Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, e.g. plasmids, or their isolation, preparation or purification; Use of hosts therefor	22	18	40
Methods or arrangements for reading or recognizing printed or written characters or for recognizing patterns, e.g. fingerprints	8	31	39
Therapeutic biobank products (e.g. bone marrow, lymphocytes, etc.)	22	17	39
Fuel cells; Manufacture thereof	7	29	36
Networking: Error correction and signals processing	4	32	36
Apparel: Soles; Sole and heel units	10	25	35
Network-specific arrangements or communication protocols supporting networked applications	6	28	34
Peptides having more than 20 amino acids; Gastrins; Somatostatins; Melanotropins	13	21	34
Apparel: Uppers; Boot legs; Stiffeners; Other single parts of footwear	21	13	34
Information retrieval; Database structures therefor; File system structures therefor	9	24	33
Network architectures or network communication protocols for network security	9	22	31

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

INFORMING THE "SITUATIONAL" ASSESSMENT FOR MARYLAND MANUFACTURING: THE VOICE OF INDUSTRY AND OTHER INTELLIGENCE AND INPUT GATHERED

Quantitative analyses of the baseline industry, workforce, innovation, and other data sources provide useful insights regarding the competitive positioning of Maryland manufacturing, but without the voice of industry and manufacturing ecosystem stakeholders, many of the findings are incomplete or lack underlying context. At the direction of MD MEP, the project team conducted a series of nearly 20 one-on-one interviews with manufacturing leaders across the seven clusters and regions of the state, as well as interviews with ecosystem leaders and key staff from the state's Departments of Commerce and Labor, and MD MEP.

To align with the project goals and objectives, industry interviews focused on the following topics and themes:

- The company's business needs and requirements to stay competitive in an increasingly "smart" Manufacturing 4.0 environment, including challenges or barriers to compete and to grow.
- Manufacturing supply chain dynamics, strengths, and opportunities in Maryland.
- The company's experience, if applicable, in partnering with MD MEP and/or Maryland's colleges and universities for workforce or leadership training, technology and cyber assistance, R&D, or other areas.
- Utilization of and recommendations for incentives, programs and funding including MD MEP programming, State-offered incentive programs and policies, and supportive infrastructure for manufacturing.

When combined with the following resources and additional intelligence, this input and the voice of industry forms a foundation for better understanding the situation for manufacturers regarding investing in Industry 4.0 technologies and related needs and challenges. The additional intelligence was drawn from:

- The preceding baseline quantitative assessment of MD manufacturing industry and ecosystem;
- The Department of Commerce 2021 survey of more than 200 Maryland manufacturers;
- Annual Reports from Maryland DoC and DoL economic development programs/incentives; and
- MD MEP projects/engagements since 2015 as reported to NIST.

The project and its interim work products, key findings, and conclusions have further benefitted from the regular guidance and input provided by the project Advisory Committee, consisting of a blend of manufacturing leaders representing industry, state government, MD MEP, and the national NIST organization. In addition, project leadership met with and presented preliminary findings to Maryland's Transforming Manufacturing Workgroup, a group of more than two dozen manufacturing leaders, state government leaders, legislators, university representatives, and other key stakeholders. Both the Advisory Committee and Transforming Manufacturing Workgroup have provided valuable feedback that largely confirmed key findings but also suggested helpful input and refinements, essentially serving as well-designed focus groups for the course of this project.

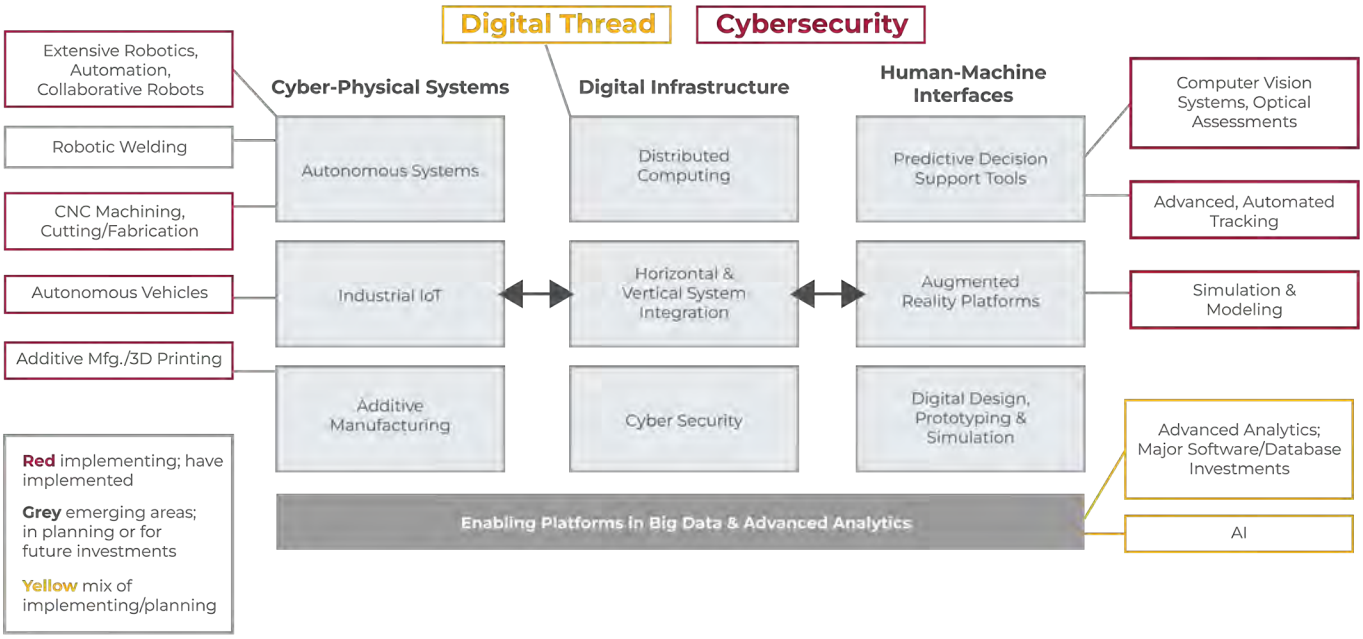
THE SITUATION FOR INDUSTRY 4.0 TECHNOLOGY ADOPTION/ INTEGRATION IN MARYLAND: PRIMARILY DISCRETE IMPLEMENTATION, COMPANIES POINT TO SEVERAL CONSISTENT CHALLENGES, BARRIERS TO TECH ADOPTION

Maryland manufacturing leaders are adopting and integrating numerous technologies and capabilities squarely in the digital automation and Industry 4.0 context; however, this adoption, particularly among SME manufacturers, is most often discrete and not broadly integrated to realize the full capabilities and data-driven insights of a 4.0 environment. Interviews indicate a generally low adoption rate of integrated industry automation and 4.0 technologies, and that Maryland is lagging behind as a state. Maryland manufacturing SME's today typically use primarily discrete individual technologies (e.g., a 3D printer, virtual reality simulation, robotic welding equipment) but are not yet implementing multi-technology, digitally integrated systems that harness the full potential of Industry 4.0 advances and data-driven insights.

Figure 21 maps the types of Industry 4.0 technologies being adopted today and in the near future. It is important to note that these are based on the set of interviews conducted, and are not an exhaustive survey or inventory of Maryland manufacturing.

Figure 21: Types of Industry 4.0 Technologies Being Adopted/Integrated in Maryland Today and in Near-Future

(Based on Maryland manufacturing interviews, not an exhaustive inventory)



Source: TEConomy Partners, LLC.

The technologies and capabilities mapped to the outer edges of Figure 21 were assigned a color-coding based on the implementation status described by the companies interviewed. Most of the technologies with a red outlined box are relatively well-developed and accessible for "plug and play" today. Others, such as those in yellow outline, represent more advanced, higher-order capabilities that lean toward harnessing AI and advanced analytics for predictive modeling and maintenance, automated communication and planning with suppliers (such as requiring and leveraging both internal and external data streams), and customizing production runs.

Several forces are driving the integration and adoption of Industry 4.0 technologies (Figure 22). The most consistent challenge reported by employers, and the most-cited driver for adopting automation technologies, is a lack of qualified workers to fill vacancies—a situation exacerbated by retirements that accelerated amid the COVID-19 pandemic, an aging workforce, and broader competition for the skilled manufacturing workforce (e.g., with tech companies like Amazon). These talent gaps and shortages are a major driver of Industry 4.0 and other automation solutions. Acute shortages reported by several manufacturers span both traditional roles in operations such as welders and industrial maintenance, but also areas critical for advanced automation and Industry 4.0-enabling roles, such as automation mechanics. A key question is: Can the rate at which manufacturers have been posting jobs for and hiring high-skilled IT and engineering talent continue?

As a backdrop to sourcing and retaining talent, manufacturers report Maryland's already high and rising labor costs represent an additional pain point for hiring. Manufacturers often "poach" the workforce of competitors, for example, by offering slightly higher wages to high-demand, translatable skilled trades such as welding or industrial maintenance. But increasingly, given the new labor market dynamics of the COVID and post-COVID years, they cite competition against rising wages paid in fast food and other industry competition they previously had not had to consider. The competition for the existing and potential manufacturing workforce is stiff and more often is out of employers' hands.

A longer-term existing challenge, and one that is not unique to Maryland, are the negative perceptions of manufacturing careers in the minds of students and young workers and professionals. MD MEP and others are working to counter these perceptions with programming such as the "Faces of Maryland Manufacturing" which promotes awareness of the breadth of exciting opportunities in a modern production environment.

While overall talent and key skill shortages present a major challenge to Maryland manufacturers today, interviews suggest it is a major driver of Industry 4.0 technology investment. Companies increasingly recognize that in today's constrained talent pool, they cannot hire their way to increased productivity and output.

THE ONGOING (AND WIDENING) SKILLS GAP IN U.S. MANUFACTURING

Maryland manufacturers are not alone in their workforce challenges—the industry as a whole is experiencing serious difficulty in finding the right talent and filling open positions. In recent years, Deloitte and The Manufacturing Institute have surveyed manufacturers to understand and project national skills gaps and other labor force dynamics within and across the industry.[1]

Their latest survey of more than 800 U.S. manufacturers found:

- The skills gap in U.S. manufacturing is expected to leave 2.1 million jobs unfilled by 2030.
- This potential gap could result in a $1 trillion economic impact (cost) to the nation's economy.
- 77% of companies surveyed expect ongoing difficulties in attracting and retaining workers through 2021 and beyond.
- Finding talent is 36% harder than it was in 2018.

Manufacturers increasingly have difficulty hiring middle-skilled workers, including CNC machinists, welders, and maintenance technicians—all areas identified by Deloitte, as well as in interviews with Maryland manufacturers.

The study recognizes the implications for Industry 4.0 that are likely to exacerbate the existing challenges:

"As digital transformation in the manufacturing industry continues to develop, the skills needed to do the jobs in the smart factory will likely be different than skills used today. But today's manufacturing workforce doesn't possess many of these skills."

[1]Deloitte and The Manufacturing Institute. "Creating pathways for tomorrow's workforce today: Beyond reskilling in manufacturing." May 2021.

Figure 22: What's driving the integration of automation, Industry 4.0 technologies among Maryland manufacturers?

Labor & Talent Shortages

COVID-Related waves of retirements; aging workforce; high and increasing wages

Focus on Productivity & Quality Enhancements

Increasing output, precision, accuracy in design, production

Systems Integration

Addressing legacy IT systems as a pre-requisite to leveraging data, "predictive" capabilities

Declining Cost Curves

Declining cost curves (on some tech) leads to affordability and increasing ROI

Source: TEConomy Partners, LLC based on project interviews and discussions.

Common Barriers & Challenges to Industry 4.0 Technology Adoption

At the crux of this project and its primary objectives is assisting Maryland manufacturers in addressing major challenges and barriers to increased technology adoption. Essentially, we want to answer: How do we help to "de-risk" technology adoption, particularly for SME manufacturers? It is therefore important to consider the consistent themes raised regarding these barriers (summarized in Figure 23).

Maryland SME manufacturers have few resources to start the Industry 4.0 journey. Companies interviewed cited a general lack of resources and expertise to simply know where to start and what is appropriate for their firm. A major theme in these discussions centered around firms' interest in and needs to test, pilot, and demonstrate 4.0-related technologies before making individual investments or trying to implement digital solutions at scale. As one manufacturing CEO remarked regarding digital automation investments under consideration: "To see this type of [automation] technology demonstrated I have to leave the state, as Maryland companies only see a competitor." Other states through MEP or other organizations and nations, such as Germany and Japan, have put in place extensive resources accessible to all manufacturers to test, pilot, and demonstrate technologies—some of which will be highlighted in the following section.

The significant costs associated with digital technology investments and their integration with legacy IT systems represents another major hurdle, particularly for SMEs, but also for large manufacturers. And while pricing a particular piece of equipment or software package may be relatively easy, what's more challenging for firms is understanding the return on that investment. A key resource for manufacturers currently lacking in Maryland is a database or repository of Industry 4.0 "use cases"—real-world examples and experiences of manufacturers implementing technologies and driving them to scale—to help their counterparts understand the ROI and payback on digital investments. Just one example was illustrated in discussions with a Maryland manufacturer who had recently implemented a new robotic solution, representing a $200,000 expense. The new automation equipment allowed her firm to enter a new product line/market, and in two years it had paid for itself in the value of new sales.

Implementing Industry 4.0 technologies has major implications for the industry's workforce, both in terms of incumbents and new hires. There is a broad-based need for enhanced digital skills, additional IT specialists, data scientists, and professional engineers, technicians, and scientists who have hybrid expertise. This hybrid expertise takes the form of mechanical engineers with embedded electronics or systems skills. For example, one manufacturer emphasized the need for employees who were "both mechanically and tech competent," such as an industrial engineer with some data sciences knowledge and expertise. Thus, there are needs for education and training resources to upskill the existing manufacturing workforce that are flexible and very focused, while continuing to generate the core talent that maps to "enabling" roles.

Enabling 4.0 tech adoption by addressing foundational technologies and technology infrastructure for interoperability and systems integration. A dynamic Industry 4.0 operating environment is not simply "plug and play" but requires addressing the integration of new machinery and services into existing operations. Often, manufacturers face the challenge of integrating new smart solutions in an environment where numerous legacy software systems and hardware components must now communicate with each other, send data, and connect with cloud-based services.

These barriers and challenges raised by Maryland manufacturers are largely in-line with those seen in global manufacturing surveys. Responses from McKinsey & Company's pre-pandemic (2019) global survey of manufacturing leaders identified the following as the three leading challenges facing companies in implementing Industry 4.0 solutions:[12]

- Lack of people, skills, and knowledge (38%)
- Datasecurity concerns (32%)
- Lack of funding (30%)

In 2020, the COVID-19 pandemic shifted these to a degree, with lack of funding because of the pandemic, limited understanding of the technology and vendor landscape, and lack of people/skills/knowledge making up a nearly equal share of the top challenges.

12 | McKinsey & Company, "COVID-19: An Inflection Point for Industry 4.0," January 15, 2021.

Figure 23: Major Barriers Identified by Maryland Manufacturers to Adopting Industry 4.0 Technologies

MD MEP is engaged in developing and delivering relevant Industry 4.0-related programs and services for Maryland manufacturers; but in examining project focus, and through discussions with manufacturing leaders, there is a recognized need for MD MEP to reach a greater scope, scale, and intensity of these services, and to add capacity to guide companies on this journey. Today, MD MEP is delivering:

- Tech-focused projects with specific companies related to robotics adoption and installation, automation support, and physical-to-digital conversions
- Advanced manufacturing training and fiscal support for Industry 4.0 training opportunities identified by manufacturers
- Cybersecurity assessment and mitigation with a defense-related focus
- Supply chain resiliency projects with a focus on reducing risk and improving outcomes across the organizational supply chain
- Career awareness through its “Make It In Maryland” programming
- Networking, innovation events (e.g., the Maryland Manufacturing Innovation Conference)

Manufacturing leaders are expressing support for enhanced capacity in strategic planning services and facilitation with respect to Industry 4.0 implementation.

ADDITIONAL EMERGING MARKET AND ENGAGEMENT OPPORTUNITIES IDENTIFIED FOR THE MARYLAND MANUFACTURING STRATEGIC PLAN

In addition to and beyond the Industry 4.0 context, the baseline quantitative and other analyses, as well as the situational assessment, raise several opportunities important to future manufacturing growth and competitiveness, as well as to the role and strategic focus of MD MEP going forward. These opportunities further inform the strategic priorities for Maryland manufacturing and the recommendations that follow.

- **Despite its legacy and strong roots in Maryland, the life sciences cluster represents a continued "emerging" opportunity for economic development as a high-growth sector and for deeper engagement by the manufacturing community and associated resources (namely, MD MEP), including with adopting Industry 4.0 technologies.** Beyond its recent strong growth in biopharmaceutical and medical device manufacturing, Maryland's Biotech R&D sector in Maryland is large, highly specialized, and growing—its employment base is up 35% from 2015 and the state LQ is an impressive 2.77. This sector, while technically outside the "manufacturing" realm, represents the opportunity for future Maryland-based biopharmaceutical manufacturing as companies commercialize products and shift to a production mode. The state has an opportunity to engage and root these companies in Maryland for prototype development and small batch runs for clinical trials, but also and most importantly for longer-term production.

- **Maryland is leveraging opportunities for offshore wind farm development to bring steel manufacturing, construction, and other supply chain components to a waterfront manufacturing hub.** With wind farm development proceeding off the coast of Ocean City, US Wind, a subsidiary of Italian energy firm Renexia SpA, is turning an old shipyard at the former Bethlehem Steel mill site at Sparrows Point into an offshore wind construction and manufacturing hub.[13] The site spans 90 acres at Tradepoint Atlantic, a 3,300-acre logistics center in Baltimore County. The steel plant would build the wind turbine towers that are anchored to the ocean floor and look to supply US Wind's local projects, as well as longer-term opportunities across the national wind energy market.

- **Many Maryland manufacturers interviewed are eager to connect with intra-state suppliers.** Conversations revealed that many source commodity inputs from outside the state, both domestically and internationally due to competitive cost differentials, but there are connections on key items. The challenge is a lack of awareness of other firms' offerings.

- **Industry 4.0's emphasis on raising productivity and up-skilling existing workforce creates a misalignment with most economic incentives available to manufacturers.** Like many other states, Maryland emphasizes net new hires as a path to accessing key economic development incentives (e.g., via the More Jobs for Marylanders tax credits). Recognizing that an increasingly automated, digital manufacturing 4.0 environment will result in changes to existing roles and require up-skilling of the incumbent workforce, manufacturing leaders see an opportunity for Maryland to re-frame this emphasis toward productivity as a measure of success. This has implications for state incentive design, including, as one leader framed it, an opportunity for a Maryland "modernization" focused program or initiative.

[13]Lorraine Mirabella, "Wind Farm Developer Plans to Bring Manufacturing Back to Baltimore's Sparrows Point," The Washington Post, August 8, 2021.

COMPETITIVE THREATS TO BE CONSIDERED, ADDRESSED

Just as there are opportunities, there are threats to Maryland manufacturing, often externally generated. Discussions with manufacturing leaders raised several themes that can and should be considered as potential threats to Maryland's manufacturing sector and its competitiveness into the future:

- **Acknowledging the competitive importance and dynamics of Industry 4.0 technologies and capabilities to manufacturing, other states (and many nations) are beginning to re-direct existing incentives and state programs toward tech adoption and integration, or starting up wholly new initiatives.** As will be shown in the following section, these states are mobilizing millions of dollars to prioritize Industry 4.0, and if Maryland does not follow suit, the sector will face additional competitive challenges for its firms and talent base from other states.

- **Cybersecurity threats are real, and in increasingly cyber-physical manufacturing environments, these threats will only increase their potentially devastating impacts.** In both interviews with Maryland manufacturers and conversations with other manufacturing leaders TEConomy interacts with across the country, this is a major issue and a consistent theme that keeps CEOs up at night. Companies interviewed, particularly SMEs, often indicate they fully outsource their cybersecurity countermeasures, but this has not insulated them from a steady assault from bad actors; several cited recent ransomware attacks. These literal threats place Industry 4.0 investments in the crosshairs, and cybersecurity must continue to be a programmatic emphasis of MD MEP and others, particularly in the highly sensitive aerospace and defense systems supply chain.

- **In the Industry 4.0 context, at least a few manufacturing and state leaders recognize the potential threats of uneven adoption of digital manufacturing technologies.** The threat is envisioned as a potential dynamic of a sector characterized by "Haves" versus "Have Nots" that could be seen among:
    - » Large manufacturers and/or OEMs versus SME dynamics;
    - » Different manufacturing clusters (e.g., life sciences and aerospace and defense versus other less tech-driven sectors); and/or
    - » Different generations of manufacturing leaders and their comfort levels and familiarity with tech integration, for example Baby Boomers versus Gen Z.

FOUR STRATEGIC PRIORITIES IDENTIFIED

The key findings from all aspects of this planning effort, including the consistent themes raised across interviews and group discussions, must be considered in designing the recommended strategies and actions in the following section. The baseline quantitative and situational analyses points to four strategic priorities on which to organize and focus the recommended strategies and actions of this plan. These include:

1. Establishing resources for starting the Industry 4.0 journey for Maryland manufacturers.

2. Addressing the barriers and challenges to Industry 4.0 technology adoption and integration.

3. Strengthening intra-state supply chain connections.

4. Seizing emerging manufacturing industry and market opportunities.

Combined, these strategic priorities are aligned with the overall project goals and objectives and draws from the key findings. Each priority area is addressed in the following section, along with associated recommended actions for the state and its manufacturing leaders and stakeholders to consider.

III. RECOMMENDED STRATEGIES AND ACTIONS TO ENSURE A COMPETITIVE FUTURE FOR MARYLAND MANUFACTURING

Key findings from the preceding quantitative and qualitative project components and the situational assessment have raised four strategic priorities for Maryland to maintain a competitive manufacturing sector into the future. The priority areas frame the structure for the recommended actions for Maryland to take to seize upon the opportunities presented by Industry 4.0 adoption and integration, but also to consider "win-win" opportunities for a better-connected intra-state supply chain, as well as emerging growth market opportunities identified.

It is envisioned that MD MEP will play a lead role in many of these strategic interventions, but effective partnerships are vital for implementation as many recommendations require collaboration with state government agencies (e.g., Departments of Commerce and Labor), Maryland research universities and community colleges, industry associations, and others across the ecosystem.

Across each set of recommendations illustrative examples of programs and initiatives from other states, regions, or nations are included to help place these recommendations in an actionable context and to provide examples of best practices. In addition, suggested metrics are proposed to track the progress and outcomes most closely associated with the recommended strategies and actions in Maryland into the future.

Four Strategic Priorities Identified:

1. Establishing resources for starting the Industry 4.0 journey for Maryland manufacturers.
2. Addressing the barriers and challenges to Industry 4.0 technology adoption and integration.
3. Strengthening intra-state supply chain connections.
4. Seizing emerging manufacturing industry and market opportunities.

STRATEGIC PRIORITY 1: ESTABLISHING RESOURCES FOR STARTING THE INDUSTRY 4.0 JOURNEY

A strategic gap for Maryland manufacturers, particularly SMEs, is knowing where or how to start their Industry 4.0 journey. A consistent need has been raised for appropriate resources and expertise to get started. Companies face myriad decisions and options, ranging from which equipment and technologies are most appropriate and impactful for the nature and size of their production runs, to digital and other readiness to adopt; how to access reputable vendors and technology integrators; how to secure their data in a new cyber-physical environment; how to integrate and customize solutions aligned with supply chains; and more. Related to this is a consistent need expressed by Maryland SME manufacturers for a "sandbox" or physical lab for piloting, testing, or demonstrating new digital Manufacturing 4.0 technologies.

"To see this type of [automation] technology demonstrated I have to leave the state as Maryland companies only see a competitor."

Maryland Manufacturing Leader

MD MEP is playing an important role in assisting with tech-focused projects, including robotics adoption and installation, automation support, and the physical-to-digital conversion, but many of these engagements are further "upstream" on implementation rather than conducting upfront Industry 4.0 assessments and strategic planning facilitation with respect to a path to staged implementation. The recommended actions within this strategy envision MD MEP in the lead role in partnership, where appropriate, with state partner organizations.

Other states and nations have already, or are in the process of, mobilizing early-stage 4.0 resources, particularly for manufacturing SMEs whose needs in this earliest phase of adoption are greatest (see text boxes for best practices examples).

The following recommended actions are designed to establish key resources for starting the Industry 4.0 journey for Maryland manufacturers.

Action 1.1: Offer Manufacturing 4.0-specific assessments and facilitation for Maryland SMEs.

- MD MEP should take the lead on this initiative but will need to add capacity and expertise.
- Utilize the NIST-MEP network to understand best practices and lessons learned in one-on-one, in-depth assessment design and implementation of assessments and counseling practices that are designed specifically for SMEs. Several state MEP programs are utilizing these today, including MMTC and Automation Alley in Michigan, CIRAS in Iowa, and MassMEP.
- Actively promote the use of these assessments online but also through regional networking events to ensure strong participation and ability to meet firms where they are today.
- Post-assessment, vet and facilitate connections with reputable technology integrators for actionable follow-on projects by participating companies.

Action 1.2: Invest in and support a Maryland Manufacturing 4.0 Tech Demonstration and Training Lab primarily targeted toward SMEs.

- It is important to establish a physical, collaborative, highly accessible space given the nature of manufacturing engineering challenges.
- Begin with identifying core technology capabilities relevant to a wide array of manufacturers, sectors, and production processes so as to serve a varied "customer" base; these could include augmented reality devices, co-bots, and 3D Scanners.
- A demonstration lab can take various forms—Germany's Mittlestand Digital SME Competence Centers have embedded demonstration and testing labs into their regional sites; the GENEDGE Alliance (Virginia's MEP) has developed a mobile demonstration lab.
- Explore strategic partnerships to fund a Lab or Center to ensure that access is granted to SMEs at no-cost.
- Plan to hold both in-person and virtual networking events at the Lab to promote its services and resources.
- Align applicable technology demonstrations with 4.0 assessments for SMEs to see equipment in action.

Action 1.3: Catalog and showcase "Use Cases" in communicating the ROI and the journey for other manufacturers that have successfully implemented Industry 4.0 technologies and to assist in making the business case for investments.

- Host a digital library and integrate into networking and informational sessions statewide Industry 4.0 "where to begin" events for SMEs.
- Promote peer networking for SMEs to share their experiences, challenges, solutions, and key lessons learned.

Action 1.4: Provide assessment and informational resources for systems integration and addressing interoperability challenges.

- Develop and provide an interoperability assessment and basic informational resources for Maryland SMEs to assist in anticipating and evaluating challenges and potential obstacles to integrating new automation equipment and Industry 4.0-enabled technologies. This will require leveraging subject matter experts (e.g., technology integrators, consultants) but the logical access point, assessment, and information delivery should be through MD MEP and its website.
- Resources should include best practice solutions across key technology layers, including machine-to-machine (M2M) interoperability, authentication and data transfer protocols, and cloud-based services.

Action 1.5: Implement regular survey efforts to gauge progress on Industry 4.0 adoption among Maryland SMEs.

- Design and implement biennial surveys to assess the progress of Maryland manufacturing SMEs on the Industry 4.0 journey, as regular and proper assessment will reveal commonality of needs, challenges, technologies, and other characteristics MD MEP and others should focus on.
- Capture information by key demographics including size of firm, manufacturing cluster, region, growth trajectory.
- Focus questions on manufacturer's ability to access resources and expertise within the state, initial steps on the 4.0 journey, pain points along the way, key equipment or applications utilized, scale and scope of 4.0 integration, etc.

Example programs and illustrative best practices related to these recommendations include:

Iowa: CIRAS' Digital Manufacturing Lab is De-Risking Tech Adoption

- Partnership between Alliant Energy and Iowa State University's Center for Industrial Research and Service (CIRAS) helps business evaluate problems and find opportunities using innovative 4.0 technology
- Provides no-cost access for lab tours, testing & training, assessment, connections with vendors for implementation

CT: Matching Grants for Digital Readiness & Cyber Assessments

- The Smart Industry Readiness Index (SIRI) helps companies assess their readiness for incorporation of Industry 4.0 technology, assess their current capabilities for digital transformation, benchmark their current status in key areas against other like manufacturers, prioritize areas for focus/investment, and provide a roadmap to incorporation.
- **This matching grant program will underwrite up to 50% of the cost** of such an assessment to lower the cost for manufacturers to access such an analysis. **In addition, this program will be used for cybersecurity assessments and roadmaps.**

Germany: Mittelstand Digital SME Competence Centers

- Initiative consisting of 26 competence centers scattered throughout Germany providing information and digitalization support to SMEs free of charge
- Centers provide expert knowledge use cases, and networking
- Centers are focused on technology adoption with demonstration and test environments, model industry 4.0 production lines, access to technology integration services, and mobile solutions labs

To track progress on this strategy into the future, industry stakeholders should measure and track:

- Participation in Industry 4.0 and digital readiness assessments by SMEs
- The share of assessment participants that have proceeded to early-stage adoption of Industry 4.0 technologies
- The share of SMEs that are reaching scale in Industry 4.0 adoption

It is important to implement and utilize surveys and follow-on reporting to track these progress measures.

STRATEGIC PRIORITY 2: ADDRESSING BARRIERS AND CHALLENGES TO INDUSTRY 4.0 TECHNOLOGY ADOPTION, INTEGRATION

The steep costs of digital and advanced automation technology investment and the costly process of integrating with legacy IT systems and capabilities is cited as a leading barrier to Industry 4.0 adoption—both in Maryland and globally. Today, many states, including Maryland, will provide targeted incentives to manufacturers to hire new employees or to re-locate their operations. These initiatives and resources are viewed by many manufacturers as outdated and out of touch with their more relevant focus on productivity-enhancing investments, which are increasingly digital in nature, and even include software purchases. Several states—including Connecticut, Indiana, Iowa, and Massachusetts—are now reconsidering the focus of their traditional economic development incentives for manufacturers and expanding their purview to provide significant resources for Industry 4.0 technology investments.

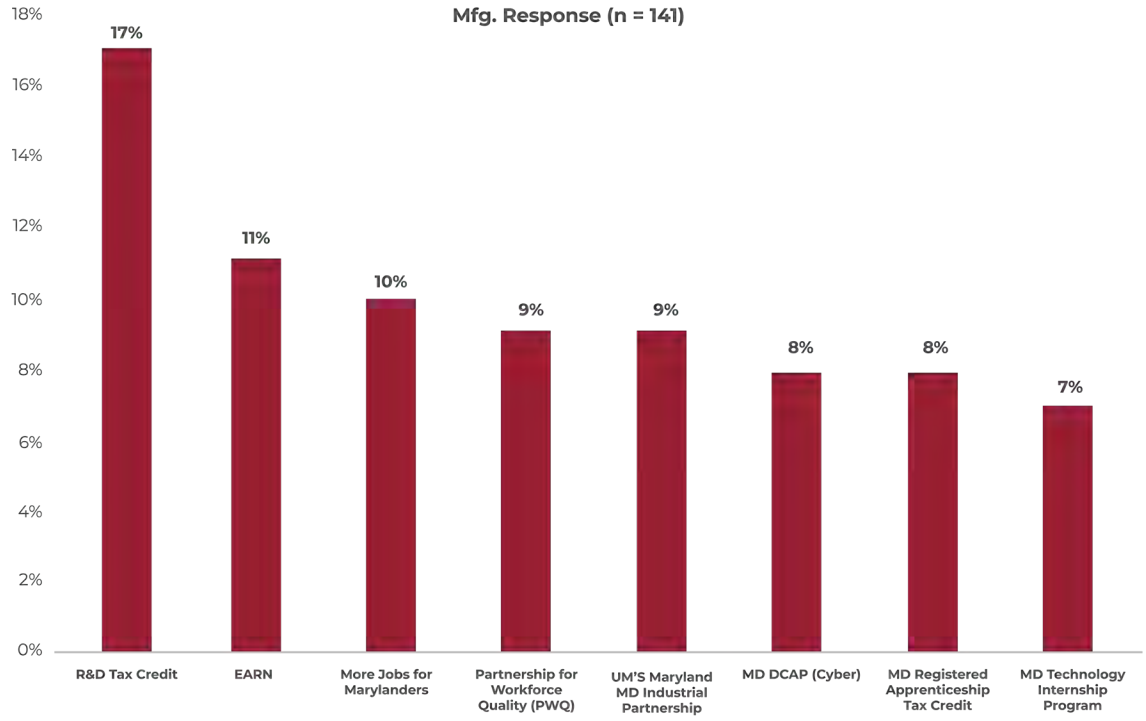
> "As a state, we're 100% in the dark [with respect to Industry 4.0], our leadership is not fostering a culture...we're way behind."
>
> **Maryland Manufacturing Leader**

To remain competitive in a truly global manufacturing marketplace and to adjust to the reality of fewer skilled employees upon which to draw, Maryland manufacturing must advance Industry 4.0 adoption broadly. The centerpiece of the recommendations made under this strategic priority is a re-orientation of resources to de-risk strategic digital investments.

In addition, while the state provides several appropriate programs, initiatives, and incentives to support workforce development, the shifts occurring for manufacturers in an Industry 4.0 environment are significant and require expanding some existing programming as well as embracing new and flexible approaches.

In general, there is a lack of awareness among manufacturers of key state incentives and programs; and, despite some positive experiences with programs as noted in the "strengths" section above, many programs are seen as burdensome, challenging, and expensive to access. Figure 24 shows the share of 141 manufacturing firms responding to the Maryland DoC survey regarding familiarity with numerous state programs—typically 10% or fewer were familiar with programs designed for or most relevant to manufacturers.

Figure 24: Survey of Manufacturers Finds Lack of Awareness of Key Maryland Programs, Incentives
Question: *Please indicate which of the following Maryland business tax credits, financial programs, and assistance you are familiar with. Select all that apply. (Only selected programs shown here).*



Source: Maryland Dept. of Commerce, 2021 Maryland Manufacturing Survey.

The following recommended actions are designed to assist manufacturers in successfully adopting and deploying Industry 4.0 technologies by de-risking technology investments through targeted assistance, further leveraging current incentive programs, addressing cybersecurity threats, and supporting shifting workforce dynamics.

Action 2.1: Develop and deploy a state incentives program—The Maryland Manufacturing Innovation Fund—to de-risk and address cost challenges for SMEs to invest in digital, Manufacturing 4.0 Technologies.

- Recognizing the upfront costs and funding concerns of small firms, it is recommended Maryland utilize a matching grants approach for most effectively addressing the needs of SME manufacturers (vs. tax credits).
- Consider capping matching grants at a per-project cost maximum.
- Align incentives with a set of pre-approved implementation and integration paths associated with Industry 4.0 and, guided by MD MEP, consider full costs of both hardware and software purchases.

Action 2.2: Build awareness among Maryland manufacturers of existing state incentives and programs, particularly those applicable to Industry 4.0 investments and workforce and talent development.

- Survey data and project interviews reveal a stark disconnect between manufacturers and their awareness of a varied menu of state incentives and programs. It is recommended that MD MEP, in partnership with Maryland Departments of Commerce and Labor, work to proactively educate manufacturers on types of incentives available and how to access resources—this could include via workshops or other events, or via peer networking leveraging those who have successfully made use of programs.
- Specific programs with an orientation (or potential orientation) toward assisting on the Industry 4.0 journey, including Partnership for Workforce Quality training/up-skilling matching grants, EARN, and accelerated depreciation.

Action 2.3: Advance broad-based assistance and strategic partnerships in addressing cybersecurity threats to manufacturers.

- MD MEP already assists manufacturers under the Defense Cybersecurity Assistance Program or DCAP, which targets funding and assistance for defense contractors to comply with Defense Federal Acquisition Regulation Supplement (DFARS) and NIST standards for cybersecurity.
- The defense focus of cyber assistance is highly appropriate, but cyber-related challenges are experienced across manufacturing, and a broader level of assistance is needed.
- Deploy company-specific assessments and explore collaboration to leverage extensive expertise in and across Maryland, including strategic partnerships with Maryland research institutions.

Action 2.4: Support both up-skilling and broad-based training of Maryland's manufacturing workforce–both among incumbent workers and across the education pipeline–at an appropriate scale for impending rise of Industry 4.0.

- Up-skilling the existing manufacturing workforce requires practical and flexible approaches, primarily short-duration education/training. The state should embrace and adopt 4.0-focused micro-credentialling approaches, certificates, and other "stackable" credentials
  - » Particularly for middle-skilled incumbent workforce, and
  - » Consider incentivizing data science-related cross-training for Engineering, Scientific, and Tech professals.
- Universities should continue to advance advanced analytics and data sciences programs and curriculum—particularly in a hybrid approach complementing engineering, scientific, and tech degree programs.

- Consider expanding and scaling up Partnership for Workforce Quality (PWQ) training grants with a continued focus on SME incumbent workforce, ensuring appropriate focus on Industry 4.0 tech.
    - » PWQ training/up-skilling matching grants are highly appropriate for incumbent worker training and up-skilling, but it is a program that needs to reach greater scale—in FY 2021, just 17 companies participated, only 8 of which were manufacturers.
- Leverage public-private partnerships for automation credentialling (e.g., "SACA" in Robotics)
- Leverage the EARN Maryland program for talent development around maintenance and automation techs and other high-demand positions relevant for 4.0 Tech. Just as the state has targeted "Green," Cyber/IT, and Clean Energy, there is an opportunity to focus on Manufacturing 4.0 from a strategic perspective.

Example programs and illustrative best practices related to these recommendations include:

Indiana: Conexus' Manufacturing Readiness Grants

- Conexus Indiana is partnering with the Indiana Economic Development Corporation (IEDC) to launch a new grant program.
- **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.

MANUFACTURING 4.0 TECHNOLOGY INVESTMENT PROGRAM
Innovative Technology Infrastructure Grants

- Provides grants that assist SMEs with the adoption and integration of smart technologies into existing operations in the state. Two types of grants are offered through this program (Requires 1:1 match):
    - **Mfg. Innovation Equipment Grants- Up to $50,000 grants**
    - **Mfg. IIoT Infrastructure Investment Grants- Up to $25,000** for the purchase of specialized hardware or software in the Industry 4.0 technology groups.

MA: Funding Capital Investments & Preparing Supply Chains

- Launched a **new $2 million grant program that will invest in small- to medium-sized manufacturers** across the Commonwealth. The new Massachusetts Manufacturing Accelerate Program (MMAP) aims to co-invest in small- to medium-sized manufacturers **to better prepare their businesses to meet the demands of 'Industry 4.0,'** the innovation-driven production methods powered by smart technologies such as data analytics, cloud computing, artificial intelligence, automation, and connected technologies to stay competitive.

Consider the examples highlighted above spanning new programming across several states leveraging significant resources:

- Connecticut: $8.3M recently released from a $20M fund to support series of manufacturing technology, workforce initiatives via Connecticut Manufacturing Innovation Fund.
- Iowa: $25M designated for Manufacturing 4.0 Innovation Grants.
- Indiana: $6.7M awarded for Manufacturing Readiness Grants; $20M for extending the program through 2023.
- Massachusetts: $2M for new SME grant programs
- Michigan: allocating $3M for various Industry 4.0 initiatives, proposals.

Workforce-related examples and illustrative best practices include:

Purdue University "Stackable" Tech "Badges" as Micro-Credentialing Tool

- Badges are earned online and can potentially be stacked toward a graduate degree. Cummins in Indiana recently began an "Analytics" pilot program; Intel has also worked with Purdue in Cybersecurity.
- Example Courses in Analytics: Introductory Analytics; IoT Intro; Machine Learning Technologies

Wisconsin: Gateway Technical College SC Johnson iMET Center

- Home to 12 academic programs taught in smart factory environments in partnership with a variety of national companies
- Focus on I4.0 technical professions such as IT & Data Analytics Specialists, CNC Production Techs and Programmers, and Advanced Manufacturing Specialist certification that includes training in robotics, mechatronics, motor control, PLC and HMI programming, industrial controls, and IIoT (developed in part with Rockwell Automation)
- Houses 3D industrial design "Fab Lab" maker space for training and prototyping
- Utilizes hands-on training with Rockwell Automation, Fanuc mfg. systems

To track progress on this strategy into the future, industry stakeholders should measure and track:

- Levels and trends in manufacturing GSP, both overall and for the seven Maryland clusters and the state's position relative to the nation.
- Levels and trends in manufacturing productivity, both overall and for the seven Maryland clusters and the state's position relative to the nation.
- Once implemented, track usage of Manufacturing Innovation Fund and types of projects integrated.
- Track the share of SME manufacturers receiving cybersecurity assessments.
- Via Department of Commerce surveys of manufacturers, track awareness of relevant programs/incentives.
- The share of SMEs that are reaching scale in Industry 4.0 adoption.

STRATEGIC PRIORITY 3: STRENGTHENING INTRA-STATE SUPPLY CHAIN CONNECTIONS

Maryland manufacturers are eager to connect with other Maryland manufacturers, largely for strategic reasons and increasingly due to pandemic-induced supply chain challenges or reality checks. But this interest, if seized upon and enabled through targeted efforts, can be extremely beneficial for the overall state manufacturing sector to achieve a coveted "win-win" situation.

> "When we know a good supplier in Maryland, we prefer to go with them...but we don't have the time or resources to investigate."
>
> **Maryland Manufacturing Leader**

When surveyed in 2021, 37% of Maryland manufacturers indicated it was "very important" to have access to suppliers or customers located within Maryland (Figure 25), and an additional 31% reported it was at least "somewhat important." These interests were emphasized in interview discussions.

The challenge for manufacturers is a lack of awareness of other firms and their product and service offerings to tap. In response to this challenge, states and regions often "map" supply chains for specific sectors and industry verticals to share information, enable strategic partnering and connections, and advertise expertise and capabilities outside of the region. Maryland has undertaken supply chain mapping for its defense industry conducted by Towson University[14] and should consider targeting other clusters for similar mapping opportunities. There should be no illusions that this is easy to develop or to actively maintain, but as one pillar of a two-pronged approach to achieving the win-win, is worth undertaking. Armed with information, the second pillar of the strategy is then providing financial incentivizes for supply chain connections and to "Buy Maryland."

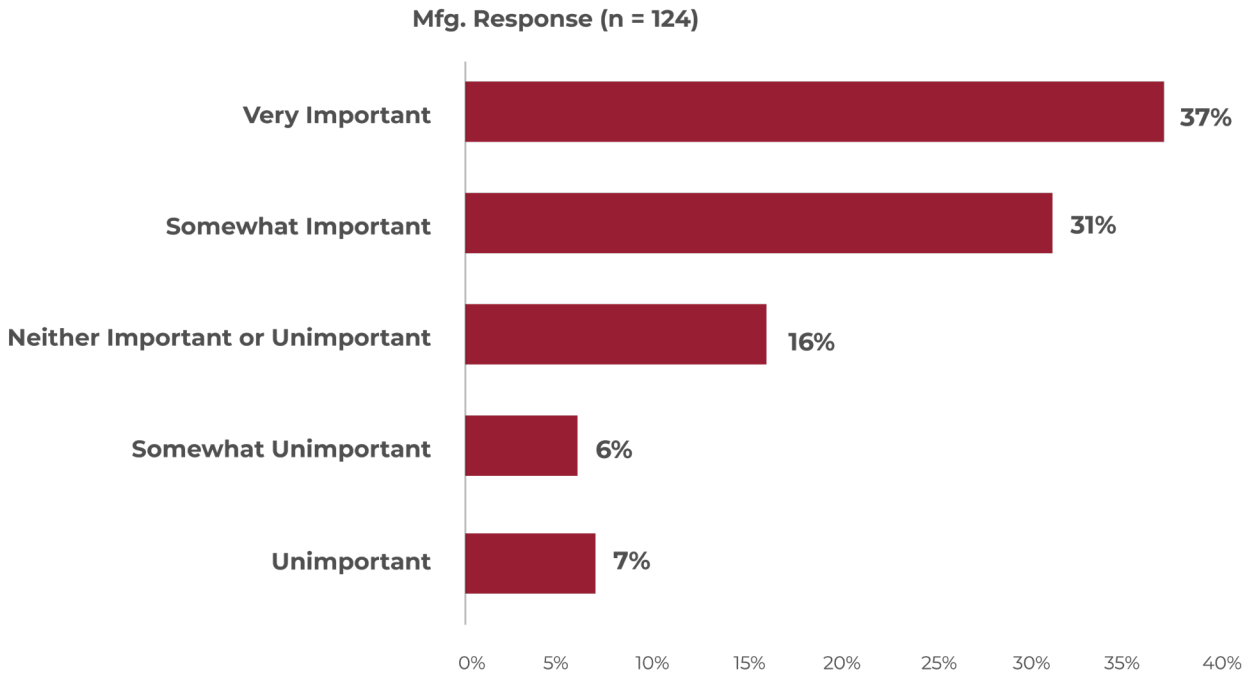
These potential connections will certainly have limitations. Conversations with manufacturers revealed that many source commodity inputs from outside the state, both domestically and very much internationally due to competitive cost differentials, and Maryland manufacturers do not produce every input to serve the production needs of their counterparts in-state. But today there are connections on key items. Examples highlighted in interviews include a food manufacturer sourcing ingredients like spices and seasonings as well as packaging solutions, and an aerospace and defense firm utilizing local machining and additive manufacturing capabilities.

The COVID-19 pandemic and resulting supply chain shocks and shortages, particularly among industries of strategic importance to the United States (and other nations) have spurred conversations around strategic "reshoring" opportunities for manufacturing—returning (or newly rooting) the production of strategic supply chain components back to US soil. The results have been mixed thus far, but the focus has been renewed with, for example, Congress writing the "CHIPS" legislation in response to a greater concentration of global semiconductor manufacturing located in Asia. Likewise, there is a focus in the United States to more firmly root or return critical biopharmaceutical inputs and production of vaccines and therapeutics, and the sensitivity and security of vast aerospace and defense supply chains are a focus as well—both industries in which Maryland has strengths. While not assured, this is a movement that can represent an economic development attraction and recruitment focus worth exploring, and ensuring there is an understanding and "marketability" of Maryland assets (e.g., via supply chain mapping) is one step in this process.

As just one gauge on prospects and priorities for reshoring, PwC's Health Research Institute, in a survey of pharmaceutical company executives, reported that 82% expect to "reshore" components of their supply chains in the next two to five years.

[14] Regional Economic Studies Institute. Mapping the Defense Industry in Maryland," 2016 Towson University.

Figure 25: Importance of Intra-State Manufacturing Connections (Share of Maryland Manufacturers)
Question: *How important is it to have access to suppliers or customers located within Maryland?*



Source: Maryland Dept. of Commerce, 2021 Maryland Manufacturing Survey.

The following recommendations are designed to meet these objectives and seize the opportunities raised.

Action 3.1: Develop Maryland supply chain mapping and directory resources for targeted manufacturing clusters.

- Mapping requires intensive research to initiate, and in-state research universities are often able to take the lead on development. To ensure relevance for manufacturing connections, these efforts require upkeep with ever-changing business dynamics and regular "maintenance," so require ongoing resources to maintain.
- Maryland should consider piloting a mapping effort for one discrete manufacturing cluster as an appropriate first step.
- Interests for intra-state connections span all firm sizes, so it is important to ensure the ultimate directory or map is "bi-directional" so both large manufacturers and OEMs as well as SMEs can effectively conduct searches and access information.

[15] PwC Health Research Institute Survey,
see: https://www.pwc.com/us/en/industries/health-industries/library/pharmaceutical-supply-chain-tax-considerations-2021-qa.html.

Action 3.2: Incent, promote in-state supply chain connections, sourcing, purchasing.

- Consider linking tax credits—e.g., a "Buy Maryland Manufacturing Tax Credit"—to in-state supply chain sourcing, i.e., how much of your product supply chain utilizes Maryland manufacturing or Maryland-based services? Consider a sliding scale approach to ensure majority of benefits accrue to SMEs.

Action 3.3: Proactively pursue potential "reshoring" opportunities in targeted industries.

- Coordinated outreach to targeted cluster representatives should be undertaken to understand supply-chain challenges and opportunities for rooting additional capabilities in Maryland from overseas.
  - » Primary targets should be aerospace and defense, recognizing its extensive, well-established and well-articulated supply chains both within Maryland and nationally, as well as life sciences.
- Coordination should occur among MD MEP and economic development leadership in Maryland, including those at the state's Department of Commerce.

Example programs and illustrative best practices related to these recommendations include:

Automation Alley®

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

- Day-long training and implementation workshop focused on a company and its key suppliers.
- Automation Alley member companies present to you and your suppliers on pre-identified high-priority Industry 4.0 areas
- Follow-on opportunities for personalized Industry 4.0 assessments offered to suppliers

IV Industrial Value Chain Initiative

Japan: Industrial Value Chain Initiative

- Founded in 2015 to target integration of Industry 4.0 and other connected hardware into manufacturer supply chains
- Hosts a number of workgroups with a specific emphasis on helping small and mid-sized enterprises in the supply chain incorporate IoT technologies into their businesses to aid more comprehensive digital connectivity across the country's manufacturing base

To track progress on this strategy into the future, industry stakeholders should measure and track:

- Once operable, track usage of supply chain mapping pilot project, request feedback on successful connections made via the tool.
- Identify companies successfully reshored and associated economic impacts of those re-locations or new locations to Maryland.

STRATEGIC PRIORITY 4: SEIZING EMERGING MANUFACTURING INDUSTRY AND MARKET OPPORTUNITIES FOR ENGAGEMENT AND ASSISTANCE BY MD MEP

While life sciences represent a long-standing targeted industry and economic strength for Maryland, the cluster is a relatively untapped strategic opportunity for MD MEP and others in the manufacturing sphere to provide expertise and assistance. In recent years, MD MEP has engaged a handful of life sciences firms on "light" touch efforts, such as supervisor efficiency training and participation in Lean peer groups. The baseline analysis has illuminated the outsized importance of life sciences within the Maryland manufacturing sector where it represents:

- The leading manufacturing cluster in value-added per worker (productivity)
- The leading manufacturing cluster in export sales
- A leader in industrial R&D, reflecting its leading innovation status and position globally
- A pipeline of future opportunity given the size, growth, and specialization of Biotech R&D
- Emerging companies that will be looking to advance into commercial production in Maryland or elsewhere

Ensuring this sector is firmly rooted, and manufacturing expertise within the state is leveraged, should be a leading priority across the Maryland economic development and manufacturing community. It must be acknowledged that life sciences manufacturing is extremely unique, and building manufacturing expertise in this space is especially challenging under a highly regulated production environment that requires Good Manufacturing Practice (GMP) facilities and extensive documentation. The cluster is not monolithic, with diverse production environments that span medical device manufacturing, biopharmaceutical production, and biomanufacturing. But Maryland is home to key assets like the bioprocessing center at UM, the vast federal NIH research complex, and military research and medical expertise at installations such as Fort Detrick, home to the US Army's Medical Research and Development Command and major bio-defense capabilities.

For MD MEP, engaging with the life sciences will require acquiring and building expertise, but recognizing the numerous assets within Maryland, the existing manufacturing-specific expertise of MD MEP represents a highly complementary partnering opportunity even today. In fact, in a recent effort to acquire federal grant funding and seize upon emerging opportunities, MD MEP collaborated with the Maryland Tech Council, an organization dedicated to advancing state Tech and Life Sciences sectors, to propose a major "Bio Hub" initiative that would combine workforce development with co-working and shared lab space with access to capital and manufacturing assistance. Although the grant was not awarded, this exercise established the basis for further future collaboration and better understanding the capabilities and competencies across organizations—just the type of collaborative approaches that this strategy envisions for MD MEP.

But assistance and partnerships are also a two-way street, and a common lament or refrain of manufacturing leaders and stakeholders is often expressed as "we will be engaged when life sciences companies wake up and realize they are manufacturers." This reflects a fundamental disconnect between this community and the cluster. In fact, most life sciences companies do understand they are manufacturers, but the sector is so unique, they have difficulty finding common ground with metals manufacturers, food processors, or injection molders.

With that acknowledged, there is common ground in areas such as manufacturing technology challenges and talent needs that span engineering, process flow, robotics, and advanced data analytics. Life sciences companies, like many of their Maryland counterparts, have little awareness of state incentives and programs and can find yet another area of common ground for assistance. While engaging with this cluster will likely require separate and unique approaches, there is common ground upon which to establish beneficial relationships.

Beyond life sciences and recognizing the vast federal purchasing complex in and around Maryland and the National Capitol region, a specialized analysis was conducted to understand the degree to which Maryland manufacturers are supplying major federal installations in the state. These installations have vast procurement needs and should and can be regularly probed for connections to and opportunities for Maryland manufacturers to source products "locally."

High-level insights emerge from a quantitative federal procurement and supply chain assessment regarding the purchasing activity of "manufactured products" by key Maryland federal government facilities (identified by the industry NAICS code of the supplier). It finds opportunities exist to increase the level of federal purchases from Maryland manufacturers across all four federal facilities examined, with a particularly low share of Maryland-manufactured goods supplied to Goddard (just 0.8% of its total).

Table 7: Manufacturing Spend by Maryland-Based Federal Agencies/Offices, FY2019-20

Agency/Office	Total Spend ($M)	Maryland ($M)	% of Total
Goddard	$845.9	$7.0	0.8%
Aberdeen	$418.2	$88.6	21.2%
NIST	$123.8	$38.3	31.0%
Ft. Detrick	$14.2	$3.5	24.4%

Source: Federal procurement data via USAspending.gov; TEConomy calculations and analysis.

The following recommendations are designed to meet these objectives and seize the opportunities raised.

Action 4.1: Increase engagement between MD MEP and the Maryland life sciences cluster to leverage strategic partnerships and collaborations with life sciences-focused state organizations and strategic life sciences assets.

- Recommend that MD MEP openly engage the industry by hosting targeted forums and focus groups for existing life sciences companies as well as emerging Biotech companies representing next generation of Maryland manufacturers. Purpose is to understand their production needs and challenges, and to ensure they understand the manufacturing resources, expertise available to them, and the value proposition for rooting production in the state.
- Strengthen strategic collaborations with key life science-related organizations and assets including the UM Bioprocess Scale-Up Facility, the Maryland Tech Council, military, and others. Ensure an understanding of expertise and value proposition that each brings to life sciences assistance and engagement.
- Partner to target joint grant, programming, education and training infrastructure investment, and other initiatives such as the "Bio Hub" opportunity to further deepen collaborations and industry engagement.
- For MD MEP, proactively engage life sciences companies regarding awareness of state economic development and other incentives and programming.

Action 4.2: Identify and seize Federal procurement opportunities for Maryland manufacturers.

- Regularly examine opportunities to increase the level of federal purchases from Maryland manufacturers across all in-state federal facilities. In particular, look for opportunities requiring purchasing needs aligned with Maryland's seven manufacturing industry clusters.
- Proactively communicate with federal leadership to better understand directions for future procurement needs for local manufacturers to strategically pivot toward.

To track progress on this strategy into the future, industry stakeholders should measure and track:

- Project and other direct engagement of the life sciences industry with and by MD MEP
- Partnering activities of MD MEP with key organizations in the life sciences
- Share of federal procurement expenditures among Maryland-based installations going to Maryland manufacturers

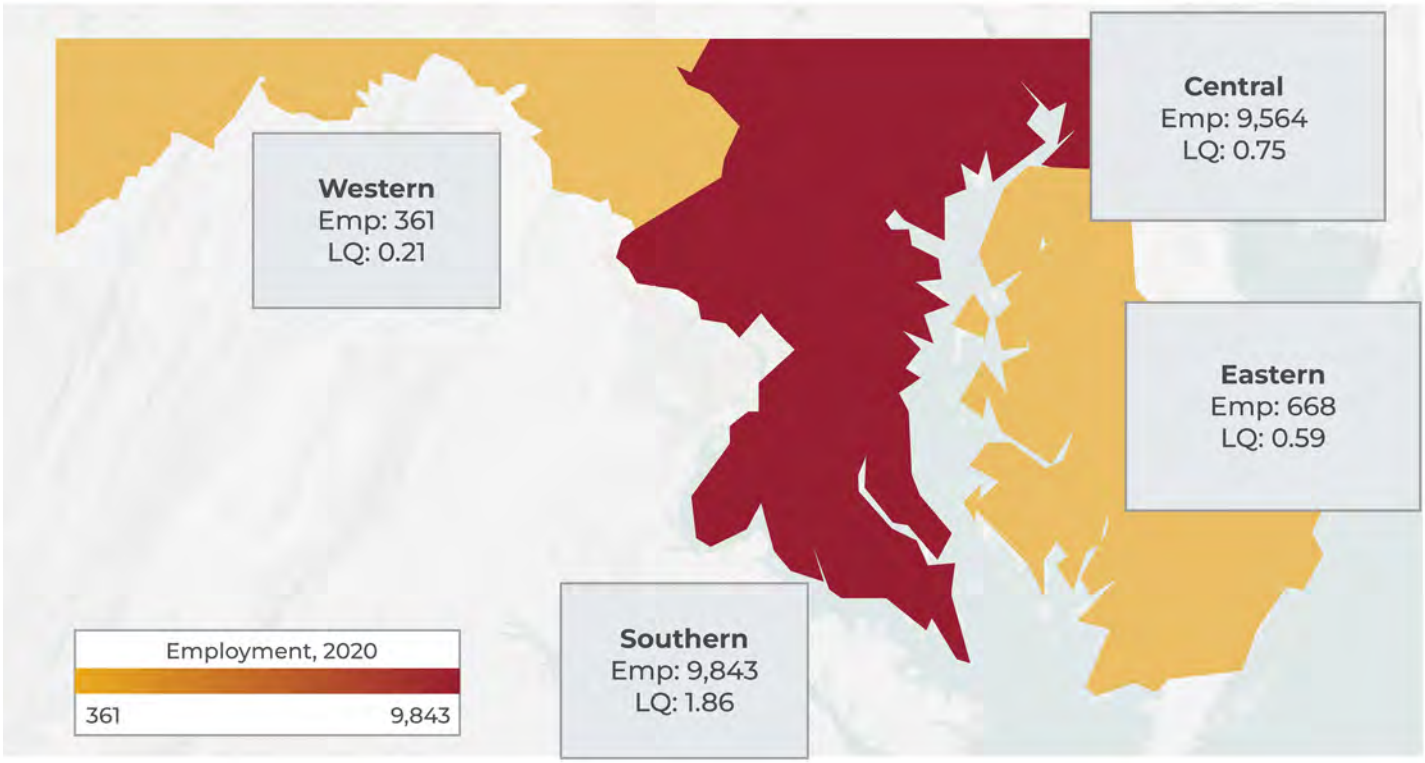
APPENDIX A: MANUFACTURING INDUSTRY CLUSTER PROFILES

AEROSPACE & DEFENSE SYSTEMS

Aerospace & Defense Systems	2020 Metrics						Recent Jobs Performance		
	Establishments	Employment	Employment Concentration (LQ)	Average Establishment Size	Productivity (GRP/EMP)	Average Wage	% Change 2015-2019	% Change 2019-2020	% Change 2015-2020
Maryland Metrics & Performance	329	20,740	0.95	63	$347,981	$120, 595	13.3%	3.2%	16.9%
US Performance				78	$257,462	107,863	6.4%	-1.3%	5.0%

- **Growth from 2015-2019**, continuing through 2020, significantly outpacing the United States.
- **Industry Targeting Analysis:** Emerging Strength
- **Key Subclusters:**
  - **Navigation, Guidance, & Security Instrumentation:** Accounts for 12,552 (61%) of employment, an LQ of 3.48, and emp growth of 27% from 2015-2020
  - **Aerospace:** Accounts for 3,178 (15%) of employment
  - **Communications Equipment:** Accounts for 2,894 (14%) of employment and an LQ of 2.44
- **Example Maryland Companies:** Northrup Grumman Systems Corporation, Lockheed Martin, Raytheon, Boeing, L3Harris, Textron Systems (AAI Corporation), Advanced Thermal Batteries

Regional Cluster Employment:



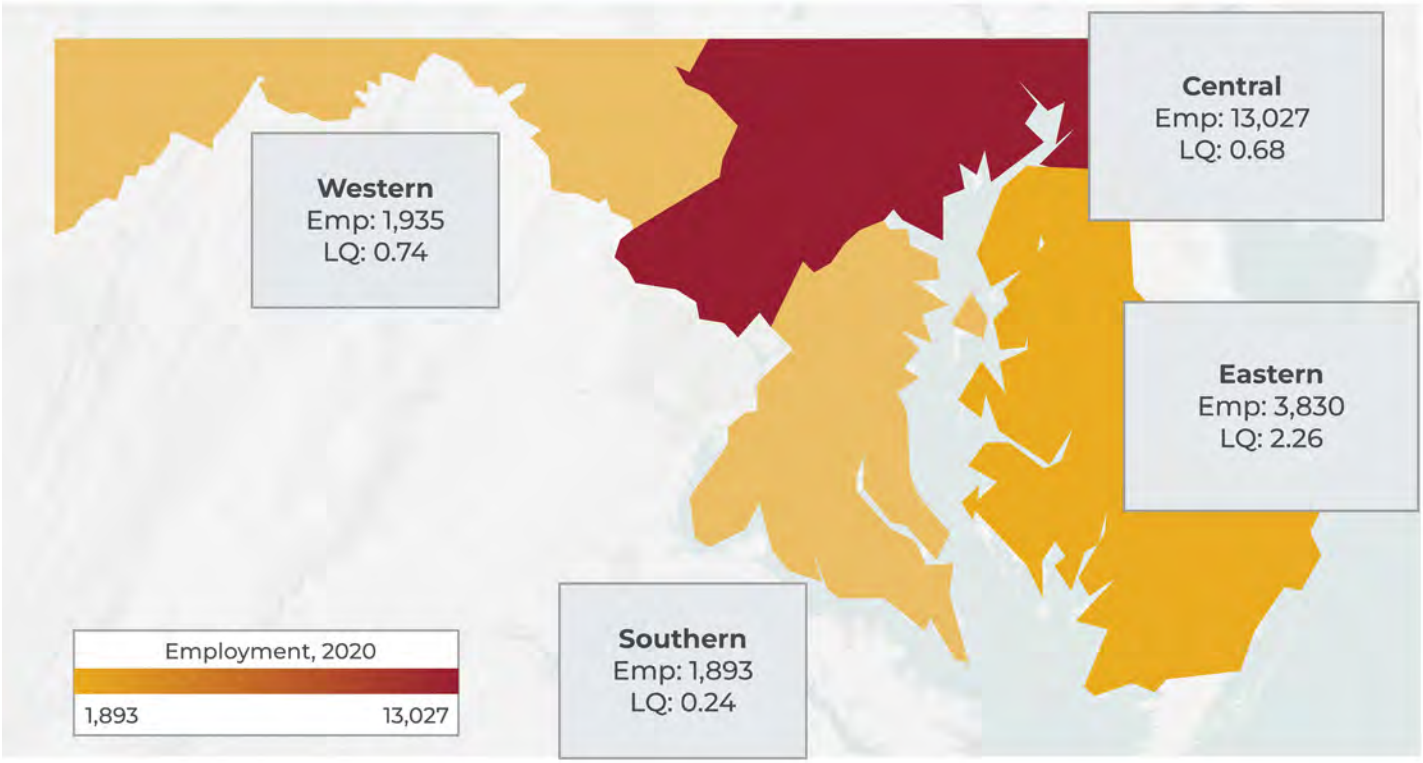
Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2)

FOOD & BEVERAGE MANUFACTURING

Food & Beverage	2020 Metrics						Recent Jobs Performance		
	Establishments	Employment	Employment Concentration (LQ)	Average Establishment Size	Productivity (GRP/EMP)	Average Wage	% Change 2015-2019	% Change 2019-2020	% Change 2015-2020
Maryland Metrics & Performance	7,195	20,908	0.64	29	$143,216	$52,548	17.8%	-0.7%	17.1%
US Performance				29	$136,441	$51,589	11.1%	-1.9%	8.9%

- **Significant growth from 2015-2019**, with slight 2020 decline likely due to COVID-19; Significantly outpacing the nation.
- **Industry Targeting Analysis:** Emerging Strength
- **Key Subclusters:**
  - » **Food Manufacturing:** Accounts for 17,115 (82%) of employment
  - » **Beverage Manufacturing:** Employment growth of 33% from 2015-2020
- **Example Maryland Companies:** Perdue Farms, McCormick & Company, Smithfield Foods, Synutra International, Northeast Foods, Ingredion, Inc., Fuchs North America, Eight O'Clock Coffee

Regional Cluster Employment:



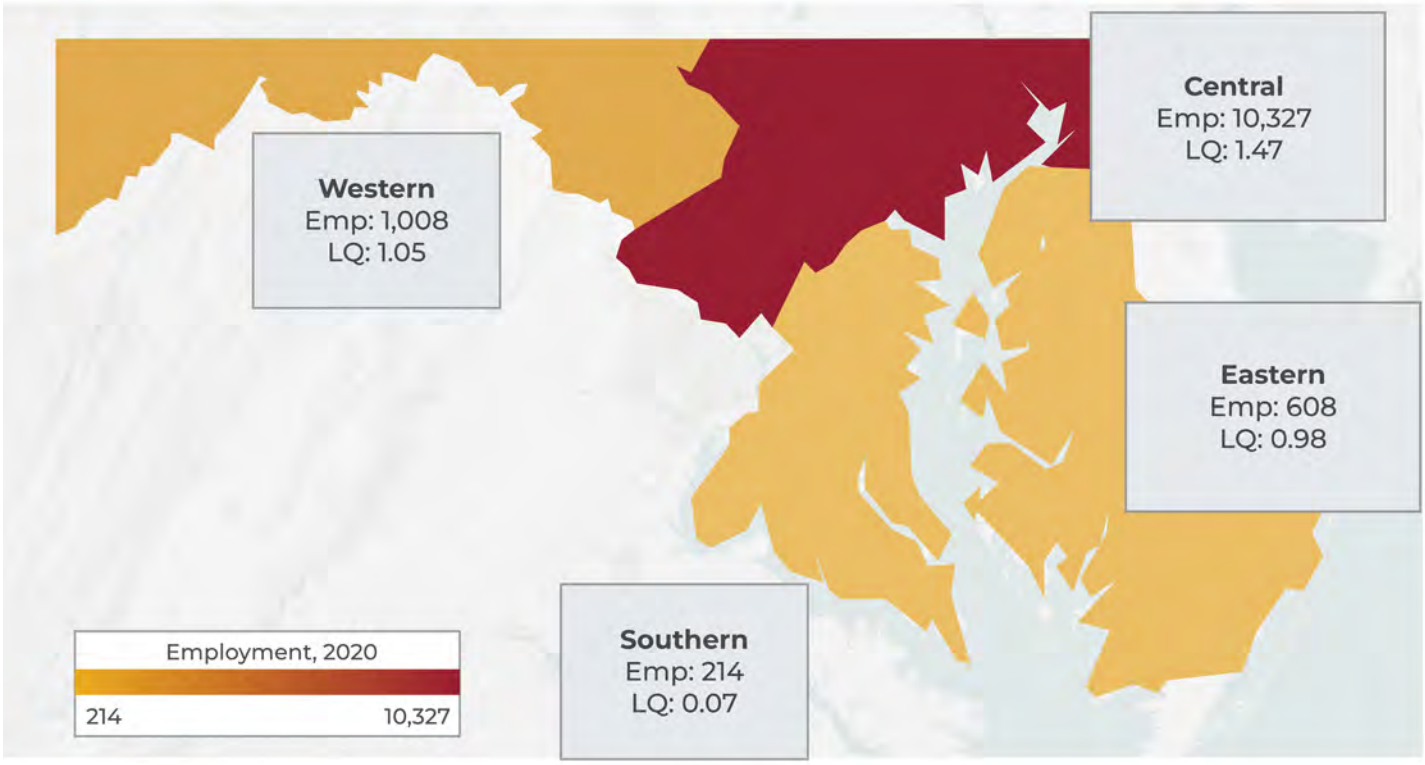
Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2).

LIFE SCIENCES

Life Sciences	2020 Metrics						Recent Jobs Performance		
	Establishments	Employment	Employment Concentration (LQ)	Average Establishment Size	Productivity (GRP/EMP)	Average Wage	% Change 2015-2019	% Change 2019-2020	% Change 2015-2020
Maryland Metrics & Performance	298	12,604	1.06	42	$130,760	$142,789	25.8%	2.6%	29.1%
US Performance				48	$383,255	$108,317	10.1%	0.8%	11.0%

- **Significant growth from 2015-2020,** outpacing the US by more than double
- **Industry Targeting Analysis:** Existing Strength
- **Key Subclusters:**
  - **Pharmaceuticals:** Accounts for 9,517 (76%) of employment, growth of 31% from 2015-2020 and an LQ=1.77
  - **Medical Devices & Equipment:** Accounts for 3,087 jobs and growth of 24% from 2015-2020.
- **Example Maryland Companies:** Celegene, Orgenesis, AstraZeneca (Medimmune), Emergent Biosolutions, Meridian Medical Technologies, Trinity Sterile, Inc., Action Products, Inc.

Regional Cluster Employment:



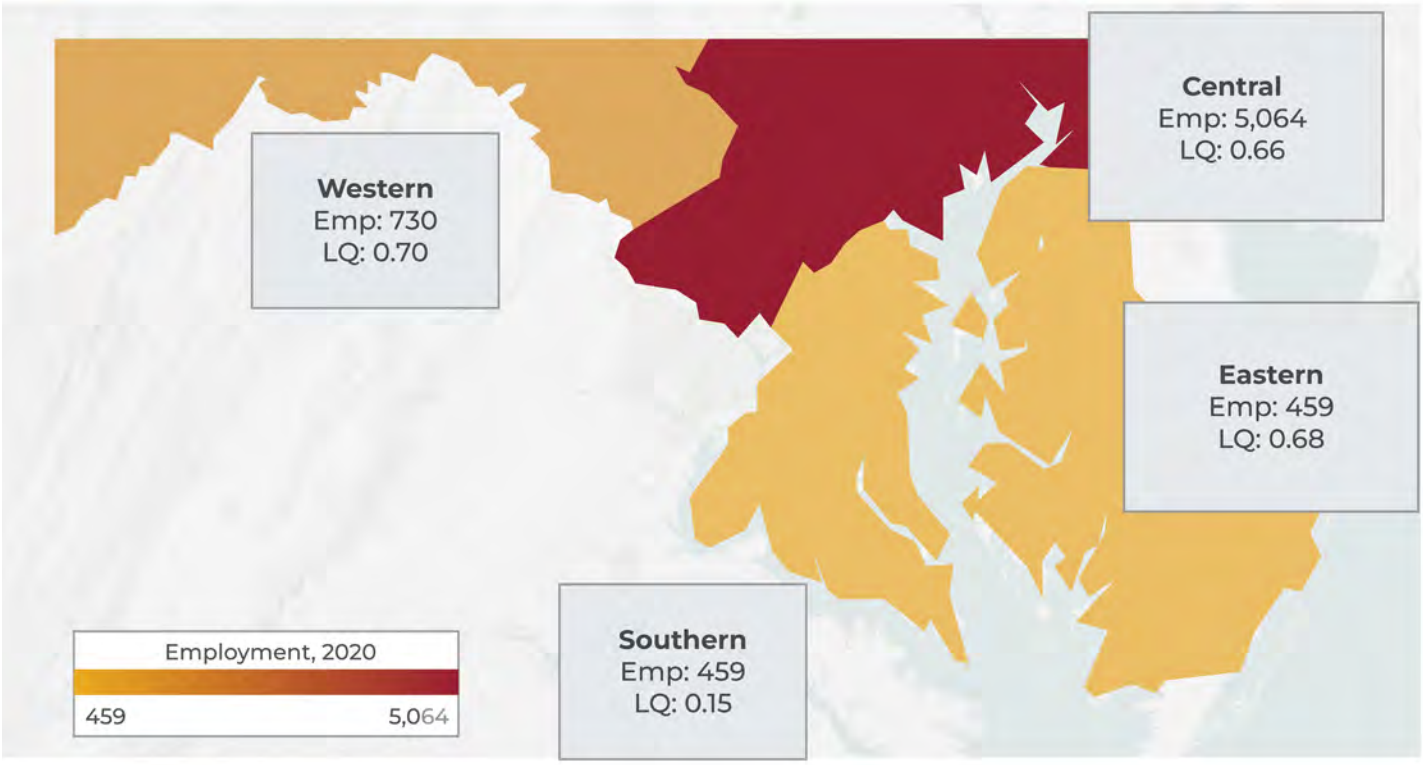
Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2).

POLYMERS & RELATED PRODUCTS

Polymers & Related Products	2020 Metrics						Recent Jobs Performance		
	Establishments	Employment	Employment Concentration (LQ)	Average Establishment Size	Productivity (GRP/EMP)	Average Wage	% Change 2015-2019	% Change 2019-2020	% Change 2015-2020
Maryland Metrics & Performance	143	6,826	0.53	48	$205,016	$80,892	3.6%	1.3%	4.9%
US Performance				48	$157,577	$62,311	5.2%	-4.8%	0.2%

- **Growth from 2015-2019 and holding its own through 2020.** Outpacing US growth.
- **Industry Targeting Analysis:** Emerging Strength
- **Key Subclusters:**
  - » **Plastic & Rubber Products:** Accounts for 5,151 (75%) of employment and growth of 8% from 2015-2020
  - » **Adhesives, Coatings & Paint:** Employment LQ=1.24
- **Example Maryland Companies:** W. L. Gore & Associates, Inc., Berry Plastics, Fawn Industries, Wm. T. Burnett & Co., Tenax Corporation

Regional Cluster Employment:



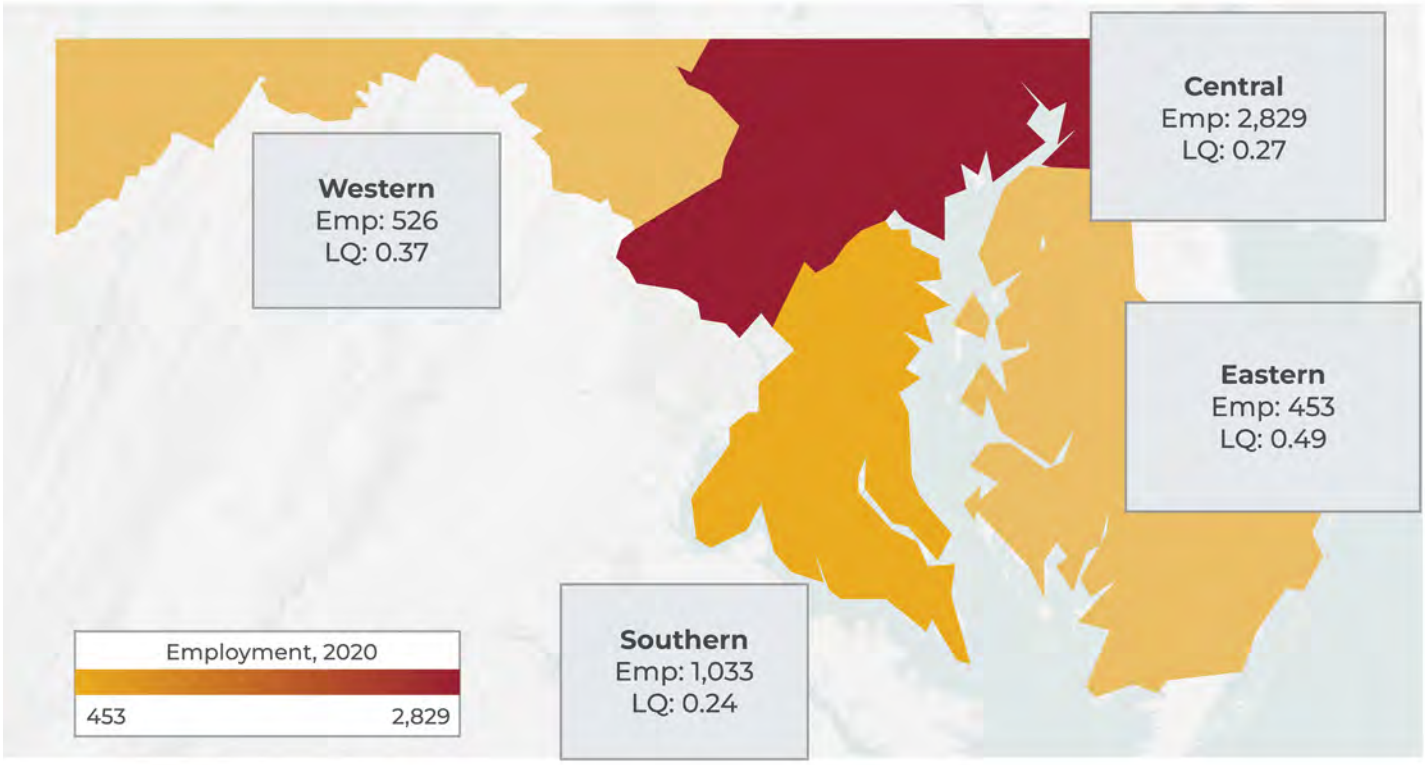
Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2).

PRECISION MANUFACTURING

Precision Manufacturing	2020 Metrics						Recent Jobs Performance		
	Establishments	Employment	Employment Concentration (LQ)	Average Establishment Size	Productivity (GRP/EMP)	Average Wage	% Change 2015-2019	% Change 2019-2020	% Change 2015-2020
Maryland Metrics & Performance	313	4,944	0.28	16	$139,624	$68,049	5.7%	-5.1%	0.3%
US Performance				22	$126,507	$66,938	-0.2%	-0.2%	-6.1%

- **Growth from 2015-2019**, with much of that growth lost in 2020 likely due to COVID-19. Overall period (2015-2020) growth outpaced decline at the national level.
- **Industry Targeting Analysis:** Emerging Strength
- **Key Subclusters:**
  - » **Precision Metalworking:** Accounts for 2,706 (55%)
- **Example Maryland Companies:** Dixon Valve & Coupling Company; Cambridge International (Rexnord), Kenlee Precision Corporation, Danko Arlington, The Bechdon Company, Inc.; Raloid Corporation

Regional Cluster Employment:



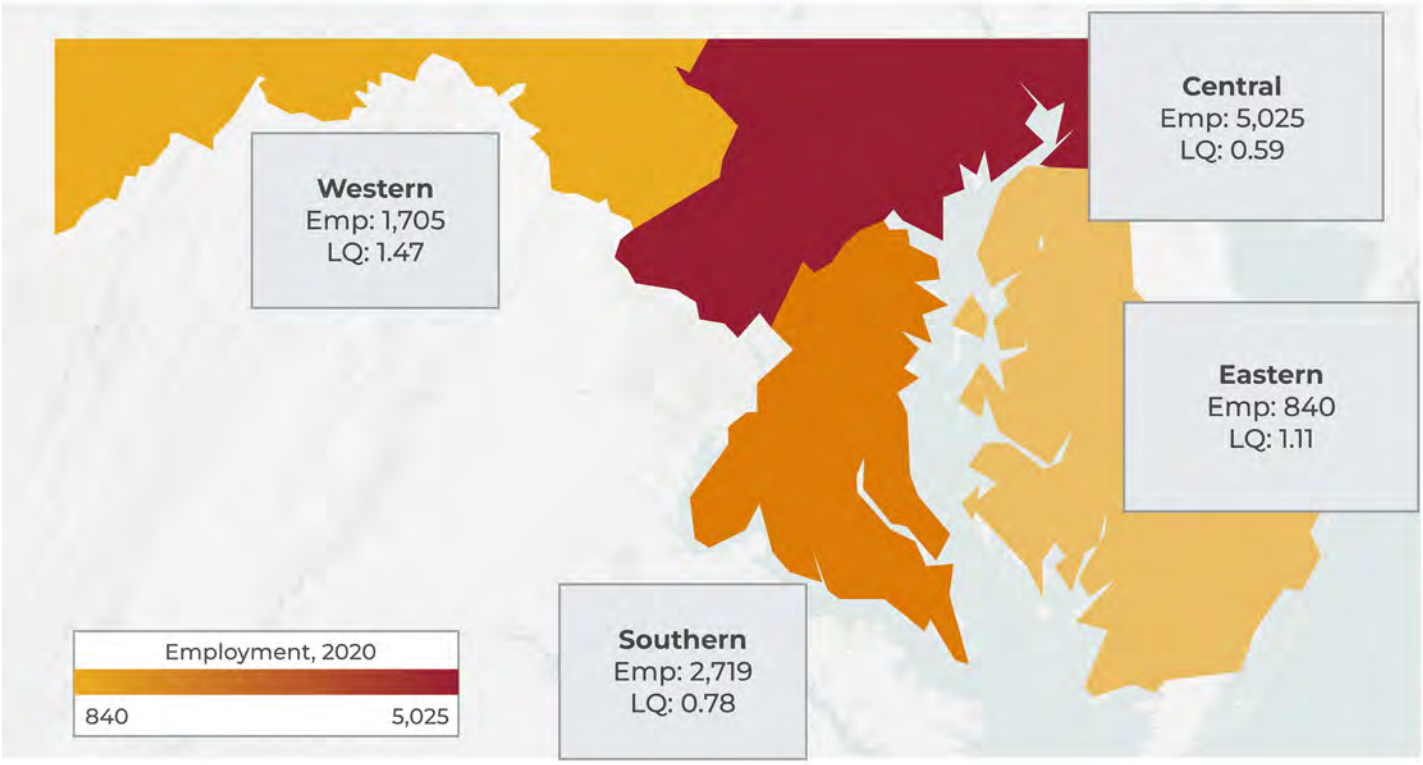
Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2)

PRINTING & PACKAGING

Printing & Packaging	2020 Metrics						Recent Jobs Performance		
	Establishments	Employment	Employment Concentration (LQ)	Average Establishment Size	Productivity (GRP/EMP)	Average Wage	% Change 2015-2019	% Change 2019-2020	% Change 2015-2020
Maryland Metrics & Performance	464	10,354	0.72	22	$111,040	$56,362	-0.4%	-9.3%	-9.7%
US Performance				23	$122,089	$58,408	-1.0%	-5.0%	-5.9%

- **Slight employment decline**, likely exacerbated in 2020 due to COVID-19. Overall US cluster also losing employment.
- **Industry Targeting Analysis**: Limited Prospects
- **Key Subclusters:**
  - » **Printing:** Accounts for 6,805 (66%) of employment
- **Example Maryland Companies:** Plastipak, Altium Packaging, Spartech, Phoenix Color, Atlas Container Corporation, CCL Label, WebbMason Marketing

Regional Cluster Employment:



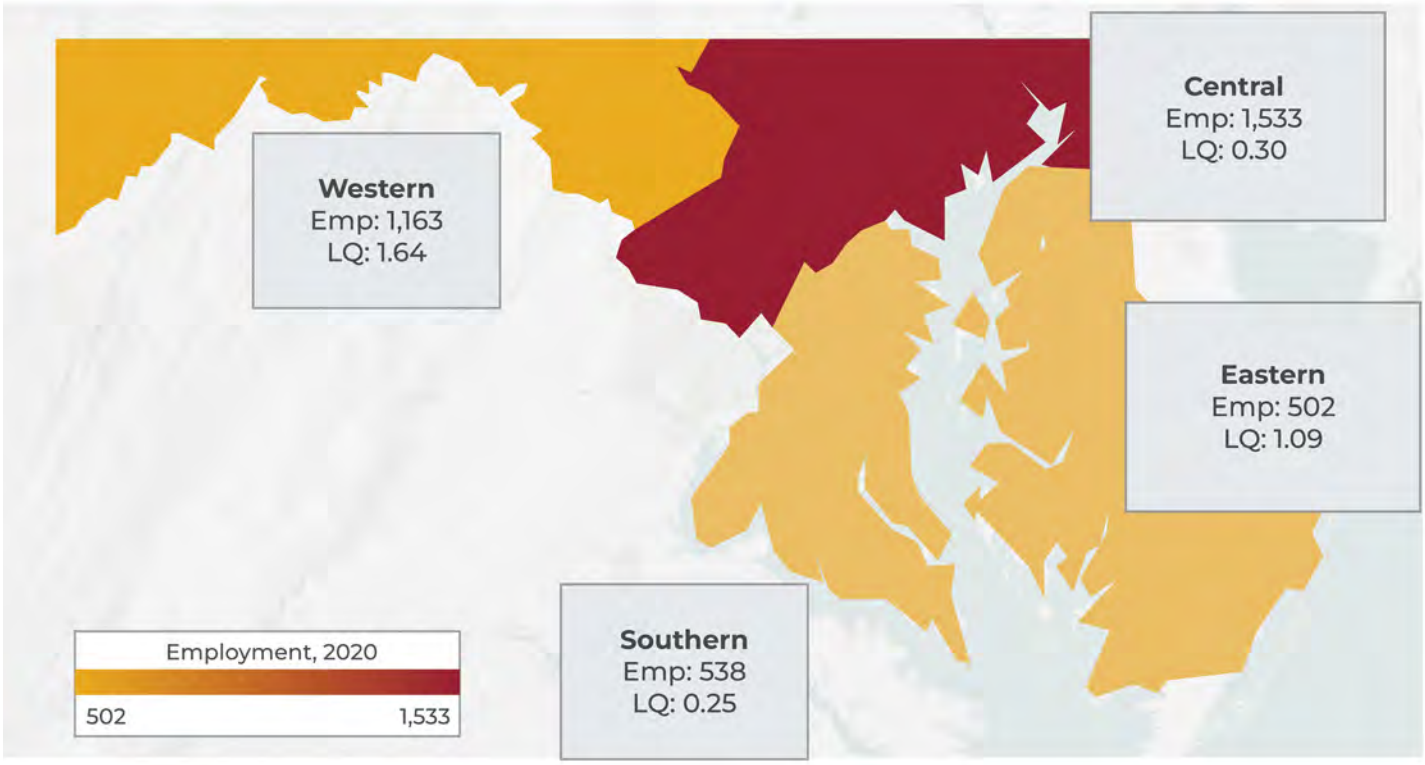
Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2)

WOOD PRODUCTS

Wood Products	2020 Metrics						Recent Jobs Performance		
	Establishments	Employment	Employment Concentration (LQ)	Average Establishment Size	Productivity (GRP/EMP)	Average Wage	% Change 2015-2019	% Change 2019-2020	% Change 2015-2020
Maryland Metrics & Performance	243	3,870	0.44	16	$122,031	$55,072	12.1%	-0.4%	11.6%
US Performance				19	$93,547	$47,301	-5.7%	-2.9%	2.7%

- **Solid growth from 2015-2019,** with a slight decline in 2020. Outpacing US cluster growth by over four times.
- **Industry Targeting Analysis:** Emerging Strength
- **Key Subclusters:**
  - » **Lumber & Building Products:** Accounts for 2,063 (53%) of employment
- **Example Maryland Companies:** Shelter Systems, Washington Woodworking, The Taney Corporation, Beachley Furniture Company, Helmut Guenschel, Inc.

Regional Cluster Employment:



Source: TEConomy analysis of enhanced US Bureau of Labor Statistics CEW data (from Emsi, Datarun 2021.2)

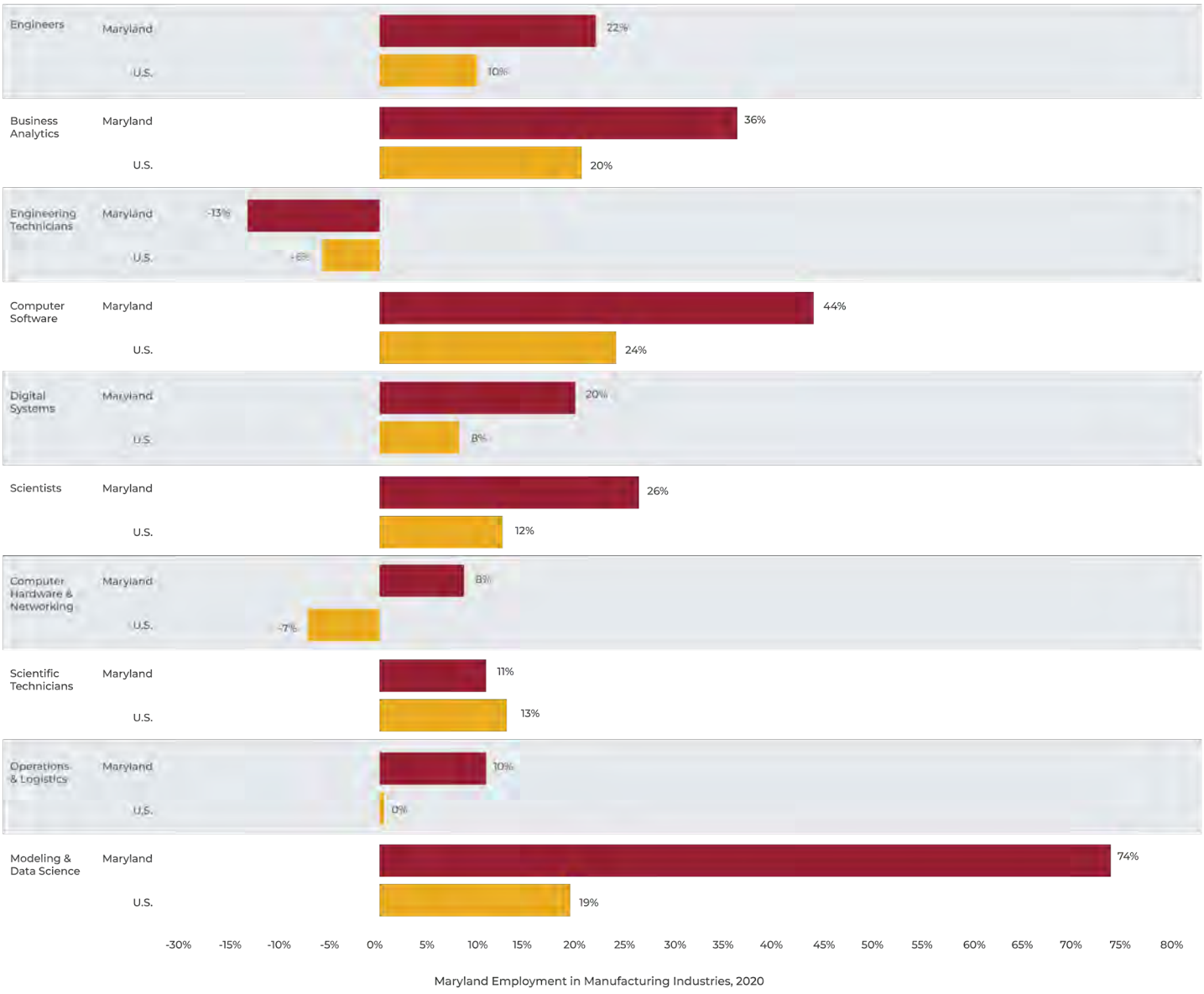
Figure A-1: Summary Employment Metrics for Maryland Manufacturing Clusters, 2020

Maryland Key Manufacturing Industries and SubSectors	Establishments		Employment				Average Wage	GRP & Productivity			
	Total, 2020	Change, 2015-2020	Total, 2020	LQ	Change, 2015-2020	Change Rel. to US, 2015-2020		Estimated Gross Regional Product ($B)	GRP Change, 2015-2020	Productivity, 2020	Productivity Change, 2015-2020
Manufacturing, Total	4,170	14%	109,244	0.52	5%	6%	$83,648	$27.58	23%	$252,472	16%
Aerospace & Defense Systems	329	15%	20,740	0.95	17%	12%	$120,595	$7.22	30%	$347,981	11%
Aerospace	36	1%	3,178	0.35	10%	3%	$90,514	$0.79	27%	$247,931	16%
Arms, Munitions, and Land Vehicles	12	48%	198	0.22	-51%	-65%	$88,997	$0.05	-32%	$263,377	40%
Communications Equipment	58	7%	2,894	2.44	-3%	-1%	$116,151	$1.15	13%	$398,328	16%
Microelectronics	71	15%	1,652	0.26	15%	15%	$68,436	$0.25	61%	$154,163	40%
Battery Manufacturing	5	6%	267	0.40	65%	19%	$83,914	$0.07	69%	$254,395	2%
Navigation, Guidance, & Security (NGS) Instrumentation	148	22%	12,552	3.48	27%	23%	$137,375	$4.90	35%	$390,527	6%
Food & Beverage	719	39%	20,908	0.64	17%	8%	$52,548	$2.99	26%	$143,216	8%
Beverage Manufacturing	216	102%	3,793	0.82	33%	6%	$50,665	$0.76	35%	$199,424	2%
Food Manufacturing	503	23%	17,115	0.62	14%	8%	$52,965	$2.24	23%	$130,760	8%
Life Science	298	58%	12,604	1.06	29%	18%	$142,789	$7.71	33%	$611,873	3%
Medical Devices & Equipment	161	59%	3,087	0.47	24%	13%	$92,797	$0.93	44%	$302,057	16%
Pharmaceuticals	137	57%	9,517	1.77	31%	20%	$159,005	$6.78	31%	$712,374	0%
Polymers & Related Manufactured Products	143	6%	6,826	0.53	5%	5%	$80,892	$1.40	20%	$205,016	0%
Adhesives, Coatings, & Paint	28	-14%	1,371	1.24	4%	-1%	$84,979	$0.42	30%	$308,374	25%
Plastic & Rubber Products	95	14%	5,151	0.29	8%	8%	$81,447	$0.91	18%	$176,877	9%
Polymers, Resins, and Fibers	20	0%	304	0.16	-28%	-27%	$53,031	$0.07	2%	$215,764	42%
Precision Manufacturing	313	1%	4,944	0.28	0%	6%	$68,049	$0.69	9%	$139,624	9%
Metal Services	40	13%	437	0.19	15%	20%	$54,839	$0.05	26%	$120,002	10%
Precision Machinery	54	21%	1,257	0.26	15%	20%	$73,266	$0.22	38%	$173,060	20%
Precision Metalworking	156	-6%	2,706	0.34	-2%	5%	$67,048	$0.32	1%	$117,020	3%
Industrial Instruments & Controls	63	-3%	543	0.20	-22%	-16%	$71,597	$0.10	-14%	$190,683	10%
Printing & Packaging	464	-13%	10,354	0.72	-10%	-4%	$56,362	$1.15	-4%	$111,040	6%
Packaging	51	-13%	2,988	0.43	-18%	-21%	$57,772	$0.38	-13%	$125,586	6%
Printing	393	-13%	6,805	1.01	-6%	7%	$54,033	$0.70	-1%	$102,261	5%
Production Machinery	20	-6%	562	0.81	-2%	1%	$77,081	$0.08	15%	$140,030	17%
Wood Products	243	11%	3,870	0.44	12%	9%	$55,072	$0.47	50%	$122,031	35%
Lumber & Building Components	101	25%	2,063	0.41	17%	12%	$61,782	$0.29	91%	$142,633	64%
Wood Cabinets, Furniture, & Millwork	142	2%	1,807	0.48	6%	6%	$47,413	$0.18	11%	$98,513	4%
Total Private Sector	172,012	4%	2,072,107	1.00	-2%	-3%	$64,193	$287.10	13%	$138,553	15%

Source: TEConomy analysis of enhanced CEW data from Emsi (Emsi Release 2020.2)

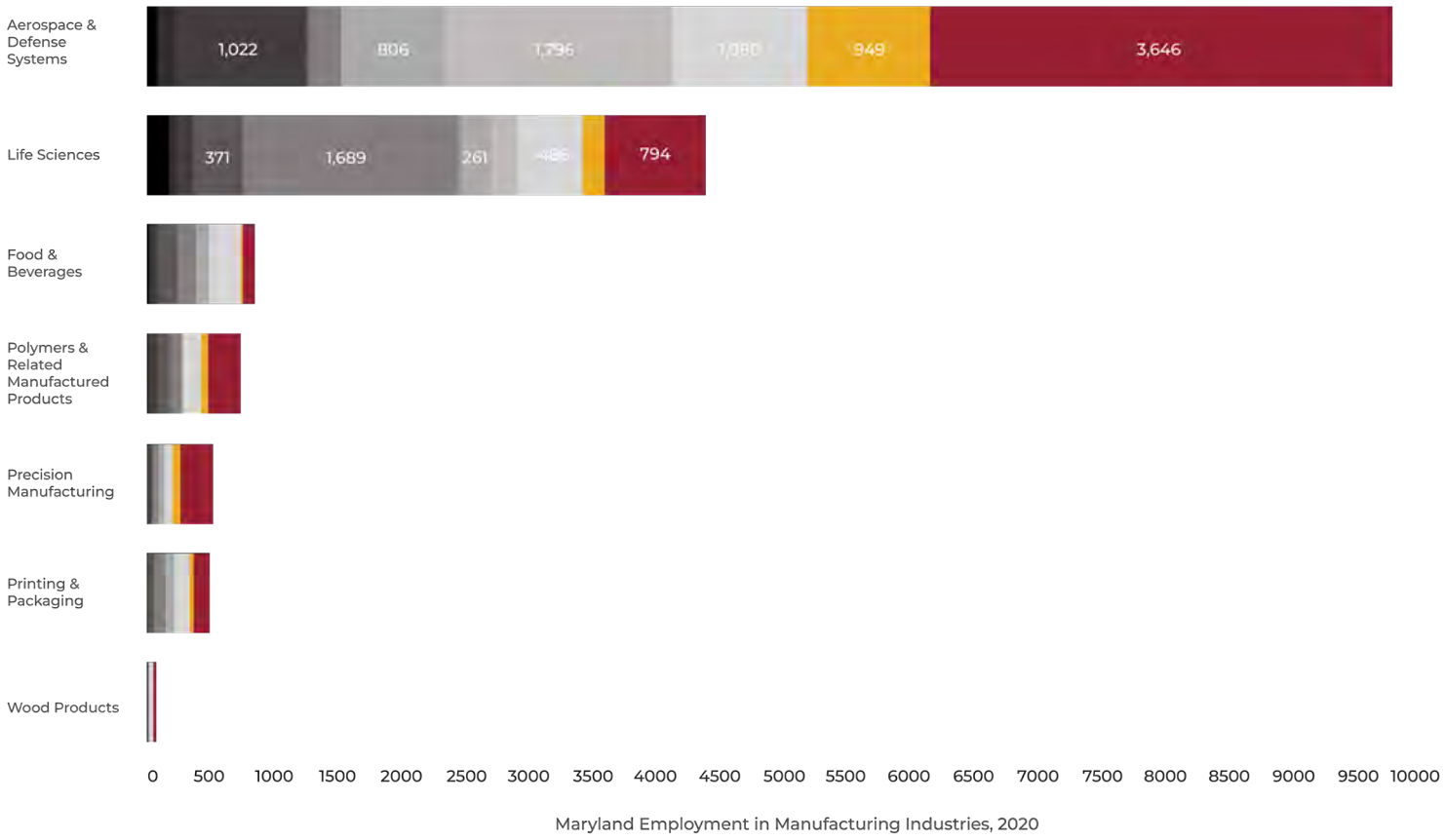
APPENDIX B: ADDITIONAL WORKFORCE & TALENT ANALYSIS OF INDUSTRY 4.0-ENABLING SEGMENTS

Figure B-1: Maryland and US Growth in Industry 4.0-Enabling Segments, 2015-2020



Source: TEConomy analysis of occupational data from Emsi (Emsi Release 2021.2)

Figure B-2: Detailed Industry 4.0-Enabling Occupational Employment within Maryland's Manufacturing Industry Subclusters



Source: TEConomy analysis of occupational data from Emsi (Emsi Release 2021.2)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