

***ADVANCED MANUFACTURING
SKILLS GAP IN THE
GREATER BERKS REGION***

PREPARED FOR:
**Berks County Workforce
Development Board**

PREPARED BY:
**Economic Development
Company of Lancaster County
and the
Center for Regional Analysis**

JANUARY 2021

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EXECUTIVE SUMMARY

Manufacturing in the Greater Berks Region (defined as Berks, Chester, Lancaster, Lebanon, Lehigh, Montgomery and Schuylkill Counties) has grown in output and employment over the past decade. One driver of this growth is the shift towards “advanced manufacturing,” which is characterized by the adoption of automation, the incorporation of technology, and the utilization of innovation in processes and systems. This sector-wide transition is visible in the data, evidenced by growth in specific occupations requiring more technical skills and reductions in general laborers. It also is clear from interviews with regional manufacturers.

For the purposes of this study, the pivotal term “advanced manufacturing” recognizes the unique blend of innovation and selective use of smart automation that firms in this Region have been doing. The definition is a bit abstract as it also must recognize that approximately 70% of the nearly 4,000 manufacturing establishments found here have fewer than 50 employees. It is not an “either-or” for whether a firm is an advanced manufacturer. Instead, the focus is how far along the advanced manufacturing trajectory it can move and at what pace.

Defining advanced manufacturing occupations recognizes the changing skills requirements of some occupations that have been embedded in the industry for well over two decades. These changes have been underway for some time and arguably reached a tipping point. Across the Greater Berks Region, its highly diverse manufacturing industry shares a key characteristic: production workers tend to have an outsized role in their labor force. The region’s heavy reliance on production workers elevates labor’s role in producing more, faster and

better with fewer resources and lower cost. Advanced manufacturing occupations are an indispensable part to achieving this objective.

Manufacturing is a strong component of the Greater Berks Region

The Greater Berks Region has maintained its significance in US manufacturing, having periods of contraction and expansion over the last 20 years. Significantly in the years following the Great Recession of 2008-2009, the manufacturing sector reversed its historical decline and began adding jobs.

- *By 2019, the sector added 11,600 jobs, accounting for nearly 81% of Pennsylvania’s job growth in manufacturing. In total, the manufacturing sector in this seven-county region included 3,900 establishments that were directly responsible for 174,200 employees (or 13% of the region’s workforce).*
- *As a share of PA’s manufacturing sector, the Region represents 27% of establishments and 30% of the manufacturing workforce.*

Manufacturing in the Greater Berks Region is anticipated to keep growing

While having grown quickly over the last ten years, future sector growth in the region is expected to be more modest but still faster than the nation.

- *This stronger regional growth plays an important role in forecasting demand for skilled occupations that outpaces national projections. In 2019, the Greater Berks Region had 94,400 production*

workers representing 54% of the manufacturing sector's workforce. Its total employment base is projected to grow between 4% and 5% by 2029. This equates to the region seeing an additional 6,460 to 8,740 jobs over the next ten years.

Advanced manufacturers in the region outline skills and labor needs

The advanced manufacturing transformation started in the early 2000s, but its impact did not become apparent until after 2010. Since then, the integration of advanced manufacturing has been more evolutionary rather than coming in leaps and bounds.

- *Interviews with employers emphasized that advanced manufacturing requires production workers who can operate equipment with programmed controls and computer interfaces. Additionally, that equipment, their user interfaces, and integration in a production process are all customized to the plant. Recognizing the specificity, employers turned to emphasizing the importance of basic entry level skills, and uniformity in the set of knowledge and training sought out for production workers.*
- *Employers indicated less demand for general laborers, concurrent with increased demand for roles that require more technical skills (such as CNC operators, machinists and programmers). The increased demand for more technical skills also reflected more cross-over from production to maintenance roles, as well as increased challenges in balancing the need for deep technical skills and knowledge with general management aptitude.*

Machine Operators and Tenders rise among production occupations in the Greater Berks Region

The interviews and data show that manufacturers in the Greater Berks Region have gradually reduced their reliance on general (unskilled) labor and increased their use of two broad classes of skills. They are workers that can operate machines that blend mechanical and programming, and workers that have specialized skills that are not easily transferred to automation. These two classes translate to a handful of advanced manufacturing production occupations: CNC operators and programmers; machinists; machine setters, tenders, and operators; and welders. A close look at occupations in the Greater Berks Region found these jobs in the “Top 20” production occupations (ie, 20 occupations representing 70% of all production workers).

CNC Operators and Programmers. Advanced manufacturing means increased importance of machines that are computer numerically controlled (CNC). Initially concentrated in a handful of durable goods manufacturing sectors, CNC operators and programmers are now present in nearly every subsector of manufacturing durable and nondurable goods. While BLS forecasts falling demand nationally for a pool of CNC operators and programmers, the regional demand is anticipated to be modestly positive given the anticipated, steady growth of manufacturing in the Greater Berks Region.

Machinist. Closely related to CNC operators and programmers are machinists. Reflecting the increased training and skills that accompany technological advancement, it is one of the few occupations that

BLS projects demand growing over the next decade. Historical demand in the region has been strong and anticipated to continue.

Machine Operators and Tenders. These roles have grown dramatically over the last 10 years, coinciding with the rise of manufacturing and likely reflecting the integration of new technology and equipment as production became cleaner, safer and more advanced. Given the strength of manufacturing in the region, demand for these skills is projected to continue its growing trajectory.

Welders. Widely recognized as a high demand skill, advanced manufacturing is anticipated to continue its strong use of these skills and demand is expected to be substantially stronger than many other production occupations.

Demand exists for installation, maintenance and repair workers

For advanced manufacturers, installation, maintenance and repair workers are essential, highly-skilled and highly-valued roles, requiring deep technical knowledge and aptitude. Interviews with manufacturers in the Greater Berks Region drew attention to the role maintenance workers play in a company’s ability to innovate and customize their products and production processes. The skills needed for these occupations are closely tied to the plant’s evolving use of technology, and demand for this talent increases with automation and plant expansion. Out of 39 installation, maintenance and repair occupations present in the Greater Berks Region, only a couple feature prominently in advanced manufacturing.

Industrial machinery mechanics are found across manufacturing and have the largest number of workers among all the installation, maintenance and repair occupations. With spill over into duties similar to **millwrights**. Manufacturer interviews alluded to the importance of these occupations, noting that the speed and efficiency in which companies can turnover machines to meet customer demand was a key part of their competitiveness, allowing them to service a wider swath of customers and smaller production orders.

Figure ES.1

Occupational Demand for Production Workers in the Greater Berks Region				
OCCUPATION	EMPLOYEES IN 2019	PROJECTED DEMAND BY 2029 ^A		
		BLS	LOW	HIGH
Machine Operators & Tenders	13,620	13,360	14,120	21,220
CNC Operators & Machinists	4,670	4,750	5,860	6,240
Welders	4,030	4,160	5,420	6,590
<i>Demand for Advanced Manufacturing Workers</i>	22,320	22,270	25,360	32,510
All Other Production	72,020	67,840	67,190	74,420
All Production	94,340	90,110	92,550	106,930
<i>Manufacturing Sector (all occupations)</i>	174,190	180,650	181,150	182,930

^A Projected demand reflects a range of values, built on BLS occupational projects for the nation and regional specific estimates. The regional estimates form the basis for the “low” and “high” values.

General maintenance and repair workers are present in all 21 manufacturing subsectors. Seemingly generic, this occupation (49-9071) is a “catch all” that reflects a critical aspect of advanced manufacturing – multiple areas of domain expertise, such as electro-mechanical, and machining – with responsibilities that extend beyond routine maintenance.

Demand for these occupations has generally grown between 2010 and 2019, with demand having accelerated over the last five years. Forecasted demand is projected to grow modestly in the Greater Berks Region.

Region’s educational institutions supply advanced manufacturing workers

Since coming out of the Great Recession, and now through the pandemic, manufacturing has demonstrated its resilience and importance to the economy. Despite these strengths, manufacturing is not immune to the challenges of attracting and retaining talent. Past perceptions of manufacturing jobs as dirty, dull and dangerous, coupled with a decades-in-the-making cultural shift of emphasizing college education resulted in reducing the appeal of these jobs. Exacerbating these hurdles is an aging population shrinking the pool of labor.

Most production roles in manufacturing offer career paths that do not necessitate postsecondary education and training for entry. While high school education and on-the-job training – as minimum requirements – equally apply to advanced manufacturing occupations, the knowledge base and skills are evolving.

Career and technical centers (CTCs) in the region attached to secondary education and postsecondary institutions have curriculums that meet the needs of advanced manufacturers to varying levels of comprehensiveness. They offer training and provide certifications and degrees to demonstrate deeper proficiency potentially allowing new workers to enter at more advanced levels or current workers to advance their capabilities.

Figure ES.2

Occupational Demand for Maintenance Workers in the Greater Berks Region				
OCCUPATION	EMPLOYEES IN 2019	PROJECTED DEMAND BY 2029 ^A		
		BLS	LOW	HIGH
Electrical & Electronic Repairers	275	285	275	285
Industrial Machinery Mechanics	2,935	3,395	3,395	3,430
Millwrights	220	235	235	410
General Maintenance & Repair Workers	2,695	2,805	2,775	2,805
<i>Demand for Advanced Manufacturing Workers</i>	6,125	6,720	6,680	6,930
All Other Maintenance	2,590	2,240	2,280	3,010
All Maintenance	8,710	8,960	8,960	9,930
<i>Manufacturing Sector (all occupations)</i>	174,190	180,650	181,150	182,930

^A Projected demand reflects a range of values, built on BLS occupational projects for the nation and regional specific estimates. The regional estimates form the basis for the “low” and “high” values.

Individual, county-level CTC systems across the Region offer 30 or more programs across multiple campuses (from auto mechanics to cosmetology to veterinary care), typically attracting around 10% to 15% of the high school students. While the number of high school students is falling, the CTCs generally report being able to grow their enrollments. Their success has been tied to flexibility that enables them to offer courses that reflect the interests of students and parents. Some of the most attended programs reported by CTC leaders are in the healthcare/allied health fields. However, interest in programs leading to advanced manufacturing careers has had limited traction.

Based on information gathered through interviews with CTC leaders, it is estimated that across the Greater Berks Region, the CTCs collectively produce 250 to 300 students a year with backgrounds supporting advanced manufacturing careers. Assuming these graduates represent the bulk of potential incoming workers to advanced manufacturing occupations and that the capacity and level of courses remains unchanged, the CTCs will graduate between 2,750 and 3,300 students over the next 10 years.

Although high school graduates represent a significant and steady source of potential new workers, postsecondary institutions play a vital role in producing workers equipped with the knowledge and training to succeed in advanced manufacturing careers – particularly for maintenance occupations. The Greater Berks Region is fortunate to have well-respected postsecondary institutions that are invested in the programs that support the region’s manufacturing sector. Like the CTCs, these institutions invested in delivering programs and course offerings for advanced manufacturing careers

but face similar challenges in attracting students. Several commented on how they appeal to only a fraction of their total student population.

Aging workforce impacts the availability of workers in advanced manufacturing occupations

While the population has been growing since 2010 and is projected to continue to grow across the Greater Berks Region, the size of its workforce has been getting smaller. The manufacturing sector is often mistakenly perceived as having an older workforce. The median age for the manufacturing sector is 44, which is not much different from other sectors (e.g., median age of the professional and business service sector is 42.8; transportation and warehousing is 44.8).

For the manufacturing sector as a whole and its general pool of production workers, one-quarter are likely to be at least 55 years of age. This implies that around 23,170 of its estimated 94,340 production workers are likely to retire by 2029. The age profile for maintenance workers is only marginally younger than production workers. 24% of the estimated 8,710 maintenance workers in manufacturing are over the age of 55 and likely to retire by 2029.

Net skills gap is not insurmountable

The Greater Berks Region potentially faces a critical skills gap shortage for filling advanced manufacturing occupations. This gap is not insurmountable, but it does require coordinated steps to be addressed to protect the vitality of manufacturing in the region. The growth in demand coupled with supply contracting amplify a skills gap that is widening over

time. This gap ranges between 5,880 and 13,885 workers by 2029. Comparison of the projected changes in demand and supply show that the gap is a function of industry growth that drives increased need for advanced manufacturing workers and an aging workforce with retirements that are not offset by incoming younger workers.

At the current rate, less than 1% of graduating high seniors leave secondary education armed with skills and knowledge to pursue advanced manufacturing careers. This highlights the incredible potential that exists to attract young workers to these careers. Additionally, the supply estimates provide only a cursory estimate of the potential for attracting adults interested in pursuing new careers to the sector.

Recommendations

Two overarching and connected recommendations are offered.

Recommendation 1: Establish a collective impact backbone approach to “re-set the table” on solving manufacturing workforce needs in the Greater Berks Region.

Recommendation 2: Develop a holistic, tactical plan that results in a growing pipeline of Machine Operator/Tenders, CNC Operators and Machinists, Welders and Maintenance Workers by 2030.

The recommendations hope to recognize and build on the myriad of strategies and activities that have been put in motion over the past several years by industry, economic development, workforce development and educational partners.

Figure ES.3

Projected Change in Demand and Supply of Advanced Manufacturing Workers in the Greater Berks Region between 2019 and 2029		
	PRODUCTION OCCUPATIONS	MAINTENANCE OCCUPATIONS
2019 Employment	22,320	6,125
2029 Projected Employment	25,360 - 32,510	6,680 - 6,930
Increased demand by 2029	3,040 - 10,190	555 - 805
Net shortage of entry and exits by 2029 ^A	2,070 - 2,670	220
Projected Net Shortage of Advanced Manufacturing Workers by 2029	5,110 - 12,860	770 - 1,025

^A Entry reflects projected number of new workers to advanced manufacturing occupations from secondary and postsecondary education by 2029. For production workers, between 2,700 and 3,300 new workers are estimated to fill production roles, and 5,370 workers are anticipated to retire. For maintenance workers, 1,500 new workers are forecasted and 1,720 are expected to retire.

REPORT QUICK STATISTICS

By 2019, the manufacturing sector in this seven-county region was comprised of 3,900 firms and 174,200 employees (or 13% of the region's workforce). As a share of PA's manufacturing sector, it represented 27% of establishments and 30% of the manufacturing workforce.

In Berks County, manufacturing's share of GDP is a considerable 21.5% and for the other counties in the target Greater Berks Region, it ranges from 10-24% of local GDP.

At the three-digit NAICS level, nearly every subsector is present in every county in the Greater Berks Region.

Manufacturing is made up of small, medium and large firms. Roughly a quarter – 28% of establishments – are larger and represent half of the employment base. The balance, 70% of all manufacturing establishments, represent the balance, in firms that average fewer than 50 employees.

In 2019, the Greater Berks Region had 94,300 production workers and 8,700 maintenance workers. Collectively, they represent just under 60% of the sector's total workforce.

With over 100 production occupations in the Greater Berks Region, just 20 capture 70% of production workers. Ten of these are identified as Advanced Manufacturing occupations that fit into four broad categories: CNC operators and programmers, machinists, machine operators and tenders, and welders.

Approximately 50 installation, maintenance and repair occupations are linked to the manufacturing sector but four specific occupations capture 70% of the workers.

Demand for advanced manufacturing workers (production and maintenance occupations) is projected to grow, rising from 28,450 in 2019 to between 32,040 and 39,440.

The supply of manufacturing workers is projected to fall over time, driven by retirements and limited attraction of young workers to the industry. 43,800 workers in the manufacturing sector are expected to retire by 2029. Of these, around 7,100 are likely to be in advanced manufacturing production and maintenance occupations.

Net shortage of advanced manufacturing workers (maintenance and production occupations) by 2029 is estimated to be between 5,890 and 13,890.

INTRODUCTION

The manufacturing sector in the Greater Berks Region (defined as Berks, Chester, Lancaster, Lebanon, Lehigh, Montgomery and Schuylkill Counties) has grown in output and employment over the past decade. One driver of this growth is the shift towards “advanced manufacturing,” which is characterized by the adoption of automation, the incorporation of technology, and the utilization of innovation in processes and systems. This sector-wide transition is visible in the data – as evidenced by growth in specific occupations requiring more technical skills and reductions in general laborers. It also is clear from interviews with regional manufacturers.

For the purposes of this study, the pivotal term “advanced manufacturing” recognizes the unique blend of innovation and in some ways the tinkering with smart automation that firms in this Region have been doing. The definition is a bit abstract as it also must recognize that approximately 70% of the nearly 4,000 manufacturing establishments found here have fewer than 50 employees. Broadly speaking, many of these firms survive (and thrive) on being customer service focused, able to navigate customization, with lean management teams all while finding ways to save margins, enhance efficiencies and/or reduce waste. This diffuse spectrum of small to mid-sized firms in aggregate has a noteworthy economic impact on the region and provides meaningful employment opportunities, often in clean and sophisticated environments.

There is no shortage of research or efforts focused on ensuring the long-term growth of advanced manufacturing from a national perspective down to a more local one. A whole host of assets – educational, workforce and economic development and

non-profit associations – play some role in supporting the manufacturing industry, with the emphasis on providing a qualified workforce in the face of demographic and technical shifts. Certainly, in the Greater Berks Region, the list of assets is long and includes Career and Technology Centers, Workforce Development Boards, Manufacturers Industrial Resource Centers, economic development organizations and other higher education institutions. This depth of resources aligns with the strength of this sector. Many of these interests rightfully point to progress being made over the past several years in redefining manufacturing, away from ‘dirty and dangerous’ toward meaningful family-sustaining jobs and leveraging an enhanced focus in K-12 education toward career planning.

Still, what this report documents and what manufacturers are saying now is that critical gaps exist between the supply of workers in this Region and the needs of businesses. This report’s take is to both simplify and narrow the discussion to sensible and measurable actions that can be initiated quickly yet require a long-term (many year) commitment. The emphasis is not on trying to solve gaps that exist today but to build a targeted supply of talent over time to meet future needs that leverage strengths throughout the system.

Based on the quantifiable analysis, the recommendation is to focus on a handful of production and maintenance occupations that make up the most significant portion of skills advanced manufacturers need. Specifically, for production, they are machine operators, computer numerically controlled (CNC) operators, machinists and welders. For maintenance, the occupations include industrial

mechanics, and millwrights. The opportunity is to align the workforce development ‘system,’ essentially the education, association and economic/workforce development assets along with the private sector, to prioritize these occupations.

This analysis, conducted primarily from July – November 2020, factored in considerable data from standard sources such as the Bureau of Labor Statistics. Notable assumptions were required to project occupational demands into the future. Additionally, the analysis involved the gathering of qualitative information, primarily gained from interviews with nearly 50 manufacturers and eight secondary and postsecondary institutions in the Greater Berks Region. Limitations to the available data and the assumptions needed to drive calculations underscore the value of the interviews. They affirmed, colored and contextualized what the numbers indicated. Ultimately, the value of the report is not found in any one specific data point; rather it is in the overall narrative derived from all the material gathered and the synthesis of that information into a succinct, tangible course of action.

Study Purpose

On January 9, 2020, the County of Berks, on behalf of the Berks County Workforce Development Board (WDB), issued an RFP outlining a scope of work with the purpose of developing, conducting and reporting out on a comprehensive study of current and projected advanced manufacturing skills gaps impacting employers in the Greater Berks Region (defined as Berks, Chester, Lancaster, Lebanon, Lehigh, Montgomery and Schuylkill Counties). The RFP stated that ‘these advanced manufacturing

skills are commonly found in technical occupations such as industrial maintenance/mechatronics, robotics, precision machining, additive manufacturing, precision welding and diesel engine technology.” The contracted work also sought to identify emerging occupations and skills with an emphasis on **Industry 4.0** and an identified time horizon of 2030.

In the Greater Berks Region, the pivotal term “advanced manufacturing” recognizes the unique blend of innovation and in some ways the tinkering with smart automation that firms in this Region have been doing.

Since the issuance of the RFP, the world literally changed due to the global pandemic. Practically speaking, the pandemic extended the RFP process and has also altered the initial timeline for work contemplated in the RFP. More broadly and significantly, as of the writing of this report and with the public health crisis still upon us, several key issues that were core to Berks WDB’s foundational assessment of the region’s manufacturing base have only been further underscored and exacerbated. Specifically, the pandemic has crystalized across industry, and certainly in manufacturing, the value of automation and technological advancements. It has highlighted the strengths and weaknesses of global interconnectedness as supply chains broke or were pushed to the limits as different parts of the world shut down and then re-opened. And perhaps most significantly, alarm bells about workforce shortages that were ringing pre-COVID-19, are sounding even

louder as employers are driving production and now navigating new employee challenges and barriers.

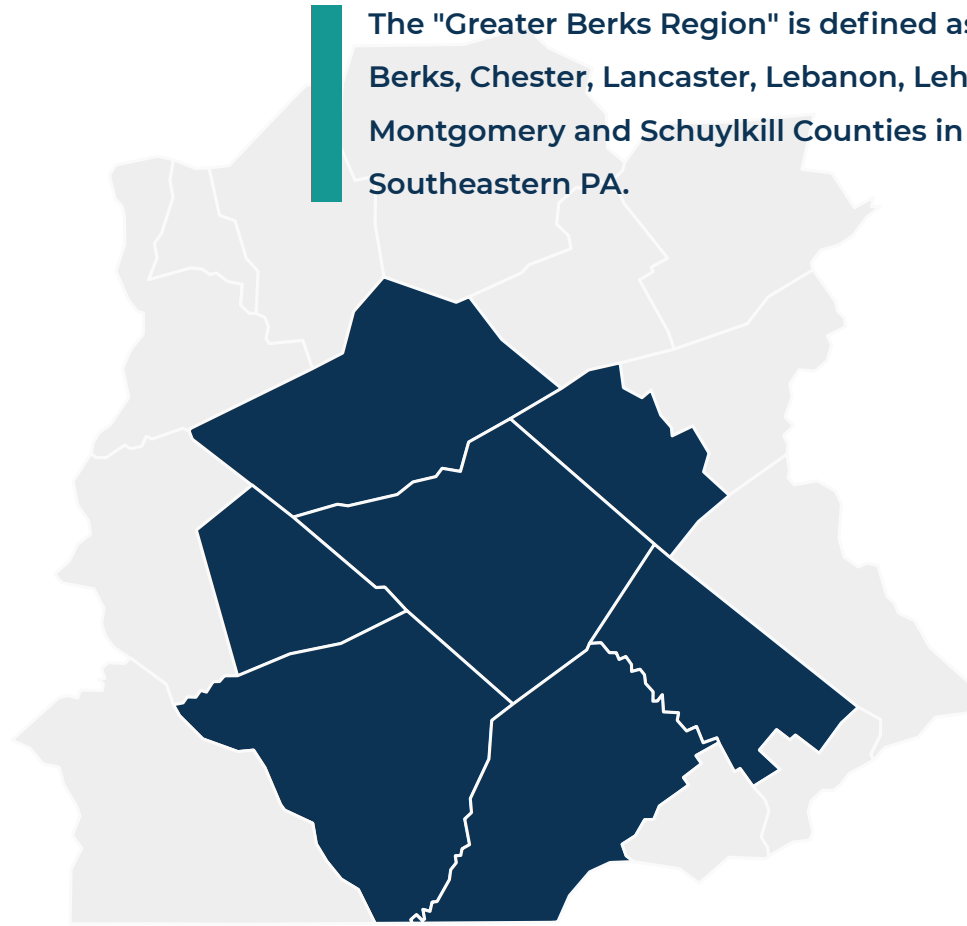
In some ways, the revised delivery date of this analysis and the anticipated discussions that will follow may be even better timed than when contemplated initially by Berks County. Two important take-aways are already clear coming out of the pandemic that should be leveraged today: (1) change and the ability to be incredibly agile are possible, whether the topic is manufacturing, higher education or workforce and economic development; and (2) the value of talent and the labor pool is significant.

Contract Background

The County of Berks and the Berks County Workforce Development Board (Berks WDB) contracted with the Economic Development Company of Lancaster County (EDC) and its sister organization, the Center for Regional Analysis (CRA), in June 2020. The scope of work includes a detailed supply/demand analysis focused on regional advanced manufacturing, with an emphasis on assessing and understanding workforce needs, including specific occupations and skills gaps. The goal is to ensure this significant segment of the economy is competitively positioned for continued growth in the future, cognizant it will require a strengthened alignment of the labor supply and demand. Berks WDB proposed a regional approach, recognizing the breadth of assets across the broader geography – companies, educational institutions and workforce and economic development entities – plus the potential transient nature of workers across county lines.

Berks WDB has appropriately identified a serious threat to the retention and growth of manufacturing in the region: access to a robust talent pipeline and the ability to overcome skills shortages (due to an aging workforce and other demographic factors). This threat may also act as a disincentive for firms to make necessary capital investment in local plants, further undermining the region's competitiveness.

The "Greater Berks Region" is defined as Berks, Chester, Lancaster, Lebanon, Lehigh, Montgomery and Schuylkill Counties in Southeastern PA.



EDC/CRA Approach

EDC and CRA's work spanned nine months, with the data collection principally conducted from July – November 2020. It builds upon research, analysis, discussions and other strategies in the region similarly focused on the manufacturing labor pool and skills needs. This research effort coincides with considerable national focus on the manufacturing sector, including workforce shortages and technological adoption. This report includes and reflects detailed supply and demand analysis and forecasting, with an emphasis on production and maintenance roles in advanced manufacturing and includes several scenarios to reflect the uncertainty and limitations of data. It layers in real-time knowledge gained from interviews with 50 manufacturers throughout the region, plus insights from educational institutions and regional economic and workforce development partners.

The report starts with discussion on the term advanced manufacturing, as a unique segment of manufacturing more broadly. It then transitions to an overall outline of manufacturing in the region to provide broad context of the sector. With this foundational information, the report shifts to the core questions of the demand, supply and gaps in key advanced manufacturing production and

maintenance occupations that are both quantified by data and supplemented by interviews. The final section presents a series of findings and two high-level recommendations.

The report aggregates information at the Greater Berks regional level. In forecasting, it is important to note that any projections at levels of disaggregation below the regional level are less reliable than the aggregate whole. Still, both sets of data – regional and county-level, when available – are important. The manufacturing sector, taken regionally, is formidable and dynamic. Additionally, the network of workforce development resources across the region is significant and, when considered as regional assets, opens up opportunity. Conversely, a regional look risks oversimplifying the manufacturing sector, as important real differences as well as notable nuances exist across all seven counties, from the composition of each of their manufacturing bases, changes in their establishments and workforces over time and in local policy priorities.

The development of the report was done through a strong partnership between EDC/CRA and the Berks County WDB, its leadership team and with engagement by key stakeholders and committees. Significant expertise and knowledge exist 'on the ground' and has been incorporated into the analysis.

DEFINING ADVANCED MANUFACTURING

*Driving Productivity,
Precision and
Efficiency through
Automation
and Technology*

Before diving into the data and analysis, some discussion on an essential term – advanced manufacturing - needs further definition, both in terms of how it is used broadly by experts and how it is used in this report. Over the past decade, the evaluation of technology adoption, capital investment in automation and information technology systems has and continues to be a major focus to ensure this sector’s global competitiveness. That said, the phrase ‘advanced manufacturing’ is, in many ways, a ubiquitous term that is also unclear. During interviews conducted with manufacturing firms, it was clear that no single or simple definition is widely accepted. In fact, one interviewee reflected on the phrase as ‘the language of economic and workforce development people.’

At the national level, the Advanced Manufacturing National Program Office offers two definitions:

**“Use of innovative technologies to create existing products and the creation of new products
Advanced manufacturing can include production activities that depend on information, automation, computation, software, sensing, and networking.”**
– *Definition of Advanced Manufacturing*

“Aims to improve product design and manufacturing processes across the board by seamless integration of information technology systems across the supply chain. Digital manufacturing focuses on reducing the time and cost of manufacturing by integrating and using data from design, production, and product use; digitizing manufacturing operations to improve product, process, and enterprise performance, and tools for modeling and advanced analytics, throughout the product life cycle.”

– *Definition of Industry 4.0 or Digital Manufacturing*

These two definitions tied to advanced manufacturing provide broad guideposts recognizing the investments firms are making regularly to stay competitive. The core elements are the deployment of technology – via IT or equipment - to achieve basic production goals often through automation and enhanced connectivity.

A Definition of Advanced Manufacturing in the Greater Berks Region

With efficiency and quality assurance as drivers to automation and the investment in upgraded IT systems, the concept of advanced manufacturing is a continuum. Firms don't fall into two categories – advanced manufacturing or not advanced manufacturing. Instead, the focus is on how far along the advanced manufacturing trajectory can a company move and at what pace.

Interviews and data support a view of manufacturing in the Greater Berks Region as competitive, agile, and innovative. These descriptors capture the strategic positioning manufacturers in the Greater Berks Region have pursued over the last 10 to 20 years, which is to:

- *Customize products and production volumes to customer specifications;*
- *Offer quick turn-around service while serving a broad and diverse customer base; and*
- *Serve local and regional markets (thereby avoiding international competition).*

They have been able to achieve these goals through a blend of technology and labor that also transformed their production facilities into clean and modern environments, flying in the face of stereotypes of small dirty plants.

But when asked what advanced manufacturing means to their industry, the answers were as varied as the interviewees. The technological evolution consistently described in interviews aligned with concepts of advanced manufacturing. Interviewees offered up a view of technology and automation that had a unique blend of innovation and tinkering with smart automation to get rid of the dirty, dull, repetitive and dangerous activities, while preserving the customization that differentiates them in the market.

It's not an "either or" for whether a firm is an advanced manufacturer. Instead, the focus is on how far along the advanced manufacturing trajectory it can move and at what pace.

The idea of “lights out” manufacturing was often positioned as an impediment to the customization their products offered and their ability to satisfy large and small orders. Interviews often described steady surveillance of their own production systems to identify where efficiency improvements in output or quality could be achieved through future investments – either on the IT or equipment side. Where opportunities for additional automation were limited, companies talked about the role of data capture and analysis and connectivity to better integrate production with sales, inventory and delivery systems.

Relationship Between Advanced Manufacturing and Labor

Interviews emphasized how changes tend to reverberate through the entire production process. For example, adding equipment that expands production changes the mix of current labor needs and the potential for adding skilled labor and reducing unskilled labor or redeploying labor to new activities. This makes forecasting the demand for advanced manufacturing occupations a seemingly arbitrary distinction from forecasting the sector's production labor requirements as whole. However, the distinction is meaningful when viewed in an ecosystem that brings employers, educators and workforce development practitioners together.

The focus on defining advanced manufacturing occupations recognizes the changing skills requirements of some occupations that have been embedded in the industry for well over two decades. These changes have been underway for quite some time and arguably reached a tipping point. Across the Greater Berks Region, both quantitative and qualitative data points to a highly diverse manufacturing industry with a shared characteristic: production workers tend to have an outsized role in manufacturing in their labor force. This is for good reason. Many of the companies are lean. With over 70% of the establishments having an average of 43 employees or less, the economics of the firm does not support large back office operations. This outsized concentration of production workers

elevates labor's role in producing more, faster and better with fewer resources and lower costs. Advanced manufacturing occupations are an indispensable part to achieving this objective. The interviews and data show that manufacturers in the Greater Berks Region have gradually reduced their reliance on general (unskilled) labor and increased their use of two broad classes of skills. They are workers that can operate machines that blend mechanical and programming, and workers that have specialized skills that are not easily transferred to automation. This study defines these semi-skilled and skilled roles as advanced manufacturing occupations.

Manufacturers in the Greater Berks Region have reduced their reliance on general (unskilled) labor and increased their use of two broad classes of semi-skilled and skilled workers: workers that can operate machines that blend mechanical and programming, and workers that have specialized skills not easily transferred to automation.

National data shows US manufacturing trending towards a higher percentage of production and maintenance occupations relative to other roles (sales, human resources, etc.). The Greater Berks Region has been far ahead of this trend. In part this represents the application of technology to the administration part of the business, reducing the

need for support staff through computerized ERP systems, outsourcing payroll organizations and automated online ordering systems particularly for small and mid-sized companies.

The improved productivity of production workers also drives this, as fewer employees per firm leads to fewer supervisory staff. Overall smaller firms tended to be closer to two-thirds production versus one-third support as compared to larger firms. The demand for these positions does not require highly trained and experienced workers, however. Employers unanimously described a need for entry level workers with a strong foundation in the “basics” (knowledge of mechanical, pneumatics, electrical and programming) and skills (teamwork, troubleshooting). The specialized machinery and processes within a firm do not allow for easy transition between firms, even within the same industry. Said one manufacturer of their key equipment, “I guarantee no one has worked with one of these machines before. This is the only one on this side of the country.” As a result of intrafirm specialization, every firm interviewed expected to train new employees in their machines and processes and was prepared to do so. Essential to this training is a foundation of basic skills and aptitudes allowing the new workers to flourish within the firm.

MANUFACTURING IN THE GREATER BERKS REGION IS STRONG – AND GROWING

Manufacturing plays an important role in the economy – at a local, state, and national level. It is a significant source of GDP and employment, often serving as a main driver of local and regional economies. Their plants and operations are anchor sources of jobs and major contributors to the tax base. Misconceptions about manufacturing remain – from the sense that it is a ‘dying’ industry to the outdated perception that manufacturing is dirty and unsophisticated.

By GDP: Since the late 1990s, the manufacturing sector has generated roughly 12% of national GDP. For the Commonwealth of Pennsylvania, its share of GDP has been historically higher but has fallen and is in-line with national averages (declining 17% to 12%). At a county-wide level for some communities in Pennsylvania, manufacturing’s role remains outsized relative to the state and nation. In Berks County, manufacturing’s share of GDP is a considerable 21.5%, and for the other counties in the target Greater Berks Region, it ranges from 10-24% of local GDP. With the exceptions of Chester and Montgomery Counties, manufacturing GDP increased across the region from 2010 to 2019 with a compound annual growth rate of 2%. This growth outpaced the State and coincided with an overall expansion of its workforce while simultaneously undergoing industry consolidation.

By Workers: In the United States, the manufacturing workforce had been on the decline for about 30 years from 1970 to 2010.ⁱ For the Greater Berks Region, the sharpest decline occurred between 2000 and 2010, when manufacturing’s workforce contracted at a compound annual growth rate of 5%. This resulted in the total number of workers in manufacturing in the

Greater Berks Regions dropping from 248,100 in 2001 to 162,600 in 2010.ⁱⁱ The region’s contraction was relatively faster and more significant than the state average (4% per annum).

In the years following the Great Recession, the manufacturing sector reversed its decline. Across the Greater Berks Region, the sector added 11,600 jobs, accounting for nearly 81% of Pennsylvania’s job growth in manufacturing. By 2019, the manufacturing sector in this seven-county region included 3,900 establishments that were directly responsible for 174,200 employees (or 13% of the region’s workforce). As a share of PA’s manufacturing sector, it represented 27% of establishments and 30% of the manufacturing workforce.

The Greater Berks Region has maintained its significance in the US manufacturing, even with having periods of contraction and expansion over the last 20 years. It has consistently had relatively higher levels of manufacturing jobs compared to the nation. Four out of the seven counties (Berks, Lancaster, Lebanon, Schuylkill) have a high concentration of manufacturing jobs based on the location quotient for employment. The location quotient (LQ) indicates the extent to which employment is more or less concentrated in the area compared to the national average. An LQ greater than one means greater concentration than the national average, less than one means less than the national average. For these four counties, their LQ is near to or greater than 2. This means, on average, they have twice the relative share of manufacturing jobs compared to the US average. Only Chester County has an LQ less than one. For nearly all of the counties, the LQ increased from 2010 to 2020.

The rising LQ suggests that the region intensified its share of manufacturing workers. This intensification is often associated with industry concentration and role in the economic base of a region. It is another piece of evidence pointing to how the region’s manufacturers over this past decade have strengthened their market positions driving the notable growth in productivity and labor now visible in the data. Interviews with regional manufacturers indicate a focus on servicing domestic markets, on customizing products allowing for diversification of customers across sectors and enhancing agility and driving value proposition to meet changing customer requests and requirements. Going hand in glove with these adaptations was a commensurate level capital investment in production equipment, moving many Greater Berks manufacturing firms along the continuum of technological advancement and automation.

While having grown quickly over the last 10-years, future manufacturing growth in the region is expected to be more modest. Interviews confirm that many manufacturers are continuously looking for new opportunities to invest in technology with much of the “low hanging fruit” having already been exhausted. The next round of major investments will require innovation and significant plant changes. While these investments are likely to continue, they will come at a more measured pace driven by customer demand and contribution to increased output, efficiency and quality. Interviews often noted that large capital investments required one- to three-year return on investments.

Figure 1

Greater Berks Region Manufacturing: 2010 to 2019			
YEAR	GDP ^A (2012 \$M)	ESTABLISHMENTS	EMPLOYMENT ^B
2010	27,082	3,972	162,000
2011	25,486	3,867	162,638
2012	24,862	3,806	163,511
2013	26,494	3,776	162,951
2014	27,291	3,807	165,157
2015	27,501	3,816	166,493
2016	27,302	3,867	166,244
2017	26,591	3,872	169,726
2018	27,327	3,899	174,188
2019	27,358	3,933	174,188
CAGR ^C	0.11%	-0.1%	0.77%

^A GDP figures from Bureau of Economic Analysis. Figure for 2019 is estimated based on CAGR from 2010 to 2018. ^B Employment figures from Bureau of Labor Statistics, Quarterly Census of Employment. ^C Compound Annual Growth Rate estimated from 2010-2018 for GDP. CAGR for employment figures based on 2010 to 2019.

The Composition of Manufacturing in the Region – An Industry Sub-Sector Overview

Well Diversified with Many Small (50 employees and fewer) Firms

An important aspect of manufacturing's economic impact is the diversity of size and sectors found in the Greater Berks Region. Based on Bureau of Economic Analysis data, the region has nearly 4000 establishments covering nearly every manufacturing subsector in every county. ⁱⁱⁱ The firms also range widely in size from manufacturing facilities that employ thousands of workers to many with fewer than 25 employees.

The chart and table showcase the diversity in the Greater Berks Region, detailing two dimensions of the 21 subsectors that comprise manufacturing. They show for each subsector the number of establishments and average number of workers per establishment. This provides a sense of the sector's breadth and scale. The region has a mix of large and small establishments. Roughly a quarter – 28% of establishments – employ half of the sector's workers. The other half of manufacturing workers are employed in the balance of establishment (72%). This 72% of establishments tend to be smaller, on average employing fewer than 42 people.

From an employment perspective, the **three largest subsectors** are ^{iv}:

- *Food manufacturing (NAICS 311), 16% of manufacturing sector's employment base*
- *Chemicals manufacturing (NAICS 325), 13% of manufacturing sector's employment base*
- *Fabricated metal products (NAICS 332), 12% of manufacturing sector's employment base.*

These sectors are closely followed by several that individually account for **5 – 7% of the employment** base for manufacturing:

- *Printing and related support activities (NAICS 323), 5%*
- *Plastics and rubber products manufacturing (NAICS 326), 7%*
- *Primary metal manufacturing (NAICS 331), 7%*
- *Computer and electronic product manufacturing (NAICS 334), 5%*
- *Transportation equipment manufacturing (NAICS 336), 5%*
- *Miscellaneous manufacturing (NAICS 339), 6%.*

Figure 2

Manufacturing Subsectors In Greater Berks Region (2019)

BIG COMPANIES

Few firms & lots of employees

15% of Employees

7% of Establishments

322 - Paper

331 - Primary metal

336 - Transportation equipment

SMALL COMPANIES

Few firms & few employees

6% of Employees

10% of Establishments

312 - Beverage & tobacco products

313 - Textile mills

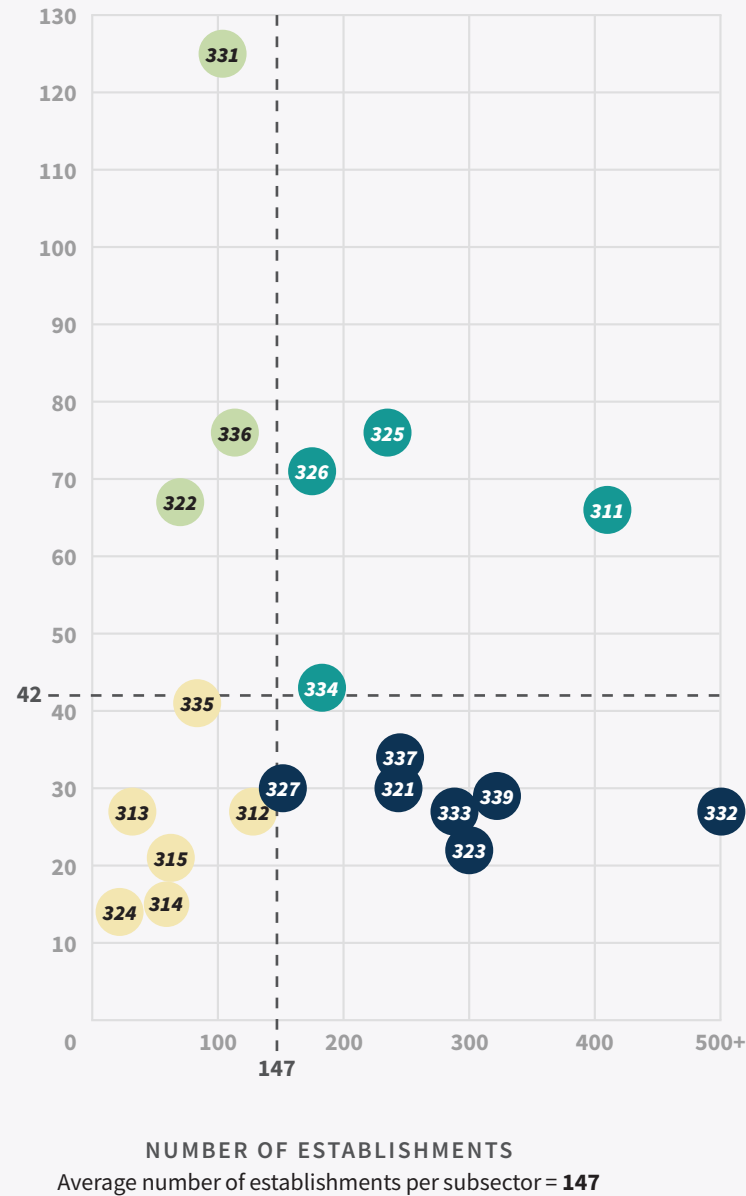
314 - Textile product mills

315 - Apparel

324 - Petroleum & chemical products

335 - Electrical equipment & appliances

AVERAGE NUMBER OF EMPLOYEES PER ESTABLISHMENT
Average number of employees per establishments = 42



MID TO LARGE COMPANIES, OFTEN WITH MULTIPLE SITES

Lots of firms & lots of employees

36% of Employees

20% of Establishments

311 - Food

325 - Chemical

326 - Plastics & rubber products

334 - Computer & electronic products

INDUSTRY CLUSTER OF SMALL COMPANIES

Lots of firms & few employees

43% of Employees

62% of Establishments

321 - Wood product

323 - Printing & related products

327 - Nonmetallic mineral product

332 - Fabricated metal products

333 - Machinery

337 - Furniture & related products

339 - Miscellaneous

DEMAND FOR SKILLED OCCUPATIONS

*Needed Skills
Evidences Advanced
Manufacturing's
Growth in the
Greater Berks Region*

The breadth of manufacturing in the Greater Berks Region is unique and differentiates it from other areas around the US with strong manufacturing. At the same time, it creates some challenges to aggregation and coordination across the establishments. Despite the heterogeneity, several key themes cut across subsectors and firms when it came to market positioning and the role of technology and labor. Advanced manufacturing is not limited to any specific sub-sector, nor is it necessarily tied to a firm's size. The processes and equipment tend to be customized to the establishment. While employers seek talent and technical skills, production roles – at least at the entry level – converged around a common, core knowledge base. The knowledge base required a blend of mechanical and electrical coupled with ability to troubleshoot, interface with computers, read schematics and work in team environments. Specialization emerged through on the job training tailored to the unique equipment and processes of the firm.

BLS Employment Projections

The Bureau of Labor Statistics (BLS) collects and reports employment by occupation and produces employment projections. The data is meant to capture national trends. The historical occupational data provides details of total employment by four-digit Standard Occupational Classification (SOC) code and industry (down to the 5 or 6-digit NAICS). The smallest geographic disaggregation is the metropolitan statistical area (MSA). The employment projections provide occupational forecasts, but only for the nation looking out 10 years. The most recent forecast spans 2019-2029, detailing projections at the industry and occupational levels. To develop these projections, BLS incorporates population changes, labor force participation rates, productivity and industry growth.

Greater Berks Region Diverging from the Nation

BLS predicts US manufacturing to be among the fastest declining employment sectors over the next 10 years. An anticipated slowing of output growth (CAGR of 1.5%), coupled with technological advancements, drive the sector to reduce its reliance on labor. With these forces at play, BLS projects the US manufacturing sector to lose 4.4 million jobs between 2019 and 2029 (or at a compound annual growth rate of -0.4%). This downtick reverses the gains made over the last decade where US manufacturing output grew at a compound annual rate of 2.0% and added 9.9 million jobs to its employment base.

It is important to understand the broad national dynamics that underpin this projection. Four local factors lead to a reasonable projection that the Greater Berks Region's manufacturing sector will experience a different growth trajectory in output and employment:

- *First, output growth at the national level is driven by large, established sectors, like aerospace and automobiles, which do not have a strong presence in the Greater Berks Region. These subsectors are characterized by mature markets, where growth comes from acquisition rather than new product.*
- *Second, the three manufacturing subsectors with the fastest expected national decline have already significantly contracted in the Greater Berks Region. They are tobacco production, alumina and aluminum products and textile and textile mills products.*

- *Third, BLS anticipates employment to fall as a result of productivity enhancing technology and international competition. International competition is not that strongly at play for the Greater Berks Region's manufacturing sector. The region's businesses largely have a mid-Atlantic and/or a domestic footprint, mitigating the impact of international competition (unlike the large multinationals and publicly traded companies that drive overall US trends).*
- *Lastly, as noted earlier, manufacturing in the Greater Berks Region appears to have already heavily invested in technology suggesting future investment is incremental. This was a common thread through company interviews, particularly for smaller scale businesses (\$5 million to \$20 million in revenue, with 20 and more employees). For them, productivity enhancing technology requires more of what they already have or moderate enhancements, rather than the seismic shift from manual processes toward automation. Planned investment in new technology or expanding current capacity require staging to preserve or add (rather than reduce) to their labor base.*

Based on these dynamics, future advanced manufacturing job growth in the region should be more modest. Interviews often conveyed that manufacturers are continuously looking for new opportunities to invest in technology, however much of the low hanging fruit has been exhausted. The next round of investments will require innovation and significant plant changes. While these investments are likely to continue, they will come at a more measured pace driven by customer demand and justified by their contribution to increased output, efficiency and quality.

Forecasting Manufacturing and Its Labor Force

Shifting from Sub-Sector to Occupations

With the interviews revealing that advanced manufacturing is present in every manufacturing subsector but at varying degrees of intensity and application within and across firms, identifying the skills gap places particular emphasis on how firms across the region have been changing the mix of production and maintenance occupations in their workforce. In other words, the investment in innovative processes, robotic equipment and IT system enhancements occurred across the breadth of manufacturing subsectors, but the investments were not uniform or tied to a particular firm size. Signaling these investments in automation and technology in the Greater Berks Region are sector-wide shifts of labor among key occupations. They indicated less demand for general laborers, concurrent with increased demand for roles that require more technical skills, such as CNC operators, machinists and programmers. The increased demand for more technical skills also reflected more crossover from production to maintenance roles, as well as increased challenges in balancing the need for deep technical skills and knowledge with general management aptitude.

The advanced manufacturing transformation started in the early 2000s, but its impact did not become apparent until after 2010. Since then, the integration of advanced manufacturing has been more evolutionary rather than coming in leaps and bounds. The interviews with employers emphasized that advanced manufacturing requires production workers who can operate equipment that requires programmed controls and computer interfaces, and that equipment, their user

interfaces, and integration in a production process are all customized to the plant. Recognizing the specificity, employers turned to emphasizing the importance of basic entry level skills, and uniformity in the set of knowledge and training desired of production workers. The interviews underscore that the next 10 to 15 years will bring steady, incremental change that necessitates retraining and equipping existing workers with the skills to be redeployed within the plant. In contrast, demand for maintenance workers grows with technological investments and the skills requirement is heightened, requiring aptitude and formal (post-secondary) training coupled with years of on-the-job training.

In advanced manufacturing, the next 10 to 15 years will bring steady, incremental change. *Production workers* will need to be life-long learners as they are continuously redeployed within the plant. *Maintenance workers* will have strong aptitude combined with formal (postsecondary) training and years of on-the-job training.

To reflect this dynamic, the analysis estimates the future demand for advanced manufacturing skills by focusing on how the current intensity of production and maintenance occupations will change over time and identifying the ones that are most closely linked to manufacturing processes where equipment is essential to achieving increased output and quality with less labor.

Production Occupations

A close look at production in the Greater Berks Region found 20 occupations represent over 70% of all production workers. These “Top 20” production occupations loosely fall into three categories:

- *Machine-based production roles that directly reflect the integration of advance manufacturing processes;*
 - *Skilled occupations not likely to be replaced with additional automation and technology investment;*
 - *General production labor which is not identified as an advanced manufacturing occupation but the demand for this type of labor is affected.*
- *15 of the occupations have grown between 2010 and 2019, with a compound annual growth rate (CAGR) of 4.1%. Total employment was 20,290 in 2010, representing 43% of all production workers. By 2019, 29,080 workers filled these occupations, representing 59% of production workers.*
 - *Five of the occupations have been contracting from 2010 to 2019. For these, employment fell at a compound annual growth rate of -5.7%. In 2010, these occupations represented 21% of production workers. By 2019, 5,770 workers filled these occupations, which was 12% of all production workers.*
 - *Notably, growth for most of these occupations varied across the three counties.*

These occupations rose to the top in a list of over 100 distinct production occupations identified by BLS as being present in the region. Because of data availability, this list draws heavily from detailed analysis of three of the counties: Berks, Lancaster and Lebanon. While not fully representative, these three counties are a substantial portion of manufacturing in the Greater Berks Region. They generate over a third of the region’s manufacturing GDP and are home to companies that employ 45% of the manufacturing labor force. Berk and Lancaster Counties, in particular, also have a broad mix of manufacturing subsectors. The data from these three counties suggest the following about the “Top 20” occupations.

- *These occupations have 500 workers or more across the Greater Berks Region in 2019 and represent 71% of all production workers and 7% of total employment (across all sectors).*

Installation, Maintenance and Repair Occupations

While production workers operate the machines, the maintenance workers keep the machines functioning. This category of occupations represents a small but essential role in the manufacturing sector. They account for only 5% of the manufacturing sector’s workforce.

Approximately 50 distinct standard occupational codes (SOCs) for installation, maintenance and repair occupations are linked to the manufacturing sector according to BLS data. Similar to production jobs, national data on the manufacturing sector reveals the lion share of workers is concentrated in a few occupations. Over half (63%) are industrial machinery mechanics (49-9041) or general maintenance and repair workers (49-9071). Another 28% fill 12 specific

Figure 3

**Three MSAs (Lancaster, Lebanon, Reading) in the Greater Berks Region –
Change in Employment by Production Occupations, 2005-2019**

OCCUPATION	2005	2010	2019	CAGR 2005-2010	CAGR 2010-2019
Assemblers & Fabricators, All Other (51-2090/2092/ 2099)	8,170	4,650	8,450	-10.7%	6.9%
First-Line Supervisors of Production & Operating Workers (51-1011)	3,170	2,990	2,150	-1.2%	0.6%
Packaging & Filling Machine Operators & Tenders (51-9111)	2,570	2,710	2,840	1.1%	0.5%
Inspectors, Testers, Sorters, Samplers, & Weighers (51-9061)	2,410	1,900	2,610	-4.6%	3.6%
Welders, Cutters, Solderers, & Brazers (51-4121)	1,860	1,350	2,100	-6.2%	5.0%
Helpers--Production Workers (51-9198)	2,870	5,170	1,790	12.5%	-11.1%
Machinists (51-4041)	1,780	1,250	1,620	-6.8%	2.9%
Printing Press Operators (51-5112)	1,700	1,700	1,560	0.0%	-1.0%
Cutting, Punching, & Press Machine Setters, Operators, & Tenders, Metal & Plastic (51-4031)	1,120	1,060	1,370	-1.1%	2.9%
Cabinetmakers & Bench Carpenters (51-7011)	580	740	1,250	5.0%	6.0%
Food Batchmakers (51-3092)	940	1,090	1,190	3.0%	1.0%
Molding, Coremaking, and Casting Machine Setters, Operators, & Tenders, Metal and Plastic (51-4072)	1,580	760	850	-13.6%	1.3%
Bakers (51-3011)	960	970	820	0.2%	-1.8%
Sewing Machine Operators (51-6031)	700	1,050	820	8.4%	-2.7%
Computer Numerically Controlled Tool Operators (51-9161, 51-4011)	520	520	810	0.0%	5.0%
Computer Numerically Controlled Tool Programmers (51-9162, 51-4012)	140	30	810	-26.5%	44.2%
Electrical, Electronic, & Electromechanical Assemblers, (51-2022, 51-2023, 51-2028)	1,010	930	780	-1.6%	-1.9%
Coating, Painting, & Spraying Machine Setters, Operators, & Tenders (51-9122/9124)	110	150	770	6.4%	19.9%
Mixing and Blending Machine Setters, Operators, & Tenders (51-9023)	820	620	640	-5.4%	0.4%
Multiple Machine Tool Setters, Operators, & Tenders, Metal and Plastic (51-4081)	0	470	620		3.1%
Top 20 Occupations Total	33,010	30,110	34,850	-1.8%	1.6%
Growing Occupations	25,770	20,920	29,080	-4.7%	4.1%
Contracting Occupations	7,240	9,820	5,770	6.3%	-5.7%
Production Occupations	58,330	47,240	49,110	-4.1%	0.4%
All Occupations (across all sectors)	438,820	427,010	477,970	-0.5%	1.3%

occupations, leaving the remaining 8% of the sector’s installation, maintenance and repair workers spread across more than 30 occupations.

Within the Greater Berks Region, local demand patterns for installation, maintenance and repair workers have to be estimated. This class of occupations covers a wide array of sectors beyond manufacturing, including utilities and service sectors, and BLS does not provide disaggregation of occupations by industry at smaller geographic areas, such as MSA or county. Out of the 50 SOCs identified in this category, 39 appear in the MSA data for the Greater Berks Region.^v Of these, only four occupations feature strongly in the data and are consistent with national manufacturing employment patterns. The table below details these “Top 4” occupations.

Key features of these occupations, based on data from three MSAs in the Greater Berks Region, are as follows.

- Each of these occupations have at least 130 workers across the Greater Berks Region in 2019 and account for just under 40% of employment in the installation, maintenance and repair category across all sectors.
- Demand for these four occupations by the manufacturing sector has generally grown between 2010 and 2019. Total employment was 7,120 in 2010. The region added 430 workers by 2019. This increase is equivalent to a compound annual growth rate (CAGR) of 0.7%. This slow growth rate masks the striking rise in demand that occurred since 2015.

This study estimates that manufacturers in the region have a proportion of maintenance workers that is similar to the national average. The US manufacturing sector has one maintenance worker for every 10 production workers. The variation across manufacturing subsectors is substantial, with the ratio of one maintenance worker ranging from as few as 6 production workers to as high as 31 production workers.

Figure 4

Three MSAs (Lancaster, Lebanon, Reading) in the Greater Berks Region – Change in Employment by Maintenance Occupations, 2005-2019					
OCCUPATION	2005	2010	2019	CAGR 2005-2010	CAGR 2010-2019
Maintenance & Repair Workers, General (49-9071) ^A		4,750	4,880		0.3%
Industrial machinery mechanics (49-9041)	1,800	1,920	2,210	1.3%	1.6%
Millwrights (49-9044)	240	120	330	-12.9%	11.9%
Electrical & electronics repairers, commercial & industrial equipment (49-2094)	340	330	130	-0.6%	-9.8%
Top 4 Occupations Total	2,380	7,120	7,550	24.5%	0.7%
Installation, Maintenance & Repair Occupations	21,190	19,810	22,300	-1.3%	1.3%
All Occupations (across all sectors)	438,820	427,010	477,970	-0.5%	1.3%

^A Projected demand reflects a range of values, built on BLS occupational projects for the nation and regional specific estimates. The regional estimates form the basis for the “low” and “high” values.

The Rise of Machine Operators and Tenders Among Production Occupations in the Greater Berks Region

The integration of advanced manufacturing processes in the region over the last 10 years contributed to a shift away from specialty handcraft and low-skilled or general labor. In its place comes growing demand for skilled labor – particularly with the use of more sophisticated machines that require workers to operate and tend to them. Having capitalized on the low hanging fruit, the significant shift in labor needs has occurred, making the future projections a more measured path that is incrementally expanding skilled roles while downsizing general labor requirements. It also means current labor demand will grow in lockstep with future investment in new and additional production equipment. Opportunity for this type of capital investment depends on the firm’s ability to grow customer demand. Many of the interviews suggests that growth for manufacturers in the Greater Berks Region will be more organic moving forward reflecting the maturity of their markets, scale of their sales operations and strategic value propositions.

Machinist and CNC Machine Programmers and Operators

Three occupations have close relationships:

- *Computer numerically controlled (CNC) tool operators*
- *CNC programmers*
- *Machinist*

While their level of on-the-job training and education plays a key role in differentiating the skills, the data suggests these three roles are a common career path. CNC operators have the lowest entry requirements. Notably among the three occupations, only the CNC operators are projected to decline over time according to BLS projections. This falling demand reflects the increased skill requirement for machine operators, particularly as equipment and production processes become more technologically advanced.

Computer Numerically Controlled (CNC)

Tool Programmers and Operators. Advance manufacturing means increased importance of machines that are computer numerically controlled (CNC). Over the last decade the importance of this technology has spread across many of the manufacturing subsectors, generating increased demand for CNC tool programmers and operators. National trends show this expansion. Initially concentrated in a handful of durable goods manufacturing sectors, CNC operators and programmers are now present in nearly every subsector manufacturing durable and nondurable goods. ^{vi}

The BLS data differentiates between CNC tool operators (51-9161) and CNC tool programmers (51-9162). CNC tool operators are far more common, typically requiring less education for entry. Nationally, for every CNC tool programmer, there are six CNC operators. This ratio is projected to fall, with

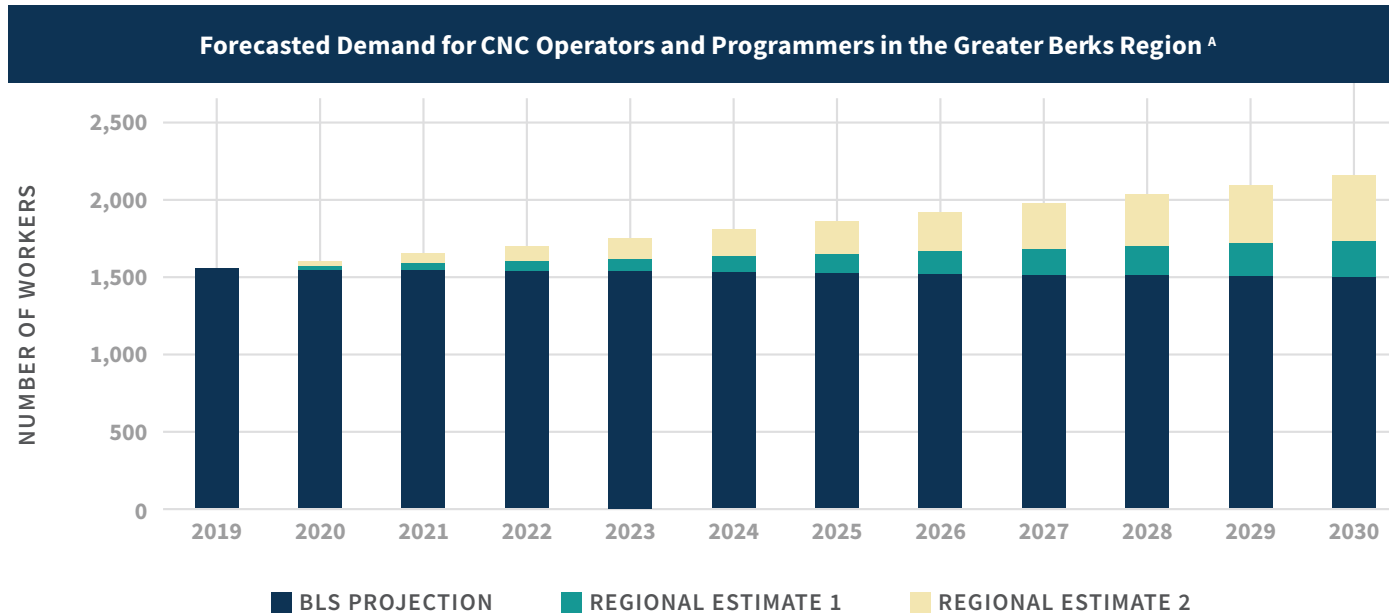
forecasted strong demand for CNC tool programmers (21.9% between 2019 and 2029) and falling demand for CNC operators (-7% over the same, 10-year period). These opposing trends mean by 2029, the ratio of programmers to operators will be 4.5. The net effect is national demand for the combined pool of CNC programmers and operators is a compound annual growth rate of -0.3%.

While BLS forecasts, nationally falling demand for a pool of CNC operators and programmers, the regional demand is anticipated to be modestly positive given the anticipated, steady growth of manufacturing in the Greater Berks Region. Interviews with regional manufacturers consistently called out CNC operators (and programmers) as desirable and an important

production role. At the same time, they noted that growth in production roles is tied to increasing output. The last ten years marked strong industry growth in output driven, in part, by significant investments in equipment and technology. This investment is evident in how CNC operators and programmers are found in a wider array of manufacturing subsectors.

Based on the MSA data for Reading, Lancaster and Lebanon, around 550 workers filled CNC operator and programmer occupations in 2010. By 2019, this number increased to 810, growing at CAGR of 4.4%. While showing strong growth, the location quotient for this occupation in this region has also increased. In 2010, the LQ for CNC Operators was 1.6 (and 1.0

Figure 5



^A Regional Estimate 1 based on Lancaster MSA historical growth rate; Regional Estimate 2 based on Reading MSA historical growth rate.

for CNC Programmers). In 2019, it was 2.0 which indicates the region has proportionally twice the number of CNC operators (and programmers) in production roles than the national average.

While having grown quickly over the last decade, future growth in the region should be more modest. This slowed growth reflects that fact that demand for these occupations is in lockstep with future investment in new and additional production equipment. Opportunity for this type of capital investment depends on the firm’s ability to grow customer demand. Many of the interviews suggests that growth for manufacturers in the Greater Berks Region will be more organic moving forward reflecting the maturity of their markets, scale of their sales operations and strategic value propositions.

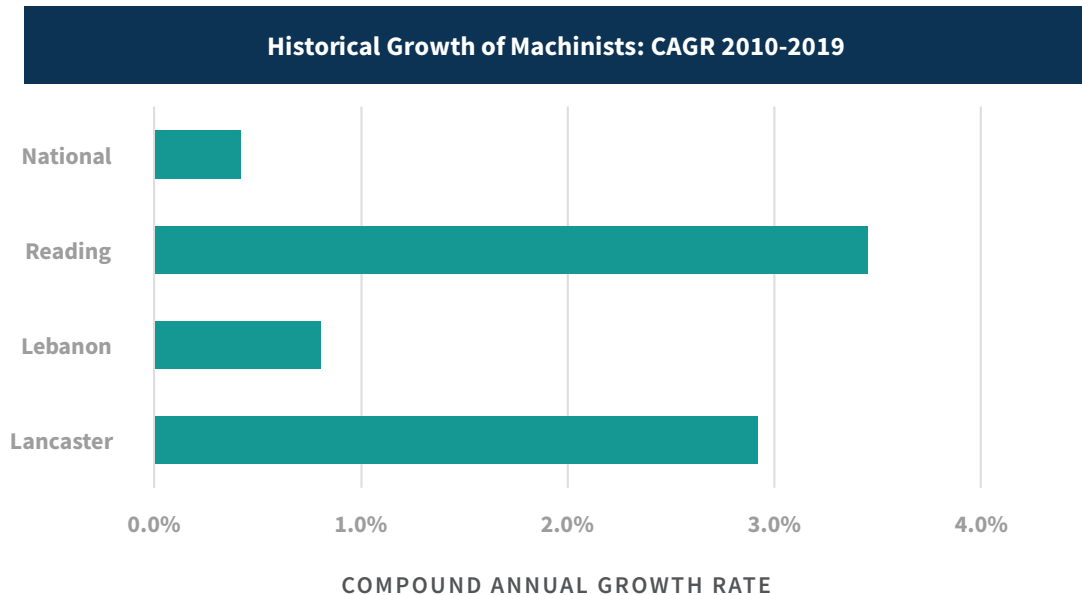
These assumptions suggest that in 2019, the Greater Berks Region had 94,400 production workers representing 54% of the manufacturing sector’s workforce. This estimate is slightly lower than what interviews suggested (closer to 60-66%). Of the 94,400 production workers, around 1,555 filled CNC tool operator or programmer roles.

Projected demand for CNC programmers and operators in the Greater Berks Region uses three different growth rates. The most conservative rate is based on the BLS-estimated, national growth rate for CNC programmers and operators. This rate suggests the demand for CNC programmers and operators will fall over time. This decline would be a strong reversal of local trends. Reflecting this, alternative projections use local growth rates that anticipate demand continuing to grow over time.

As noted earlier, historical demand for this occupation is available only at the MSA level (covering Berks, Lancaster and Lebanon Counties). Demand for this occupation varied across these counties. Applying a growth rate based on Lancaster County to the region suggests an additional 210 openings by 2029 compared the BLS forecast. Forecasting demand based on how this occupation has grown in Berks County estimates an additional 370 jobs or that 2090 CNC programmers and operators will be needed across the Greater Berks Region by 2029. The previous chart (Figure 5) shows how the different growth assumptions change the projections for the Greater Berks Region. Total demand by 2029 is estimated to be between 1,720 and 2,090.

Machinist. Closely related to CNC operators and programmers are machinists (SOC 51-4041). While requiring similar educational training, BLS data distinguishes between machinist and CNC operators

Figure 6



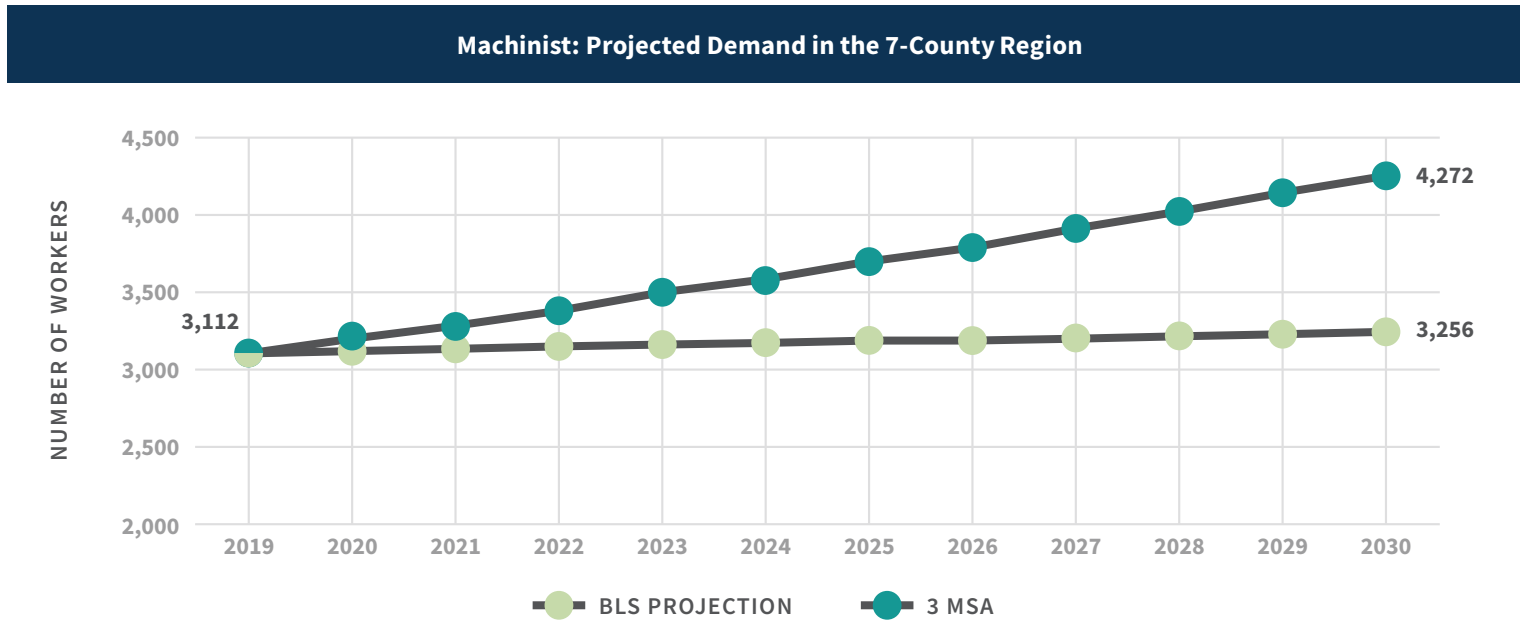
based on the amount of on-the-job training required. Machinists require more training (long-term as opposed to moderate-term). They are widely used and can be found in nearly every manufacturing subsector (except apparel manufacturing, NAICS 315). Fabricated metals (NAICS 332) and machinery manufacturing (NAICS 333) have particularly high demand for this occupation. Reflecting the increased training and skills that accompany technological advancement, BLS projects the demand for machinist to grow over the next ten years.

In the Greater Berks Region, demand for this occupation grew at very different rates across the counties. Lebanon MSA has the slowest CAGR, 0.8%, but also the fewest machinists. The CAGR for this occupation in the Lancaster MSA was 2.9% and 3.5% in the Reading MSA. By 2019, 1780 machinists are estimated to be in the Lancaster MSA and 1620 in

the Reading MSA. Based on data from three MSAs (Reading, Lancaster, Lebanon), regional CAGR for this occupation was 2.9%. Accompanying this growth, machinist also increased their prevalence among production workers when measured as a share of all production workers and by its location quotient. In 2010, machinist made up 2.6% of the production workforce. By 2019, this share was 3.3% in 2019. Meaningfully, the location quotient for this occupation also increased from below one to above one during this time.

Looking to the next 10 years, the BLS projections are far more modest, dialing back the strong expansion that the region has seen over the last decade. The BLS estimate serves as a lower bound for forecasting demand for machinist (0.41%). In contrast, growth based on local rates is faster. Using the 3-MSA average CAGR (2.9%), the two estimates yield a difference of 910 machinists across the seven-county region by 2029. It is estimated that the region currently has around 3,115 machinists and would grow to between 3,245 and 4,150 by 2029.

Figure 7



Various Machine Operators and Tenders

Like machinist and CNC operators, machine setter, operators and tenders are found in most manufacturing sectors. These roles have grown dramatically over the last decade, coinciding with the rise of manufacturing and likely reflecting the integration of new technology and equipment as production became cleaner, safer and more advanced.

Among the “Top 20,” six occupation all have “machine setters, operators, and tenders” in their title. They are:

- *Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic (51-4031)*
- *Molding, Coremaking, and Casting Machine Setters, Operators, and Tenders, Metal and Plastic (51-4072)*
- *Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic (51-4081)*
- *Mixing and Blending Machine Setters, Operators, and Tenders (51-9023)*
- *Packaging and Filling Machine Operators and Tenders (51-9111)*
- *Coating, Painting, and Spraying Machine Setters, Operators, and Tenders (51-9122, 51-9124)*

This analysis pools the demand for machine operators and tenders based on insight from interviews with manufacturers in the region. While the SOCs separate these roles based on the general function and type of

machine, the interviews highlighted commonalities, particularly at the entry level:

- *Shared skills and knowledge requirements, such as familiarity with mechanical, electrical and pneumatics, basic trouble shooting skills*
- *Importance of in-house training on an employer’s machines*
- *Rising emphasis on cross training, so that workers can operate machines throughout the production floor rather than specializing in a particular machine center*

In 2010, the national data showed these six roles accounted for almost 12% of all production roles in manufacturing, and these roles were concentrated in durable goods production. Since then, demand for these roles have grown at a compound annual growth rate of 5.6%. By 2019, nearly one in five production workers filled these six occupations, and these occupations are now present in nearly every manufacturing subsector.

In the Greater Berks Region, these occupations have also grown in significance since 2010, but not as aggressively. From 2010 to 2019, data from Berks, Lancaster and Lebanon show that the number of workers in these six occupations grew from 5,770 to 7,090. This equates to a 2.3% CAGR, about half the pace of the national trend. As a share of all production workers, these occupations increased only 2% (from 12% to 14%).

BLS forecasts four of the six occupations to have positive growth over the next ten years. Only Cutting, Punching, & Press Operators (51-4031) and Molding, Coremaking, & Casting (51-4072) are anticipated to decline. Their

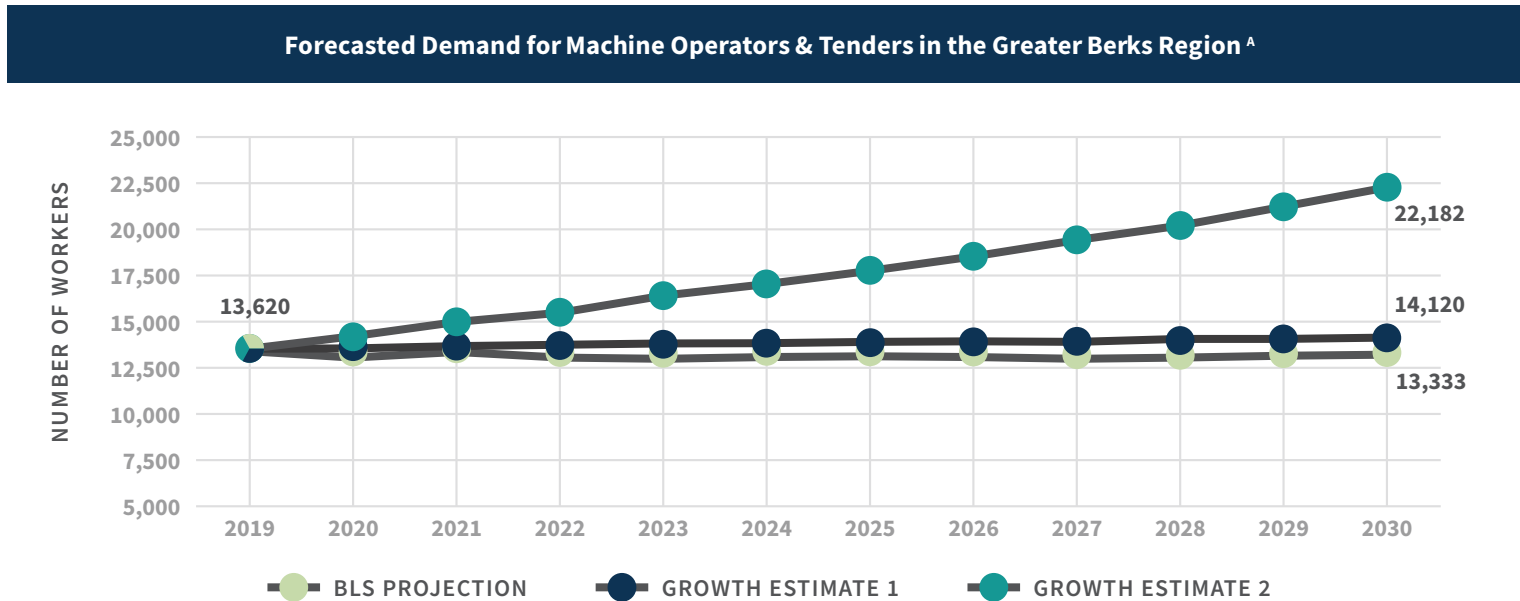
falling demand is likely attributed to subsector trends. Cutting, punching and press operators are heavily used in paper manufacturing (NAICS 322). This is a sector that had few establishments in the Greater Berks Region, and a large share of its employment base located in Montgomery County. The trend in this sector will likely drive demand for this occupation. Given the dominance of a few large companies, local growth in production labor is not anticipated. Molding, coremaking and casting machine operators (51-4072) are concentrated in plastic and rubber product manufacturing (NAICS 326). This sector is found predominantly in Lancaster County, but has a strong presence in Berks, Leigh, Montgomery and Schuylkill Counties. In the region, this sector tends to have mid to large firms. Unlike paper manufacturing, this sector has grown its workforce since 2010.

Given how the subsectors in the Greater Berks Region have performed over the last decade, forecasting demand for machine operators uses three scenarios:

- *Direct application of occupation-specific BLS growth rates*
- *Modified occupation specific BLS growth rates to account for industry growth in the region (specifically impacted 51-4072 and 51-4072, which are forecasted to decline)*
- *Demand growth based on the weighted average of the six occupations in Reading MSA*

These scenarios produce a wide range of values, with CAGR for this group of occupations that ranges from 0.3% to as high as 4.5%. The upper bound growth rate is aggressive. It mutes the

Figure 8



^A Growth Estimate 1 is based on adjusting BLS upward to account for regional trend; Growth Estimate 2 reflects the historical growth in the Reading MSA.

general contraction of manufacturing in Montgomery County which represent a sizable share of the manufacturing workforce in the region.

Scaling the number of workers in these occupations to the Greater Berks Region suggests there were 13,620 workers in 2019. By 2029, the aggregate demand for these six occupations ranges from 14,120 to 21,220.

Demand for Skilled Labor

Among the “Top 20” Occupations, several fall into skilled or specialty production roles (eg, food batchmakers, printing press operators, cabinetmakers and bench carpenters). Within this group, only welders (ie, welders, cutters, solders and brazers SOC 51-4121) is included in the forecast of advanced manufacturing occupations. Interviews with manufacturers noted that the other occupations are critical to production and impacted by advanced manufacturing practices but tend to be used within a narrow band of manufacturing subsectors. The manufacturer interviews also suggest that these occupations are difficult to replace with automation.

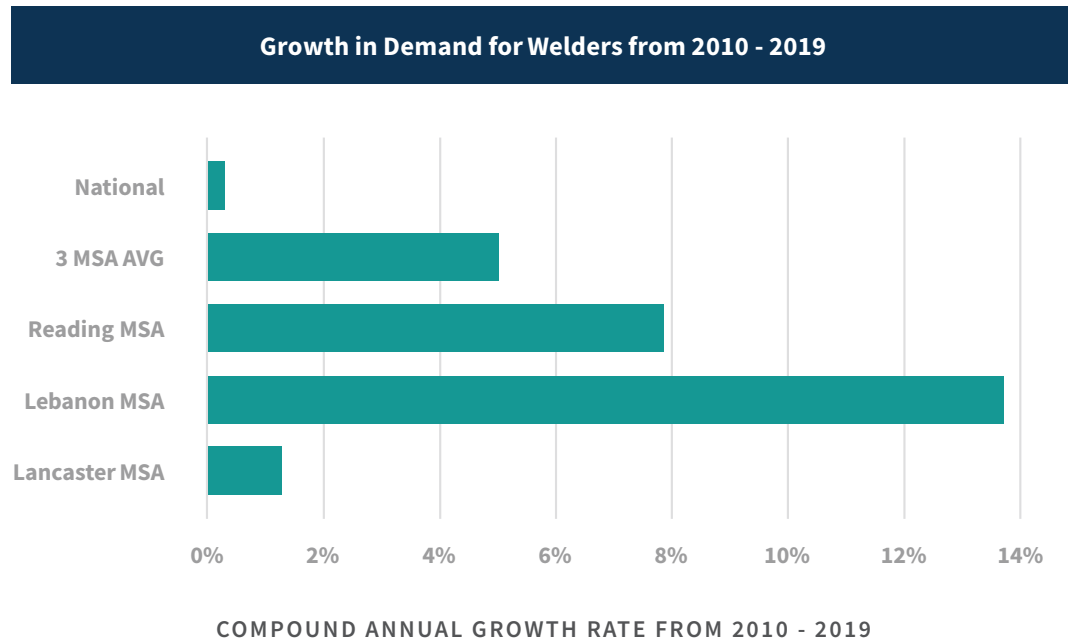
Within the region, welders are a high-demand occupation. The following chart illustrates this point, calling out that employer demand over the last nine years has outpaced the national average. Although generally employed across all manufacturing subsector, this occupation is more heavily used in durable good production (particularly in fabricated metal products, NAICS 332). Based on data from three MSAs in the Greater Berks Region (Lancaster, Lebanon and Reading), this occupation represents 4% of all production workers. Expanding this ratio to the entire Greater Berks Region, in 2019, around

4,035 workers were in this occupational category. Based on BLS projections, the demand for this occupation could increase by 125 workers over the next 10 years. Using a 3% rate which is slightly slower than what the region has experience to date, demand could increase by as much as 1,390 by 2029. Based on these estimates, the Greater Berks Region would have between 4,160 and 5,420 welders by 2029.

Demand for Maintenance Workers

Demand for installation, maintenance and repair workers is generally believed to increase with automation and plant expansion. This view is consistent with local data and insights from the interviews. BLS integrates this dynamic into its occupation projections noting that maintenance workers’ share of the workforce increases as automation in manufacturing rises.^{vii}

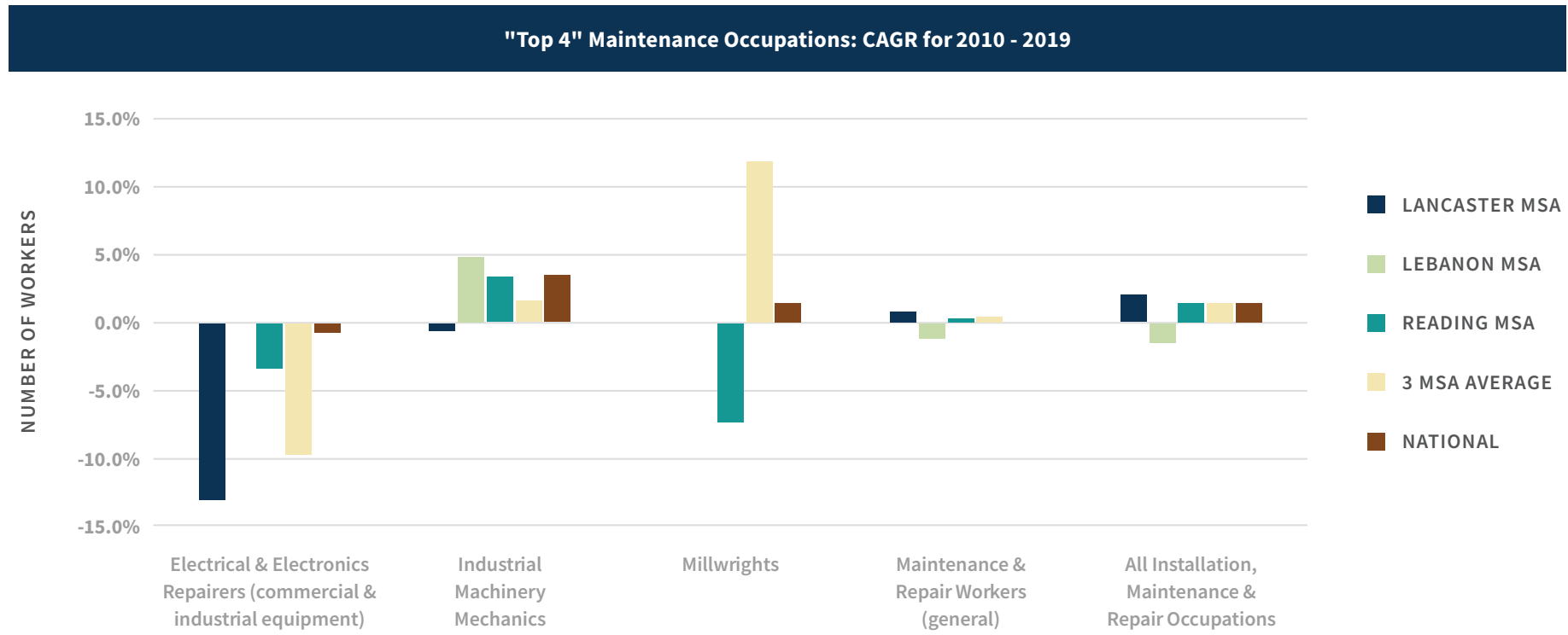
Figure 9



Interviews with manufacturers in the Greater Berks Region drew attention to:

- The essential role maintenance workers play in a company's ability to innovate and customize their products and production processes
- The fact that these are essential, highly-skilled and highly-valued roles, requiring deep technical knowledge and aptitude
- Tying the increased role of technology with a necessary expansion in the skills and knowledge required of maintenance workers; this skilling-up can be satisfied by secondary educational training, apprenticeships, and some post-secondary training
- The reality that these skills are more readily transferable across firms
- The career growth for maintenance workers in advanced manufacturing tends to follow a more traditional model where skills acquisition (both formal and on-the-job) correlate with increased pay.

Figure 10



Electrical and Electronics Repairers of Commercial and Industrial Equipment

BLS describes the occupation, Electrical and Electronics Repairers of commercial and industrial equipment (SOC 49-2094) as the repair, test, adjustment and installation of electronic equipment. Industrial robotics mechanics is an example of this occupation. It is the one occupation among the “Top 4” that BLS identifies as requiring a postsecondary, nondegree award as typical educational requirement for entry.

Based on data for the three MSAs, around 130 workers filled this occupation in 2019. Among the “Top 4” maintenance occupations, it is the only one that has contracted since 2010. But this contraction hides that local demand for this occupation has been fluctuating. Demand for this occupation grew strongly in the region over the last couple of years. It is assumed that the role has been evolving and adapting to the heavier use of robotics in production processes.

Demand for this occupation in the Greater Berks Region is forecasted to hold at current levels. This forecast aligns with BLS national projections that demand is relatively constant, growing at a CAGR of 0.2%. Across the Greater Berks Region, the manufacturing sector is estimated to employ around 275 electrical and electronic equipment mechanics. The BLS growth rate would mean the Greater Berks Region would need 285 workers in this occupation by 2029.

Industrial Machinery Installation, Repair & Maintenance Workers

This category captures two specific occupations:

- *Industrial machinery mechanics (49-9041)*
- *Millwrights (49-9044)*.

BLS describes industrial machinery mechanics as workers responsible for the repair, installation, adjustment or maintenance of industrial production and processing machinery. It may also spill over into duties similar to millwrights, who are responsible for the install, dismantle or moving of machinery and heavy equipment according to layout plans and other drawings. The manufacturer interviews alluded to the importance of these occupations, noting that the speed and efficiency in which they can turnover machines to meet customer demand was a key part of their competitiveness, allowing them to service a wider swath of customers and smaller production orders.

Industrial machinery mechanics are found in significant numbers across manufacturing and have the largest number of workers among all the installation, maintenance and repair occupations. In 2019, the Greater Berks Region had an estimated 2,935 workers employed as industrial machinery mechanics. Based on data from Berks, Lancaster and Lebanon, the demand for this occupation has grown steadily since 2010. The three counties added almost 300 industrial machinery mechanics, equivalent to a 1.6% CAGR between 2010 and 2019.

BLS forecasts national demand for this occupation to grow at a 1.5% CAGR. This level of future growth suggests the region's trajectory is likely to continue uninterrupted. Total demand for industrial machinery mechanics is projected to grow to 3,430 (i.e., adding 500 jobs across the region over the next 10 years).

Millwrights are found in 16 of the 21 manufacturing sectors, but in smaller numbers. In 2019, manufacturers in the Greater Berks Region employed around 220 millwrights, but demand for this occupation has grown faster than the other "Top 4" occupations. Between 2010 and 2019, the number of millwrights grew by a CAGR of 12%. BLS forecasts a considerably slower growth rate, 0.7% CAGR, suggesting the region would add 15 new jobs by 2029. While this growth rate seems conservative given the region's experience over the last decade, it is used as a central estimate for forecasting future demand. A closer look at demand patterns across three counties in the Greater Berks Region showed varied rates. It points to the likelihood that future demand will not continue to expand at such a fast pace. For projecting future demand, the upper bound is based on the midpoint between BLS's forecast and the region's historical growth rate.

General Maintenance and Repair Workers

This general occupation of maintenance and repair workers (49-9071) is present in all 21 manufacturing subsectors. BLS describes this occupation as someone whose work involves the "skills of two or more maintenance or craft occupations to keep machines, mechanical equipment, or the structure of a building in repair." ^{viii} The skills and duties are wide ranging,

including electro-mechanical, welding, machining, and HVAC maintenance, but exclusive of routine machinery maintenance and facilities management.

The Greater Berks Region is estimated to have nearly 2,700 general maintenance and repair workers, representing nearly 30% of all workers filling installation, maintenance and repair occupations. From 2010 to 2019, data from Berks, Lancaster and Lebanon Counties show that demand for these workers has been relatively steady, with the number of workers growing at a 0.3% CAGR since 2010. BLS forecasts this occupation to have growth that is slightly higher (0.4% CAGR) than what the region has experienced over the last decade. Given the widespread presence of this occupation and interviews signaling limited plans for significant facility expansion, forecasting demand for this occupation uses a range of 0.3% to 0.4% CAGR. This equates to the manufacturing sector increasing demand by 80 to 110 workers over the next decade. This would raise the total number of workers in this occupation to between 2,775 and 2,805 by 2029.

Summary of Future Demand for Occupations Supporting Advanced Manufacturing

The outsized concentration of production workers and the strong presence of maintenance workers that characterizes the region's manufacturing sector elevates labor's role in producing more, faster and better with fewer resources and cost. This study identifies these roles as advanced manufacturing occupations that have been and will continue to be an indispensable part to the sector preserving its competitive position.

The projected demand for advanced manufacturing occupations in the Greater Berks Region is constructed as a range of values, rather than a single point estimate, to recognize the challenges of predicting output growth and innovation that drive the industry's need for semi-skilled and skilled labor. Overall, the manufacturing sector's total employment base is projected to grow between 4% and 5% by 2029. This equates to the region seeing an additional 6,460 to 8,740 jobs over the next ten years. Of this, demand for advanced manufacturing occupations is forecasted to represent a growing share.

While BLS data identifies over 100 production occupations across the region, these three groups of occupations make up over 20% of the production workforce. The data also points to the local concentration and demand for these production occupations are greater than national manufacturing trends.

The interviews and data show that manufacturers in the Greater Berks Region have gradually reduced their reliance on general (unskilled) labor and increased their use of two broad classes of skills. They are workers that can operate machines that blend mechanical and programming, and workers that have specialized skills that are not easily transferred to automation. These two classes translate to a handful of occupations:

- *Machine setters, tenders, and operators*
- *Machinist and CNC operators and programmers*
- *Welders*

The analysis tends to use BLS projections as a conservative, lower bound to forecast occupational demand. If the region's manufacturing sector were to slow down to match the national average, production workers as a share of the workforce would shift from 54% in 2019 to 50% in 2029. The region would lose about 4,230 jobs. Significantly, most of the job loss would be in production roles that have not been attributed to advanced manufacturing. For advanced manufacturing occupations, the analysis suggests the loss would be around 50 jobs by 2029.

The outsized concentration of production workers and the strong presence of maintenance workers elevates labor's role in producing more, faster and better with less resources and cost.

The upper bound builds on local knowledge and conditions. Since 2010, the manufacturing sector in the Greater Berks Region has grown stronger and more rapidly than the national average. Interviews with manufacturers across the Greater Berks Region consistently forecasted growth in production and labor needs. This bullish outlook also underpins the rationale for using growth projections that are locally derived. Based on regional growth rates, production workers as a share of the manufacturing sector's workforce could fall slightly from 2019 (from 54% to 51%) or rise to as high as 58%. This variance translates either to losing 1,800 jobs or gaining upwards of 12,590. This upper end likely overstates growth, especially given the trends seen in Chester and Montgomery Counties.

For maintenance occupations, the Greater Berks Region is estimated to have a ratio of production to maintenance workers that is similar to the national average. These roles are consistently identified as high value, highly skilled roles that are essential to manufacturing processes. Intensified integration of advanced manufacturing is thought to strengthen the demand for maintenance workers. Among the 50 installation, maintenance and repair occupations identified by BLS, four rise to the top. All them are forecasted to have modest but positive growth.

Projected growth in demand for installation, maintenance and repair workers is positive under both the lower bound and upper bound scenarios. This forecasted positive growth is consistent with the expectation that automation and other advanced manufacturing practices will reinforce the importance of this occupational class. It also aligns with the anticipated, continued expansion in output by manufacturers in the Greater Berks Region. The analysis estimates that the region's manufacturing sector employed around 8,710 installation, maintenance and repair workers in 2019. Of these, the "Top 4" occupations were filled by 6,125 workers in 2019. They represented nearly 70% of all maintenance workers. Demand for these four occupations is expected to rise, with the manufacturing sector employing an additional 555 to 800 workers by 2029.

The tables below summarize the projected demand for advanced manufacturing occupations in the Greater Berks Region. As already described, demand for advanced manufacturing occupations generally

rises regardless of the assumptions. Only demand for machine operators and tenders and electrical and electronic repairers have the potential to fall over time. Key aspect of the results, by occupation, are as follows.

Machine operators and tenders. Under BLS projections, the region would experience a 2% decline in demand for machine operators and tenders. However, estimates derived from local conditions suggest a highly variable, but positive, range. Total demand would rise from 2019 levels (13,600) to between 14,100 and 21,200. The lower end of this range is 3.7% growth by 2029 or around 500 new jobs; the upper end of this range is 56% growth, equivalent to 7,600 additional jobs.

CNC operators and machinist. Under BLS projected rates, these occupations would expand by less than 1%, adding around 85 jobs by 2029. However, under regional rates, the analysis estimates demand could increase by at least 25%, requiring an additional 1,200 workers over the next 10 years. Total demand for this category of occupations would be between 4,750 and 6,240 by 2029.

Welders. This occupation is anticipated to see even stronger growth, ranging from 3% to 34% by 2029. The lower end reflects BLS projections, with total demand for welders being 4,160 jobs or adding around 125 jobs to 2019 level. At the upper end, 34% more demand for welders equates to 1,390 additional jobs by 2029.

Industrial machinery mechanics. Demand for this occupation is anticipated to increase by at least 16%

(or between 460 and 500 workers by 2029). Total demand would be between 3,395 and 3,430 workers. The BLS forecasted compound growth rate is 1.5%, which is just slightly lower than the growth the region experienced from 2010 to 2019.

General maintenance and repair workers. The region employed around 2,695 workers in 2019. Modest growth is projected for this occupation. BLS forecasts a compound growth rate of 0.4%, which is just slightly higher than what the region has experienced between 2010 and 2019. At this level of growth, the manufacturing sector would add 80 to 110 workers by 2029.

These projections reflect demand by manufacturing employers. The next section examines the potential supply of workers to meet this demand.

Figure 11

Demand for Advanced Manufacturing Occupations in the Greater Berks Region				
OCCUPATION	EMPLOYEES IN 2019	PROJECTED DEMAND BY 2029 ^A		
		BLS	LOW	HIGH
ADVANCED MANUFACTURING PRODUCTION OCCUPATIONS				
Machine Operators & Tenders	13,620	13,360	14,120	21,220
CNC Operators & Machinists	4,670	4,750	5,860	6,240
Welders	4,030	4,160	5,420	6,590
Advanced Manufacturing Production Workers	22,320	22,270	25,360	32,510
All Other Production	72,020	67,840	67,190	74,420
All Production	94,340	90,110	92,550	106,930
ADVANCED MANUFACTURING MAINTENANCE OCCUPATIONS				
Electrical & Electronic Repairers	275	285	275	285
Industrial Machinery Mechanics	2,935	3,395	3,395	3,430
Millwrights	220	235	235	410
General Maintenance & Repair Workers	2,695	2,805	2,775	2,805
Advanced Manufacturing Maintenance Workers	6,125	6,720	6,680	6,930
All Other Maintenance	2,590	2,240	2,280	3,010
All Maintenance	8,710	8,960	8,960	9,930
Manufacturing Sector (all occupations)	174,190	180,650	181,150	182,930

^A Projected demand reflects a range of values, built on BLS occupational projects for the nation and regional specific estimates. The regional estimates form the basis for the “low” and “high” values.

THE SUPPLY OF TALENT FOR ADVANCED MANUFACTURING IN THE GREATER BERKS REGION

The manufacturing sector remains a vital part of the Greater Berks Region, notwithstanding common assertions about the decline of US manufacturing. Since coming out of the Great Recession and, now through the pandemic, manufacturing has demonstrated its resilience and importance to the economy.

Yet, manufacturing is not immune to the challenges of attracting and retaining talent. Past perceptions of manufacturing jobs as dirty, dull and dangerous, coupled with a decades-long cultural shift toward emphasizing college education has resulted in limiting the appeal of these jobs. Coinciding with this perception, an aging population is shrinking the pool of talent.

This section looks at the potential pipeline supplying talent for advanced manufacturing in the Greater Berks Region. In describing this pipeline, the analysis focuses on understanding expected trends in entrants and exits for advanced manufacturing occupations.

While exits are largely approximated by retirement rates, the entrants consider both the number of high school graduates entering the workforce as well as the potential capacity of education and training centers to equip entering workers with the skills and knowledge to succeed in advanced manufacturing careers.

Labor force projections have traditionally focused on “prime age” workers defined as individuals between the ages of 25 and 55. For the Greater Berks Region, the primary source of labor is expanded to individuals between the ages of 20 and 65. Pushing the lower and upper bounds of the age range aligns with local conditions regarding post-secondary education and the median age of workers. It is also more consistent with the age, education and training requirements of the occupations that have been identified as advanced manufacturing. While not requiring more than a high school degree, some postsecondary training and/or certifications is desirable. This additional certification translates to seeking entry workers that are 18 to 20 years old.

Skills and Knowledge for Advanced Manufacturing Occupations

Although Skills are Evolving, These Occupations Still Draw from the Same Pool of Talent

Most production roles in manufacturing offer career paths that do not necessitate postsecondary education and training for entry. While high school education and on-the-job training – as minimum requirements – equally applies to advanced manufacturing occupations, the knowledge base and skills are evolving.

Interviews with manufacturing employers in the Greater Berks Region consistently identified the following as central to advanced manufacturing occupations:

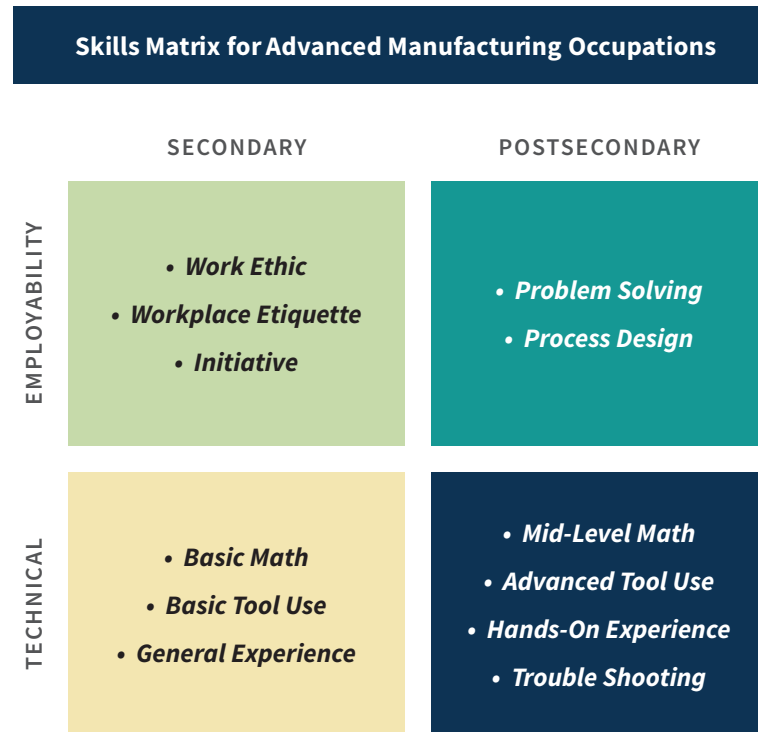
- Familiarity and/or working knowledge of mechanical, electrical, pneumatics, hydraulics
- Ability to read schematics and instruction manuals
- Basic programing and ability to interface with computerized controls

In addition to these technical skills, they identified problem-solving, diagnostic skills and teamwork as ingredients to success.

These areas, to varying levels of comprehensiveness, are in curriculums and programing offered by career and technical centers (CTCs) attached to secondary education. Postsecondary institutions also offer training in these areas, providing certifications and degrees to demonstrate deeper proficiency potentially

allowing new workers to enter at more advanced levels or current workers to advance their capabilities. Consistent in the interviews was also the desire for employers to train their employees, cultivating specialization tailored to their specific equipment, systems and standards. This latter point reinforced the importance and advantages of attracting new workers with basic skills requirements.

Figure 12



CTCs as a Pipeline for Workers Entering Advanced Manufacturing Careers

Individual, county-level CTC systems across the Region offer 30 or more programs across multiple campuses (from auto mechanics to cosmetology to veterinary care). Typically attracting around 10% to 15% of the high school students, each county CTC system can serve more than 2,000 high school aged students (and adult learners) in programs ranging from one to three years in duration. Student demographics and socio-economic status can vary greatly depending upon the local populations being served.

While the total number of high school students is falling, CTCs generally reported being able to grow their enrollments. Their success has been tied to flexibility that enables them to offer courses that reflect the interests of students and parents. Some of the most attended programs reported by CTC leaders are in the healthcare/allied health fields.

CTC leaders unanimously recognized the importance of programming that support pathways to manufacturing careers. They all offer advanced manufacturing-related programs (such as Electro-Mechanical Engineering and Technology, Precision Machining & CAM, Metal Fabrication, and Welding). The challenge is that these programs feeding into advanced manufacturing career pathways attract a smaller cohort. Incoming students show more interest in other programs than those with a career pathway to manufacturing. While potentially serving 40-60 learners per CTC system, they are often graduating fewer than ten students per program annually (depending on program structure and length).

Throughout the interview process, CTC leaders discussed the decades long K-12 and parent emphasis on college education and misperceptions surrounding manufacturing careers as ongoing challenges to recruiting into advanced manufacturing programs. All CTC systems report connections with postsecondary institutions for students who desire a related college degree or training. While the CTC systems work diligently to connect with local industry for programming input and placement opportunities, practically, it is difficult to connect with the 70% of businesses that employ fewer than 50 workers and represent 50% of the workers in manufacturing.

Annually, the public high schools across the Greater Berks Region have graduated around 32,000 students each year. Of these graduates, around 10% attended a CTC. Based on information gathered through interviews with CTC leaders, it is estimated that across the Greater Berks Region, the CTCs collectively produce 250 to 300 students a year with backgrounds supporting advanced manufacturing careers. At the current rate, fewer than 1% of graduating high school seniors leave secondary education armed with skills and knowledge to pursue advanced manufacturing careers.

Assuming these graduates represent the bulk of potential incoming workers to advanced manufacturing occupations and that the capacity and level of courses remains unchanged, the CTCs will graduate between 2,750 and 3,300 students over the next 10 years.^{ix}

With business as usual, this estimate likely overstates the regional pipeline to advanced manufacturing occupations. As one of several strategies to increase the appeal of programming in advanced manufacturing, the CTCs have forged partnerships with postsecondary institutions. Many of the CTC courses qualify for college credit. As a result, a portion of these graduates are not going directly into the workforce, but rather onto pursuing an Associates or 4-year college degree.

The small share of high school students exploring careers and training for advanced manufacturing highlights the challenge and opportunity. There is incredible potential that exists to attract young workers to these careers. If the manufacturing sector were able to attract at least 2% of graduating high school senior, the number of entry workers would offset the number of retiring workers and even potentially close the gap. Capitalizing on this potential requires focused effort to meet the growing needs of advanced manufacturing in the Greater Berk Region.

Postsecondary Institutions as a Pipeline for Workers Entering Advanced Manufacturing Careers

Although high school graduates represent a meaningful and steady source of potential new workers, postsecondary institutions play a vital role in producing workers equipped with the knowledge and training to succeed in advanced manufacturing careers – particularly for maintenance occupations. The Greater Berks Region is fortunate to have well-respected postsecondary institutions that are invested in the programs that support the region’s manufacturing sector. These institutions vary in their degree and certification offerings, such as traditional four-year college degrees, technical Associates in Applied Science (AAS) degrees, technical credit certificates, as well as non-credit certifications and training. They serve to offer three important sources of workers and skill development:

- *Advanced preparation for graduating high school students interested in further education and training that is not a four-year college degree (associates degree or college credit certificate);*
- *Adult learners interested in career changes or credentialing their on-the-job skills (including military veterans); and*
- *Incumbent workers (primarily for the purpose of upskilling or cross training).*

Like the CTCs, these institutions invested in delivering programs and course offerings for advanced manufacturing careers but face similar challenges

in attracting students. Even though secondary to postsecondary pathways have been established to afford students the opportunity to earn college credit for advanced placement, several commented on how they appeal to only a fraction of their total student population. Parents have yet to realize the potential of utilizing such model programs for their children to gain entry into good paying advanced manufacturing careers. Until this happens this source of new workers entering advanced manufacturing careers will be limited.

The scale of their contribution to the supply of workers is difficult to estimate. Enrollment data is not publicly available or disaggregated to identify how many students come through non-credit certification programs without employer sponsorship. Only those enrollments for individuals completing a credit associates degree or certificate are readily available.

Implications of an Aging Workforce on the Supply of Advanced Manufacturing Workers

Well Diversified with Many Small (50 employees and fewer) Firms

The population of the Region has been growing since 2010 and is projected to continue to grow. The size of its workforce, however, has been getting smaller. These diverging trajectories are not unique to the region, but are a common theme seen across most of the U.S. and reflect the product of rising life expectancies coupled with lower fertility rates.

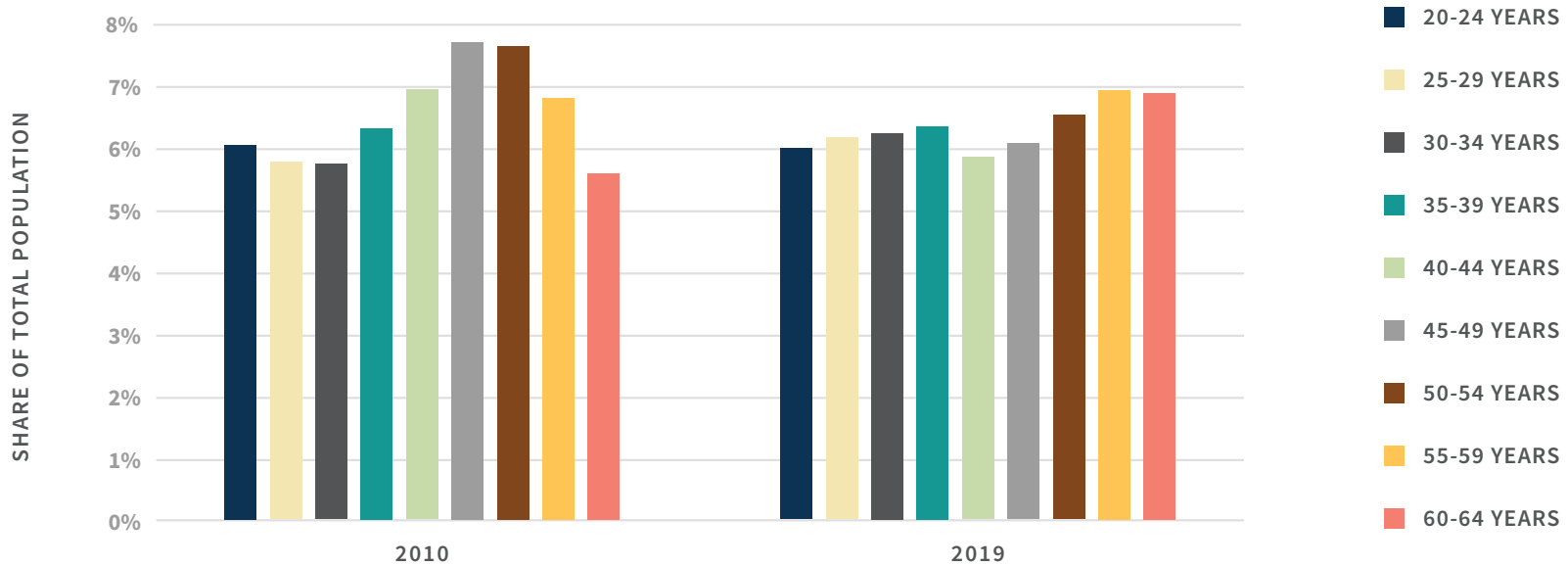
The increased rate at which workers “age out” of the workforce has been coined the “silver tsunami.” A close look at the age profile of workers in the Greater

Berks Region suggests that retirements will likely peak in the next five years. In 2010, 16% of the population was between the ages of 45 and 54, making up a disproportionate share of the workforce. By 2019, the older of these cohorts were beginning a 10-year stretch of significant retirements.

While a challenging dynamic that affects all sectors of the economy, its severity depends on the age profile of workers in each sector. The manufacturing sector is generally perceived to have an older workforce.

Figure 13

Greater Berks Region's Working Age Population: Share of Total Population, 2010 & 2019



However, national data from BLS shows that the median age for the manufacturing sector is 44. When segmenting manufacturing into durable goods production and nondurable goods manufacturing, the median age changes only slightly. The median age for durable goods manufacturing is 44.3; the median age of workers in nondurable goods manufacturing is slightly lower, 43.7. These median ages are not much different from other sectors. For example, the median age of the professional and business service sector is 42.8; transportation and warehousing is 44.8.

Age differences become more apparent at the occupation level and for finer segmentation of industries. They lend insight into anticipating how retirements associated with an aging workforce may impact the supply of workers. The median age for production workers is 43. For advanced manufacturing occupations, the BLS data shows workers tend to be younger. For CNC programmers and operators, the median age is 36 and for welders it is 39. This younger age is consistent with the strong growth of these occupations over the last 10 years. Some of the more established advanced manufacturing occupations that requires more on the job training or education have older median ages (eg, the median age for a machinist is 47). For installation, maintenance and repair workers, the median age is slightly younger, 42.5. However, the more skilled occupations, such as general maintenance and repair workers and millwrights are older (47 and 45, respectively). Similar to production roles, the older median age for key maintenance positions is consistent with the higher skill requirements and on-the-job training necessary for these roles.

The younger age profile of workers in advanced manufacturing occupations, compared to production workers and manufacturing more generally, highlights how retirements over the next 10 years will have varying affects. For the manufacturing sector as a whole – and its general pool of production workers, just under one-quarter are likely to be at least 55 years of age; around 23,170 of its estimated 94,340 productions workers are likely to retire by 2029. This substantial share reaffirms concern over the disruption and the saliency of developing succession plans to ensure knowledge transfer between older and younger workers.

The age profile for maintenance workers is only marginally younger than production workers. 24% of the estimated 8,710 maintenance workers in manufacturing are over the age of 55 and likely to retire by 2029. Of these, at least three-quarters are in occupations supporting advanced manufacturing. These figures suggest that 1,470 workers in the “Top 4” maintenance occupations could exit the workforce by 2029.

As noted, among the advanced manufacturing occupations, machinists and general maintenance and repair workers are most exposed to retirements in the coming decade. Based on BLS data, one in three machinists are at least 55 years old and primed to retire in the next 10 years. With the Greater Berks Region estimated to have around 3,115 machinists, upwards of 1,000 workers currently filling these roles could retire by 2029. For general maintenance and repair workers, 30% (or 810) of these workers are at least 55 years old and likely to retire over the next 20 years.

Figure 14

US Age Distribution for Selected Occupations in 2019								
OCCUPATION	16-19 YRS	20-24 YRS	25-34 YRS	35-44 YRS	45-54 YRS	55-64 YRS	65 YRS & OVER	MEDIAN AGE
Manufacturing	1%	7%	22%	21%	23%	20%	5%	44.1
Production Occupations	2%	9%	22%	21%	21%	20%	5%	43.0
CNC Operators & Programmers	2%	12%	33%	19%	18%	13%	3%	36.3
Machinist	2%	10%	19%	16%	20%	29%	4%	47.2
Welders	3%	11%	28%	21%	19%	15%	2%	39.3
Millwrights	0%	6%	17%	25%	21%	23%	6%	45.4
Maintenance & Repair Workers, General	1%	6%	18%	21%	24%	23%	7%	46.9
Installation, Maintenance & Repair Occupations	2%	9%	23%	22%	22%	19%	4%	42.5

NET IMPACT OF CHANGES IN THE DEMAND AND SUPPLY FOR ADVANCED MANUFACTURING OCCUPATIONS

The Greater Berks Region potentially faces a skills gap shortage for filling advanced manufacturing occupations.

This gap, however, is not insurmountable.

Demand for advanced manufacturing workers:

Production. Currently the region has an estimated 22,320 workers in advanced manufacturing production occupations. Based on local conditions, demand for these occupations could hold at current levels or grow (adding up to 10,190 jobs by 2029).

Maintenance. Currently the region has an estimated 6,125 workers in advanced manufacturing maintenance jobs. Based on local conditions, demand for these occupations will grow, adding between 555 and 805 jobs by 2029.

Supply of advanced manufacturing workers:

Retirement. By 2029, the region is projected to lose 5,370 production workers and 1,720 maintenance workers to retirement.

Entering workers. The retirement exits are partially offset by entry of new workers. With a focus on CTC graduates filling production occupations, the manufacturing sector gains between 2,700 and 3,300 new workers by 2029. Additionally, postsecondary institutions are assumed to supply up to 1,500 workers for maintenance occupations.^x

Net gap in availability of workers to fill advanced manufacturing occupations by 2029:

Production. The net effect of the entrants and exits and increased demand is that the manufacturing sector in the Greater Berks Regions may face a shortage of production workers. This shortage has a wide range, between 5,110 and 12,860 workers.

Maintenance. The net effect of the entrants and exits and increased demand is that the manufacturing sector in the Greater Berks Regions may face a shortage of workers filling maintenance roles as well. This shortage is estimated to be between 770 and 1,020 workers.

The growth in demand coupled with supply contracting amplify a skills gap that widens over time. This gap ranges between 5,880 and 13,885 workers by 2029 (combined shortage of production and maintenance occupations in advanced manufacturing). Comparison of the projected changes in demand and supply show that the gap is a function of both industry growth that drives increased need for advanced manufacturing workers and an aging workforce that is anticipated to retire over the next 10 years that is not offset by younger workers pursuing these careers.

Focused strategies to attract younger people to careers in advanced manufacturing could overcome this gap. At the current rate, fewer than 1% of graduating high school seniors leave secondary education armed with skills and knowledge to pursue advanced manufacturing careers. If the manufacturing sector were able to attract 2% of graduating high school senior, the number of entry workers would offset the number of retiring workers and potentially close the gap. This highlights the incredible potential that exists to attract young workers to these careers. Additionally, the supply estimates provide only a cursory sense of the potential for attracting adults interested in pursuing new careers to the sector.

Figure 15

Projected Change in Demand and Supply of Advanced Manufacturing Workers in the Greater Berks Region between 2019 and 2029		
	PRODUCTION OCCUPATIONS	MAINTENANCE OCCUPATIONS
2019 Employment	22,320	6,125
2029 Projected Employment	25,360 - 32,510	6,680 - 6,930
Increased demand by 2029	3,040 - 10,190	555 - 805
Net shortage of entry and exits by 2029 ^A	2,070 - 2,670	220
Projected Net Shortage of Advanced Manufacturing Workers by 2029	5,110 - 12,860	770 - 1,025

^A Entry reflects projected number of new workers to advanced manufacturing occupations from secondary and postsecondary education by 2029. For production workers, between 2,700 and 3,300 new workers are estimated to fill production roles, and 5,370 workers are anticipated to retire. For maintenance workers, 1,500 new workers are forecasted and 1,720 are expected to retire.

FINDINGS AND RECOMMENDATIONS

The combination of gathering, reviewing and analyzing data with one-on-one interviews results in a number of general observations that distill into four notable key findings and two significant recommendations.

Observations

- The manufacturing sector in the Greater Berks Region, perhaps despite broad misperceptions, is strong, diverse and growing with a compelling economic impact.
 - While overall, the diversity of manufacturing is a strength, the breadth of small- to medium-sized employers may present a challenge. Many of these companies are relative unknowns, have lean management structures and are typically only seeking a handful of employees at any given time. Smaller firms are often harder to engage in long-term workforce development strategies.
 - There is solid evidence of investment in automation and IT – through shifts in the occupational data and as outlined in one-on-one interviews – that has led to the sector’s strengthening over the past decade in the Greater Berks Region at a faster pace relative to the nation.
- Today, advanced manufacturers routinely cite a one- to three-year return on investment horizon for deploying capital for equipment or IT upgrades, with the ROI not often coming from a reduction in labor cost but rather other efficiencies or margins.
 - Signaling these investments in automation and technology in the Greater Berks Region are sector-wide shifts of labor among key occupations. The next 10 to 15 years will bring steady, incremental change. Production workers will need to be life-long learners as they are continuously redeployed within the plant. Maintenance workers will need strong aptitude combined with formal (post-secondary) training and years of on-the-job training. Employers will have need for more technically-skilled workers, such as CNC programmers and machinists that can cross over from production to maintenance roles. Equally significant, they need workers that complement their technical skills with general aptitude to work in team environments.

- The Greater Berks Region has a strong infrastructure of educational and workforce assets in place to support manufacturing.
- Economic and workforce development systems and terminology about the manufacturing industry don't easily translate to the industry, especially to smaller firms who are focused on production and margins. This translation issue results in a disconnect between what businesses want and when they want it and what system partners hear and have the capacity to deliver. Additionally, competing interests in the educational and workforce network are real and need to be understood as variables in the system.
- Planning efforts to support the manufacturing industry will benefit by shifting from technical nomenclature to lay-person terms. Discussions on sub-sectors, specific occupations, certifications and technical skills are valuable yet also can be rabbit holes that limit progress. Future dialogues may be most productive if language and actions are simple, measurable and broad-based.
- While there is urgency today – both by industry and the workforce development network – given current workforce gaps and shortages in manufacturing, intentional and impactful solutions will require a longer-term focus and broad system changes, not quick fixes.

Findings

- The past decade was a pivotal period for manufacturing in the Greater Berks Region, now bearing out through federal data. At a pace faster than the nation, this region saw real gains in both

productivity and the demand for labor. This growth broadly signals investments in technology and automation and a corresponding and notable shift in labor. As a result of the last decade of strong growth including the implementation of 'low-hanging fruit' automation improvements, a more measured and moderate growth trajectory is anticipated.

- There is a skills gap (and/or a pipeline numbers gap) that exists between what manufacturers are forecasted to need and what today's systems are providing. That gap, however, is not insurmountable if existing capacities and capabilities already in the market are better leveraged with production and maintenance manufacturing occupations clarified, simplified and prioritized.
- Much of the focus is on today or the immediate short-term. Employers want to hire employees that have familiarity with programming, robotics, pneumatics and being able to read a schematic – with math and problem-solving skills. This is the ideal or preferred hire. Today, however, trying to navigate growth in a tight labor market, with the overlay of the pandemic, many employers are left finding 'a warm body' that shows up on time. Educators are also responding to students (traditional and non-traditional) in the pipeline, what their immediate interests are and what capacities/capabilities they can accommodate.
- The opportunity – and more forcefully – the need is for the 'system' to shift to a longer-term focus that maximizes capacities, recognizes competitive environment factors, and has each asset that is part of the continuum performing its core function. This shift doesn't happen overnight.

Recommendations

What actions are needed to make that shift and to fill the workforce gap, meet employer needs, provide fulfilling opportunities for existing and future employees, and maximize the regional educational infrastructure? The forecast calculates a potential skills gap that will exist but is not insurmountable, with focused attention and action underpinned by a long-term acknowledgement of the importance of the manufacturing sector to the region's overall economic health.

Two overarching and connected recommendations are offered here in the spirit of a simplified, manageable approach.

Recommendation 1: Establish a collective impact backbone approach to “re-set the table” on solving manufacturing workforce needs in the Greater Berks Region.

Recommendation 2: Develop a holistic, tactical plan that results in a growing pipeline of Machine Operator/Tenders, CNC Operators and Machinists, Welders and Maintenance Workers by 2030.

The analysis presented in this report adds to the considerable volume of reporting over the past decade touting the strength of American manufacturing. It also coincides with current research, including the November 2020 MIT “Work of the Future Report” and the 2019 Manhattan Institute article “The Workforce Training Grant,” both of which point to the need for U.S. investment and innovation in skills and training, with a particular emphasis on strengthening

the community college infrastructure and the connectivity between educators, employers and workforce development partners.

This analysis specifically calls out a few select occupations that align with the automation transition and IT investment that have occurred and will continue to occur in Greater Berks Region manufacturing facilities. These employer actions, which are driven by return on investment to remain competitive, have shifted basic and core skill sets that regional manufacturers require in the workplace.

The data, supplemented by one-on-one interviews, documents growth in advanced manufacturing in the region and a potential net gap of future workers based on supply and demand projections.

Key aspects of the recommendations include:

- *Shifting the focus away from needs today to future needs;*
- *Recognizing the complexity of this workforce development challenge, including that there are many players at the table, all with different orientations, needs and capabilities that must come together around a common, shared objective; and*
- *Deploying a business approach by keeping strategies and tactics simple, not jargon-filled and not overly technical and quantifying, measuring and tracking activities and progress both to validate investments in any implementation efforts and to build momentum.*

While a much longer ‘laundry’ list of recommended actions could easily have been developed, what is offered reflects the need for a long-term view, the hard work of cultural change, and a recognition that while many good efforts are in place now, enough progress is not being made. These recommendations are intentionally kept at a high altitude to encourage discussion, prioritization and the inclusion of ideas, expertise and the consideration of best practices. Additionally, it is recognized that the full impacts of the pandemic on the future of education, workforce and manufacturing are not clear, meaning the path ahead will require agility and adaptability. The recommendations hope to recognize and build on the myriad of strategies and activities have been put in motion over the past several years by industry, economic development, workforce development and educational partners.

ENDNOTES

- i. <https://fred.stlouisfed.org/series/MANEMP>
- ii. BLS Quarterly Census of Employment and Wages
- iii. The only notable exceptions are textile mills (NAICS 313), textile products (NAICS 314), leather and allied product manufacturing (NAICS 316), and petroleum and coal products manufacturing (NAICS 324). These sectors are not found throughout the region and each generates less than 1% of total employment in the manufacturing sector. In some cases, companies in these sectors could be sizable employers in a specific county not across the region. For example, the Census Bureau's 2018 County Business Patterns shows identifies around 20 establishments as textile manufacturing found in three counties (Berks, Lehigh and Montgomery Counties). Seven of the establishments are located in Berks County and likely larger in scale (ie, over 100 employees). While in Montgomery County, the eight firms tend to be smaller (eg, with less than 20 employees).
- iv. Based on industry codes (North American Industry Classification System, NAICS), a super sector, like manufacturing has a two-digit code. At the three-digit level, manufacturing has 21 subsectors. At the four-digit, there are 65 subsectors. This code can be extended to six digits, providing further disaggregation.
- v. Consistent with the analysis of production occupations, this list draws heavily from detailed analysis of three of the counties: Berks, Lancaster and Lebanon. This reliance on three MSAs is necessary given data availability. While not fully representative, these three counties are a substantial portion of manufacturing in the Greater Berks Region. They generate over a third of the region's manufacturing GDP and are home to companies that employ 45% of the manufacturing labor force. Berk and Lancaster Counties, in particular, also have a broad mix of manufacturing subsectors.
- vi. BLS data shows in 2010, CNC operators and programmers in durable goods manufacturing sectors (321, 327-339). By 20219, these two occupations were in five more subsectors (311, 321, 322, 323, 324).
- vii. Table 1.12 of BLS occupational projections 2019-2029.
- viii. https://www.bls.gov/soc/2018/soc_2018_definitions.pdf
- ix. The projection is based on rolling forward current public school enrollments. This means students in 7th grade in 2019 will approximate the number of students graduating in 2024
- x. The supply of entering talent for production and maintenance workers emerges from both CTCs and post secondary institutions. The analysis makes a simplifying assumption by distinguishing between two sources of trained talent (CTCs and postsecondary institutions). In reality, talent entering into production and maintenance roles can directly come from either educational sources and through more complex pathways.