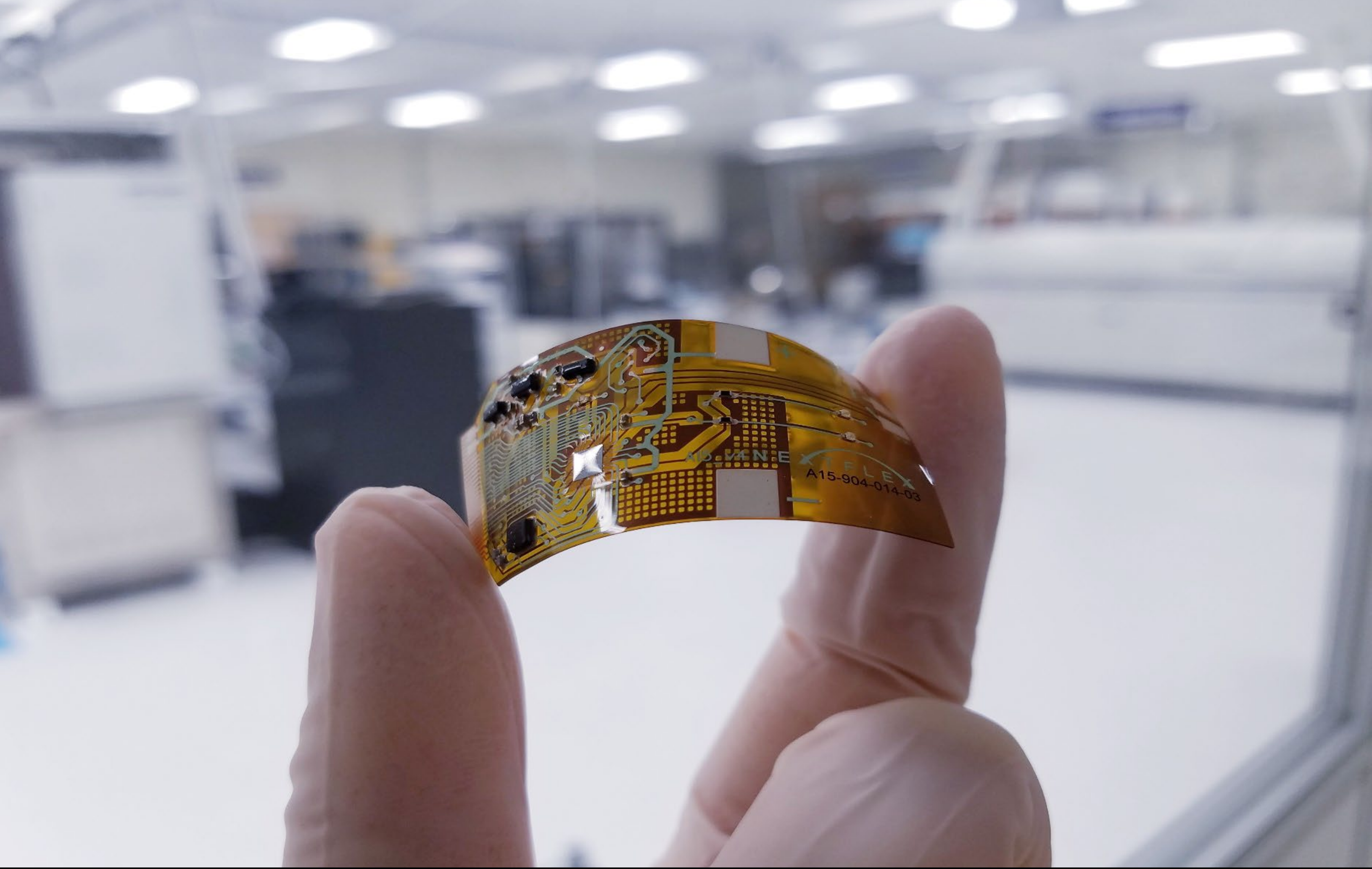

Preparing the Advanced Manufacturing Workforce: A Study of Occupation and Skills Demand in the Flexible Hybrid and Printed Electronics Industry

September 2021

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Cover image: Curved Microcontroller. Photo courtesy of NextFlex.

Acknowledgement

The authors would like to thank the DOD Office of Manufacturing Technology and the Massachusetts Technology Collaborative for the resources that made this study possible. Additionally, we are indebted to NextFlex and the Massachusetts Manufacturing Extension Program. Without these groups, the interviews that underpin this study would not have been successful.

Note: This report is a part of a Workforce Roadmap series that characterize technical workforce needs for advanced manufacturing areas focused on highly specialized training for jobs aligned with specific U.S. Manufacturing Institutes including integrated photonics, robotics, flexible electronics, functional fabrics, and 3D/additive manufacturing.

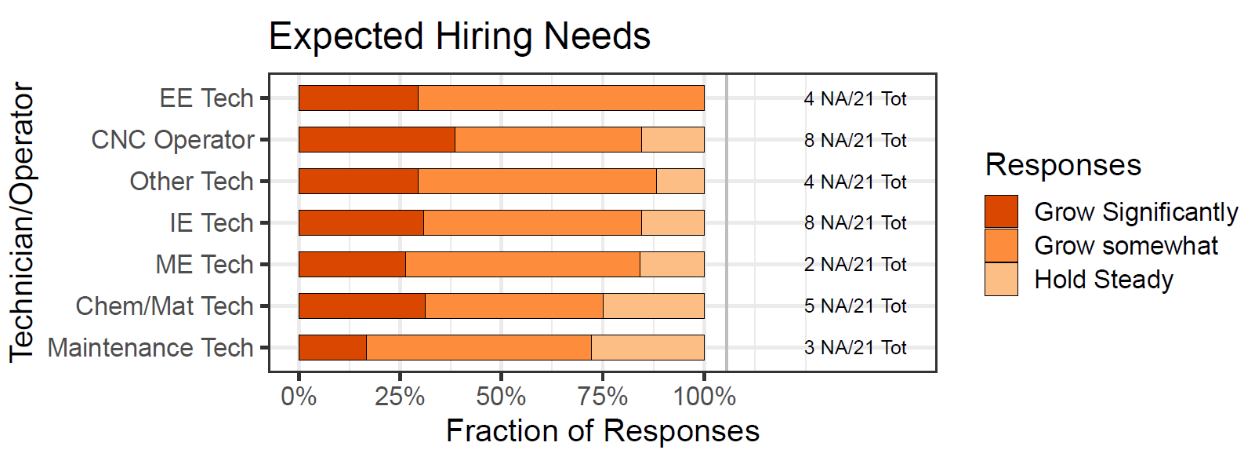
Executive Summary

Semi-structured interviews with operations managers in the flexible and hybrid electronics (FHE) industry from twenty-one firms across the U.S. were conducted to identify workforce needs within the FHE supply chain. The interviews were focused on middle-skilled technical occupations (except for information technology occupations). Firms emphasized the skills gaps, hiring and training challenges, and the importance of specific technical and human skills relevant to the FHE industry.

Firms expect increasing demand for all middle-skilled technical workers evaluated in this study, especially for electrical engineering technicians.

Training for technical workers in the flexible electronics industry should increase emphasis on the following skills:

- Repair and maintain equipment
- Interact with computers
- Prepare specimens, tools, or equipment
- Test and evaluate for quality
- Data collection and synthesis
- Communicating and collaborating with engineering and management staff



An econometric analysis was performed to understand the growth trends in the FHE industry by estimating the expected number of positions and openings within the industry. Data from the US Bureau of Labor Statistics, market intelligence reports, and survey responses were used to project both anticipated positions and openings. We estimate middle-skilled positions within this industry to grow from around 1,000 today to 2,500 by the end of the decade (see Figure ES 2). This translates to over 3,300 cumulative openings for middle skilled technical workers or around 300 new middle-skilled workers per year. Assuming a typical training program graduates about 15 students per year, the US would need more than 20 programs to meet the demand of this industry. In a Massachusetts context, we estimate around 100 total openings in these positions for this sector. This translates to about 10 middle-skilled openings per year, indicating the need for an educational program to train middle-skilled technical workers for the state's FHE industry.

Respondents indicated significant hiring challenges for all technical, middle-skilled workers as well as the need for extensive on-the-job training across the board. The occupation that exhibited the most significant hiring and training challenges and that was broadly employed across firms was the electrical engineering technician.

Emerging and human skill importance was evaluated for each position including a

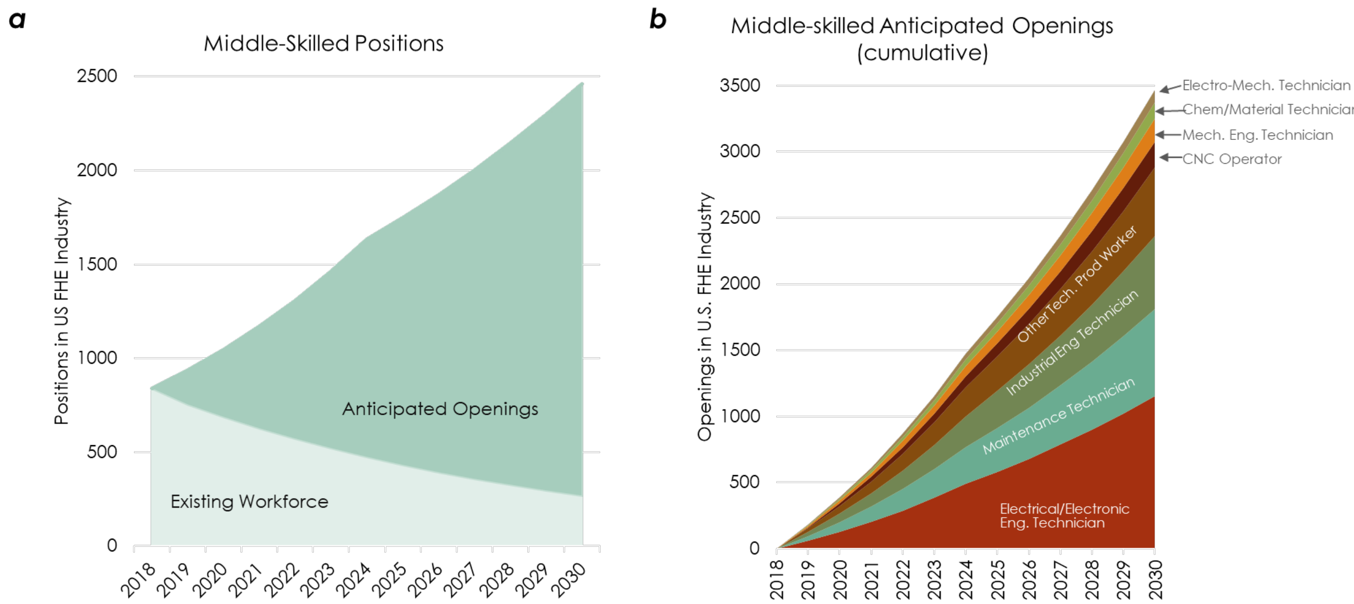


Figure ES 2. Survey results, data from the US Bureau of Labor Statistics, and market intelligence reports were used to project existing positions and expected openings for middle-skilled technical workers. (a) Shows an overview of trends. (b) Provides details by position.

critical thinking needs assessment. An emerging technical skill that was emphasized across all positions was working with digital collaboration tools. Human skills are also growing in importance for technicians in the FHE industry. In particular, interview responses indicate that the following skills should be emphasized in training:

- Taking initiative to learn new skills or technologies
- Independently organizing time or prioritizing skills

FHE firms shared that technicians are critical to solving problems since they are on the manufacturing front line and therefore become very sensitive to problems and develop an intuition on the causes of problems over time. While some firms don't expect technicians to be able to have critical thinking skills at first, they do expect them to be able to develop these skills with time. Results indicate that the majority of engineering technicians (71%) are expected to have competency in nearly all aspects of critical thinking (perceiving, hypothesizing, testing, and interpreting testing). Of the total number of responses, 49% of respondents expect engineering technicians to also be able to communicate the outcome of the process. Most other technical production workers are expected to only perceive the issue and hypothesize a cause (47%) while a third of the respondents expected these workers to be able to master all aspects of critical thinking.

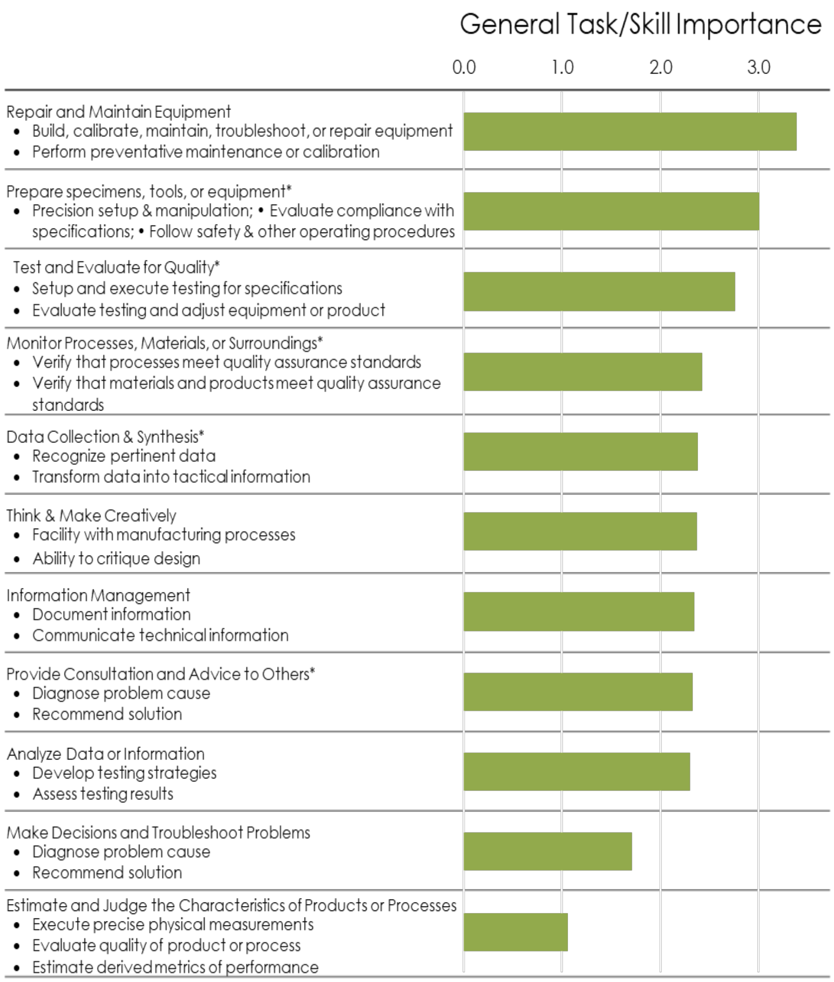


Figure ES 3 General Task/Skill (GTS) are classes that include many related specific skills. Here relevant GTS are ranked by weighted average importance of the specific skills within that class. Only GTS that are shared across at least two occupations are labeled as common and, therefore, included in this figure. Asterisks indicate skills that also have a critical gap and are of significant importance.

We highlight the specific technical skills that are both increasingly important and exhibit skills gaps for five occupations: mechanical engineering technicians, electrical engineering technicians, industrial engineering technicians, chemical/materials technicians, and CNC tool operators.

Because the interviews focused on skills described in the Bureau of Labor Statistics O*Net dataset, it was possible to not only identify job-specific skills but also to use the taxonomy within that dataset to aggregate survey responses to more generalized classes of skills (referred to as General Task/Skill, GTS). Figure ES 3 shows the result of that aggregation across all survey responses.

Looking across all middle-skilled positions, the top five generalized skills that are expected to be the most important for middle-skilled workers in the FHE industry are:

- Repair and Maintain Equipment
- Prepare specimens, tools, or equipment*
- Test and Evaluate for Quality*
- Monitor Processes, Materials, or Surroundings*
- Data Collection & Synthesis*

To get a better understanding of where training resources would be best applied, we also examined whether important skills also exhibited a significant skills gap (difference between competency of new hires and that required by industry). As shown in Figure ES 4, four of the most important GTS categories of skills were also frequently flagged as exhibiting a significant skills gap.

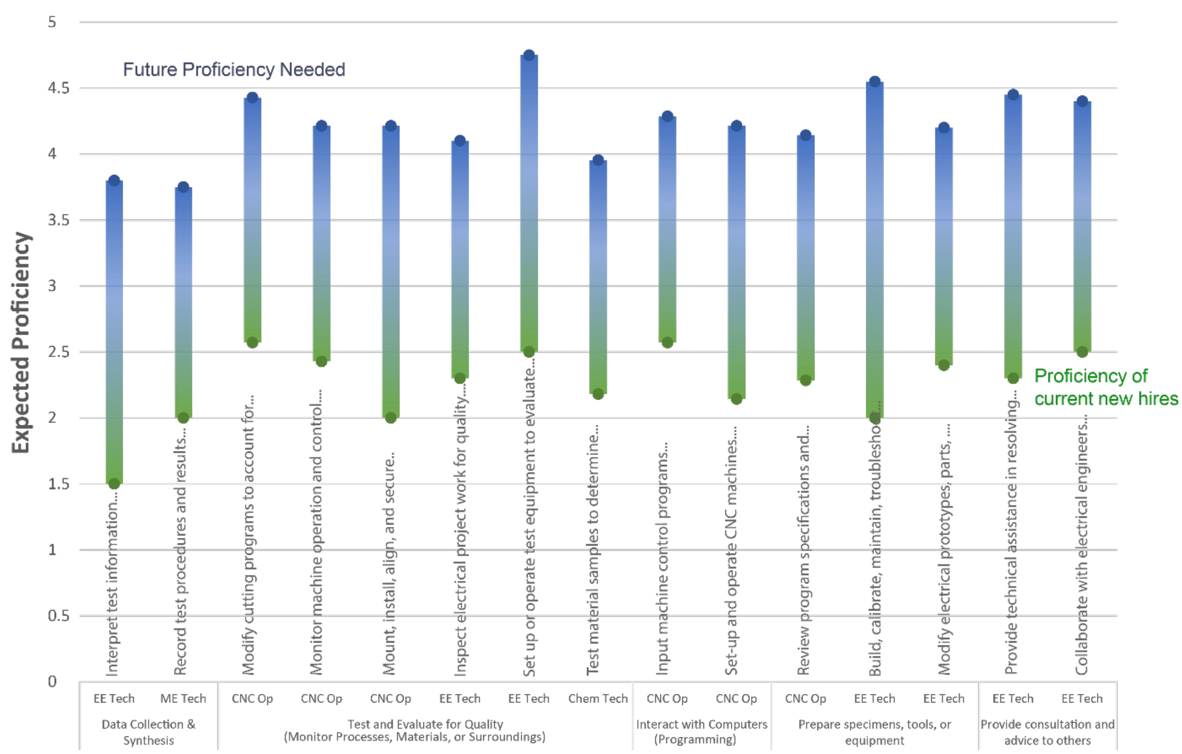


Figure ES 4 High priority skills across all positions studied in the FHE industry. The green dot represents the proficiency of current new hires and the blue dot represents the future proficiency needed for the middle-skilled level.

An emphasis in training these skills that exhibit significant training gaps, importance, and are common among multiple positions would add value to the FHE workforce. Data collection and synthesis as well as interacting with computers suggests improved training in data management as well as programming to perform multiple functions. Preparing specimens, tools, or equipment involves the ability to follow operating procedures and safety guidelines and attention to detail. Technicians in the FHE industry should also improve knowledge of quality, attention to detail, and knowledge of testing.

For middle-skilled workers in the FHE industry, the analysis of generalized skills points to the growing importance of the abilities to operate, maintain, and troubleshoot equipment, to program computers and equipment, ensure quality standards, and to collect and synthesize data.

The results from this study demonstrate the growing opportunity for technical careers in the FHE industry across the U.S. and areas of improvement for the training and skills development for those pursuing FHE careers.

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Introduction to the Workforce Roadmapping Report Series

Manufacturing – particularly advanced manufacturing[1] – is widely recognized as important for the United States for economic, strategic, and, more recently, public health benefits. Realizing those benefits will require both critical investments and intelligent policies. One challenge facing advanced manufacturing in the US that is less widely discussed is a mismatch between the supply of qualified employees and the needs of industrial employers.

In fact, 83% of manufacturers in the United States report a shortage of qualified employees (Huang et al. 2015). A recent study by Deloitte and the Manufacturing Institute estimates that this shortage may lead to as many as 2 million manufacturing jobs going unfilled over the next decade(Giffi et al. 2018). This structural unemployment has been attributed to both evolving manufacturing technology and to a declining interest in manufacturing jobs.

Furthermore, the emergence of new technologies can initiate new structures for knowledge coordination across formerly well-defined occupational boundaries. Technological changes can impact how worker tasks and therefore skills needs evolve and influence labor- demand effects and training as shown with automation and parts consolidation (Combemale et al. 2019). For example, the introduction of CT scanners changed the balance of knowledge between radiologists and technicians. Radiologists, less familiar with complex CT topics than they were to the simpler X-ray technology, evolved to a more collaborative approach to working with technicians (Barley 1986). Similarly, Frank Gehry's complex designs strained the modular boundary between architect and builder, with the separate roles collaborating much more closely in the design and building processes (Yoo, Boland, and Lyytinen 2006). These relationships can modularize again as technologies and knowledge become more mature, only to re-integrate as new technology or market concepts arise (Christensen, Verlinden, and Westerman 2002).

In a recent study, Combemale et al. (2021) find that new technologies are likely to lead to such workforce changes explicitly within the integrated photonics industry. Specifically, they find that changes in technologies for advanced manufacturing industries impact the distribution of demand for worker skills. Their study captures the labor-demand effects of technological changes in the automation of production processes and consolidation of parts using shop-floor data from various semiconductor firms. The O*NET database was used to identify skills and abilities[2] for each optoelectronic

[1] Advanced manufacturing includes both the application of new manufacturing processes and the production of innovative new products using either traditional or new processes.

[2] This study complements the work of Combemale et al. (2021) by focusing on O*NET work activities, detailed descriptions of worker tasks, rather than O*NET skills and abilities

occupation for each process step. Results indicate that automation of production processes would reduce the need for middle-skilled operators while conversely product integration would increase demand for middle-skilled workers. While these technical changes are not expected to reduce the number of jobs, they would be expected to change the portfolio of skills that are most valued. Furthermore, there is no reason that such trends would not carry over to other industries as the automate and develop more functionally integrated products.

In light of these needs and trends, this report aims to better characterize the evolving technical workforce needs within a specific advanced manufacturing sector – the advanced fabrics and fibers industry in the New England Region. We give particular focus to middle-skilled occupations[3] but also examine selected lower-skilled occupations that are uniquely important to this industry.

As part of this characterization, we attempt to

- estimate the demand for middle workers by occupation type
- identify what occupations represent the most serious hiring and training challenges
- identify what skills are most important for a given occupation

An understanding of the skills required in the current workforce can aid in informing education and training programs to prepare future advanced manufacturing workers.

To explore these questions, we develop and apply a new research method because traditional sources of information about labor needs are not well suited to answer questions within advanced manufacturing. The most widely consulted source of data on the US labor market is the Occupational Information Network (O*NET) database maintained by the Bureau of Labor Statistics (BLS)(U.S. Department of Labor 2020). That database contains information about workforce needs broken down into around 1000 occupation types across more than 100 industrial sectors. Although this serves as an invaluable source of information for workforce questions, there are at least two challenges to applying it to examine needs within advanced manufacturing. First, despite the scope and detail of the O*NET database, it is difficult to isolate the needs of emerging industries within that data. It will always be the case that advanced manufacturing sectors such as photonics, robotics, and additive manufacturing will operate at the interfaces of traditional sectors and as such will not be simply mapped using conventional industrial classification systems. Secondly, there will always be

[3] Here we define middle-skilled workers as those with training beyond a high-school diploma, but short of a bachelor's degree. The terms middle-skilled worker and middle worker will be used synonymously. Middle-skilled occupations are those filled predominantly by middle-skilled workers. More formal definitions are provided in the methods section.

concern that government databases are not updated frequently enough to capture the trends within rapidly evolving industries.

Defining the Flexible Hybrid Electronics Industry

With advancements in printing processes and manufacturing, more electronics are moving away from the traditional rigid shapes to flexible forms. Flexible Hybrid Electronics (FHE) integrate silicon integrated circuits with flexible and printed electronics. The combination of these two technologies enables an electronics platform that is large-area compliant, conforms to organic shapes, and is economically viable due to the ability to manufacture in high volumes (Khan et al. 2020; NextFlex 2021). There is demand for FHE in automotive, consumer electronics, healthcare, industrial, and defense sectors. For example, combined with sensors, FHE can be leveraged for health monitoring with flexible wearable medical devices (Ray et al. 2019). FHE can also be used in industrial settings such as infrastructure monitoring for roads, bridges, buildings, and more (NextFlex 2021)

Despite these promising FHE applications, there are many challenges with advancing the development and manufacturing of FHE. For instance, material selection remains a challenge due to the need for increased material stability in soft, flexible materials and conductive and nonconductive adhesives (Khan et al. 2020).A skilled workforce able to work at the intersection of silicon-based electronics and flexible printed electronics is also needed yet requires significant on-the-job training.

Methods

Workforce needs and gaps have been identified for the FHE industry through interviews of firms within the FHE manufacturing supply chain. Four steps were used to develop and structure the interview including: 1) discern the firms that make up the industry of interest; 2) posit occupations most relevant to those firms and skills most relevant to those occupations; 3) develop and deploy a semi-structured interview to characterize the relative importance of those occupations and skills; and 4) analyze the results to identify workforce and skills gaps (see Figure 1). More details of the research method are provided in the appendix to this report.

Figure 1. Key steps in the research method applied in this study.

Discern emerging advanced manufacturing industries

The global FHE industry is expected to reach $44.8 billion by 2026(Global Industry Analysts Inc 2021) . The D&B Hoovers Proprietary SIC 8-digit Code (SIC8) classification system (Cramer 2017), an expansion of the original SIC system, was used to discern the firms that comprise the FHE industry. These firms were mapped to industrial classification codes used by the Bureau of Labor Statistics (these are modifications of three to four-digit NAICS codes) to characterize workforce levels and economic activity by sector within the US economy. The specific codes and sectors that were used to represent the FHE industry are listed in Table 14 and Table 15 in the Appendix. The detailed process used to classify firms is described in the Appendix section, Detailed Methods.

Posit Relevant Occupations and Skills

Identify Relevant Occupations

To leverage the extensive surveying knowledge embedded within the US Department of Labor O*NET database(U.S. Department of Labor 2020), we use the BLS equivalent NAICS codes to identify a relevant set of occupations for our industry of interest. Specifically, occupation codes were identified using a combination of the 2018 National Employment Matrix (NEM) (U.S. Bureau of Labor Statistics 2018) and the O*NET database.

Middle-skilled workers are often defined as those with an education level beyond a high school diploma and less than a Bachelor's degree (Fuller and Raman 2017). Occupations are always held by workers with a range of education. For this research, we define middle-skilled occupations to be those for which both greater than 30% of the workforce is middle-skilled and less than 50% of the workforce is either lower-skilled or upper-skilled.

Based on these definitions, we identified 17 relevant middle-skilled positions associated with the FHE industry. To facilitate survey data collection, these were grouped into eight representative positions, as shown in bold in Table 1. This set includes four types of engineering technicians – electrical / electronic, industrial, mechanical, and chemical– as well as technical maintenance personnel (e.g., mechanics, electricians), computer-numerical-controlled machine operators, and machinists.

Table 1. Focal occupations that were evaluated in this study. Bold titles represent representative occupations that were served as proxy for the subsequent specific occupations.

Occupation	Standard Occupation Classification Code
Middle-skilled	
Electrical and electronics engineering technicians(representing)	
Electrical and electronics engineering technicians	17-3023
Electrical and electronics drafters	17-3012
Industrial engineering technicians(representing)	
Industrial engineering technicians	17-3026
Aerospace engineering and operations technicians	17-3021
Mechanical engineering technicians(representing)	
Mechanical engineering technicians	17-3027
Mechanical drafters	17-3013
Chemical/materials technicians (representing)	
Chemical technician	19-4031
Materials scientist	19-2032
Maintenance and Support Technicians (representing)	
Industrial machinery mechanics	49-9041
Maintenance workers, machinery	49-9043
HVAC mechanics and installers	49-9021
Mobile heavy equipment mechanics, except engines	49-3042
Electrical & electronics repairers, commercial & ind. equipment	49-2094
Computer-controlled machine tool operators(representing)	
Computer-controlled machine tool operators	51-4011
Computer numerically controlled machine tool programmers	51-4012
Other Technical Production Worker (representing)	
Machinists	51-4041
Tool and die makers	51-4111

Identify Relevant Skills

For each identified occupation, an associated set of competencies (skills) and tools was developed from two sources of job characterization information: the U.S. Department of Labor O*Net database (U.S. Department of Labor 2020) and a real-time labor market intelligence analytics database, Burning Glass Labor Insight™ (Burning Glass Technologies 2021). The O*Net database uses a hierarchical taxonomic approach to organize tasks and skills. (Peterson et al. 2001). The database was originally developed through survey methods to create a relational database of occupation attributes for the U.S. economy (Peterson et al. 2001)and helps create a common language for job descriptors. For each occupation, the database includes tasks in the job, tools employed in the job, and technologies employed on the job.

Using all of this information, the research team selected six to ten technical skills for each occupation based on the O*NET task descriptions to characterize their importance and any existing skills gap for these skills within the FHE industry. The specific skills explored are listed in the results plots and tables in the results section of the report.

Emerging Technical Skills

While the O*NET database provides valuable insight into the current technical skills needed for these occupations, the research team also wanted to get a sense of what skills are emerging as important within the FHE industry.

To accomplish this, we made use of two methods to identify potentially relevant emerging skills. The first method relied on discussions of the changing nature of work within the academic literature. Specifically, based on information within MIT Production in the Innovation Economy (PIE) survey (Weaver and Osterman 2017), the essential skills framework used by the Canadian government (Government of Canada 2015), and the Future of Work report (Autor, Mindell, and Reynolds 2020). Based on the authors' synthesis of these reports, we identified the following skills as potentially relevant and emerging for technical middle-skilled workers in manufacturing:

- Programming and troubleshooting automated process equipment (CNC, programmable production equipment, etc.)
- Conducting and assessing the results of statistical process control analyses or design of experiments
- Optimizing production flow based on the use of qualitative observations and quantitative analytics
- Using lean manufacturing principles (value stream mapping, minimize waste)
- Decreasing inventory and stockouts by understanding your own operations and your suppliers
- Working with digital collaboration tools (Computerized maintenance management software, connected worker platforms, workflow management, etc.)

The second method was to make use of a real-time labor market intelligence analytics database to identify emerging skills for each occupation. Burning Glass Labor Insight™ (BGLI) collects job posting data from job boards, firm websites, and job ad websites that represent more than 40,000 online resources and 3.4 million jobs (Burning Glass Technologies 2021). Duplicate postings are removed and natural language processing methods extract the in-demand occupations, skills, and credentials. Two approaches were used to identify relevant skills list from the BGLI database. It is important to note that while we did not specifically include tools and technologies in our interviews due to limited time; however, knowledge of in-demand tools and technologies can help inform trends in the FHE industry.

In the first approach, referred to as a keyword-based query, we attempted to identify relevant skills by querying middle-skilled posting associated with manufacturing and with the keywords representing the FHE industry. Specifically, we applied the filters shown in Table 2 **Error! Reference source not found.** which yielded 451,683 job postings. Finally, we added a filter where the job title must include "technician" resulting in 147,958 postings. Comparison between these two queries (with "technician" and without), helped to highlight technician-specific skills and isolate skills that are typical for all types of middle skilled positions within the industry (e.g. Microsoft Office Suite).

Table 2. Filter criteria applied for relevant education levels and keywords in the Labor Insight™ database.

Criteria	**Filter Applied**
Time Period	07/01/2016-06/31/2021
Education	High school or vocational training or Associate's degree
Industry	Manufacturing
Keywords	Electronic(s), printed electronics, printed circuit board, flexible electronics, hybrid electronics, wearable devices
Location	Nationwide
Title includes	Technician

In a second approach, referred to as an employer-based query, we searched for relevant and current skills by querying postings specifically associated with the two middle-skilled technician positions identified within BGLI –industrial/mechanical engineering technician or general engineering technician – and with firms specifically known to be in the FHE industry. The filtering on employer and types of occupations as shown in Table 3, resulting in 446,091 job postings. To once again narrow the search and reduce noise in the dataset, the "technician" filter was added, reducing the number of postings to 1,534.

Table 3. Filter criteria applied for relevant employers and occupations in the Labor Insight™ database.

Criteria	**Filter Applied**
Time Period	07/01/2016-06/31/2021
Occupation(s)	General engineering technician or industrial/mechanical engineering technician
Employer	64 FHE firms
Location	Nationwide

Title includes	Technician

The top 200 technical skills and software skills were identified from both approaches and compared with the O*NET tasks, detailed work activities, tools (and examples), and technologies (and examples) associated with the three technician positions found in both databases: electrical engineering technicians, mechanical engineering technicians, and industrial engineering technicians.

To identify skills not represented in the O*NET database, we performed a two-stage assessment. First, an NLP tool, UDPipe in R (Wijffels 2021), was used to lemmatize[4] the text of both the BGLI skills and the O*NET data and, then, to identify matches between the two. Matches and partial matches of at least 25% commonality were flagged for human evaluation. Based on this, skills or tools that were present in BGLI but not in O*NET were flagged to ensure all emerging skills, tools, and technologies are identified to inform curriculum development and training.

The O*NET database is a source of comprehensive job classification information with detail and context that is needed for in person interviews. The BGLI data is uniquely able to identify emergent skills and technologies in the field, but the information can require effort to contextualize given their brevity and occasional specificity. Overall, O*NET and Burning Glass Labor Insight™ complement one another in the skills gap analysis for the FHE industry.

Delays in accessing the BGLI database and the pressing need to deliver results in a timely manner, resulted in BGLI results not being available before interviews began. As such, for this report, we were unable to explicitly include emerging skills flagged by the BGLI analysis within industry interviews. While there were very few such skills that were absent from the survey questions, it is still important to identify them. As such, we call these out in the results section in Figure 13 and Appendix Figure 19-Figure 21 and Table 20-Table 22 and recommend that all programs monitor the importance of these skills to their local industry.

Human Skills: What about "Soft" skills?

The focus of this study was to assess the training gaps associated with specific applied skills for technical workers. This focus in no way implies that the research team believes that such technical skills are more important than other non-technical skills (also known as "soft" or human skills). Research was focused on technical skills for two reasons. First, our primary goal was to develop insights to shape training programs aimed to support the FHE industry. Such programs themselves focus on technical skills and, therefore,

[4]Lemmatization is a linguistics process of combining the inflected parts of a word to analyze them as a single item. It is a common natural language processing technique.

require feedback on the same. Secondly, the interview applied in this research was of a scale that taxed most respondents. As such, tradeoffs had to be made to limit its scope and content. As a result, this study explores only a limited set of human skills including a novel analysis of critical thinking.

Although they were not the focus of this study, it is important for training programs to recognize that human skills complement technical skills, enhance employability, and improve productivity (Schulz 2008; Rao 2014). Although both industry and academia are reaching consensus that employees need human skills in addition to the technical skills taught in most STEM training programs (Kumar and Hsiao 2007), there is no consensus on which human skills are most important or even how to frame and organize human skills.

A recent study by researchers at MIT's Jameel World Education Lab attempts to bridge that gap by synthesizing more than 40 skills frameworks into the Human Skills Matrix (HSM). Their analysis found that communication and self-management skills were the most commonly identified important human skills. These were followed by creativity, problem solving, critical thinking, and teamwork. The HSM synthesizes this information into 24 non-technical skills that employees need to thrive (Stump, Westerman, and Hall 2020). These skills are grouped into four categories including Thinking, Interacting, Managing ourselves, and Leading. This framework was used to guide the selection of human skills studied here.

Specifically, we asked operations managers about the importance of these six human skills (as well as a detailed question about critical thinking) for middle-skilled manufacturing occupations:

- Effectively managing people and projects (Leading)
- Managing unfamiliar problems and situations (Thinking)
- Independently organizing time or prioritizing tasks (Managing ourselves)
- Communicating and collaborating with engineering and management staff (Interacting)
- Taking initiative to learn new skills or technologies (Managing ourselves)
- Knowing the science and engineering underlying the product (Thinking)

Critical thinking is widely cited as a skill that leads to success. Nevertheless, there are no established methods to characterize it. Here we define critical thinking as "the ability to analyze evidence and facts to form a judgment" (Gambrill 2005).To better characterize the role of critical thinking for technical middle-skilled occupations, we decompose the judgment process into the following sub-tasks:

1. Perceiving the issue – What should I measure or observe to know that a problem exists?
2. Hypothesizing about problem cause – What might be causing the problem?
3. Developing a framework for hypothesis testing – How can I confirm my hypothesis?
4. Inferring whether tests confirm the hypothesis - Does the test suggest that my hypothesis was right?

5. Communicating the outcome – How (and to whom) do I report on what has happened?

Respondents were asked to identify what aspect of critical thinking is important of technicians working at their facility.

Identifying Important, Common Skills

While it is valuable to understand the skills trends within individual occupations, in many cases, training programs or courses will need to be more broadly applicable, serving the needs of multiple types of learners. Combemale et al. (2021)also recommend that formal training must become more general for technician-level positions to be valuable in various types of advanced manufacturing industries. To that end, the research team has attempted to identify those skills that are both important and shared (common) among multiple occupations.

This was accomplished by making use of the hierarchical nature of the O*NET dataset from which occupation-specific skills were identified. Weighted average importance levels for generalized tasks/skills (GTS) and intermediate tasks/skills (ITS) were computed based on survey responses for occupation-specific tasks and skills. Details of the relationships among specific skills and higher levels of aggregation and the method of computing an importance score are described in the Appendix.

Semi-Structured Interview

Interview design

The interview is structured into four main sections:

1) firm characterization,
2) hiring and training challenges
3) workforce scaling, and
4) emerging and human skill needs including critical thinking.

In the first section of the interview, respondents were asked to identify the primary role that their firm plays in the FHE supply chain. Additionally, respondents were asked to estimate the firm's annual revenues and overall employment levels.

In the second section, respondents were asked to identify which of the focal occupations were relevant for their firm. Then for each relevant occupation they were asked whether

- Demand for that position would (Hold, Grow Somewhat, or Grow Significantly)?
- Filling an open position was (Easy, Average, or Hard)?
- In house training for new hires tends to be (Basic, Moderate, or Extensive training)?

Next, respondents were randomly assigned three relevant occupations. For each of these, they were asked to characterize the expected skill level for each position for their current technicians, the skill level of new hires for these positions, and rank the importance of the skills in 5 years compared to today. The categories for skill level included the following:

- Not applicable
- Aware of
- Familiar with
- Competent at
- Proficient with
- Mastery of

The expected importance ranks from much less important than now to much more important than now.

For each of these positions, respondents were asked to evaluate the importance of emerging skills when evaluating a new hire in five years. The importance categories included the following:

- Extremely important
- Very important
- Moderately important
- Slightly important
- Not at all important

Finally, the closing questions of the interview included in-depth questions about critical thinking and troubleshooting for technicians relevant to the respondent's firm. The respondents were asked to identify which of the judgments in the critical thinking process were most common for each technician ranging from:

- Issue perception
- Cause hypothesizing
- Hypothesis testing
- Test result inference
- Reporting and recommending

It was assumed that if a respondent chose "reporting and recommending" then they felt that the technician was capable of performing all of the previous steps as well.

To understand the importance of troubleshooting for hiring, respondents were asked to explain the relevance of this ability at their firm and how they test and train troubleshooting abilities.

Semi-Structured Interview Process

The interview responses were captured in the Qualtrics online platform(Qualtrics XM 2021) and interviews were conducted with FHE firms located throughout the U.S. Twenty-one responses where the respondent completed the entirety of the interview template were received and incorporated into the following results.

Results

Results from twenty-one semi-structured interviews with operations managers across the FHE supply chain highlight the skills gaps among new and incumbent technician workers as well as the significant hiring challenges, especially for small- and medium-sized firms. The first section includes responses about the overall demand for middle-skilled workers and details projections for future demand. Next, hiring and training challenges of these workers are shown. Recommendations for high and moderate priority skills are detailed based on an assessment of the importance and skill gap for specific skills by position. A common skills analysis is performed to highlight skills that are important across positions in the FHE supply chain.

Demand for occupations

Question
We expect demand for this type of position in our firm will....

FHE firms indicated that the demand for the positions studied is strong and will continue to grow into the future (Figure 2). The occupation expected to have the highest demand growth is the electrical engineering technician. Beyond this, selected firms emphasized a need for more CNC and drilling operators because skilled candidates for these positions are difficult to find.

Among the occupations studied, nearly all were both utilized by most FHE firms and expected to experience moderate demand growth.

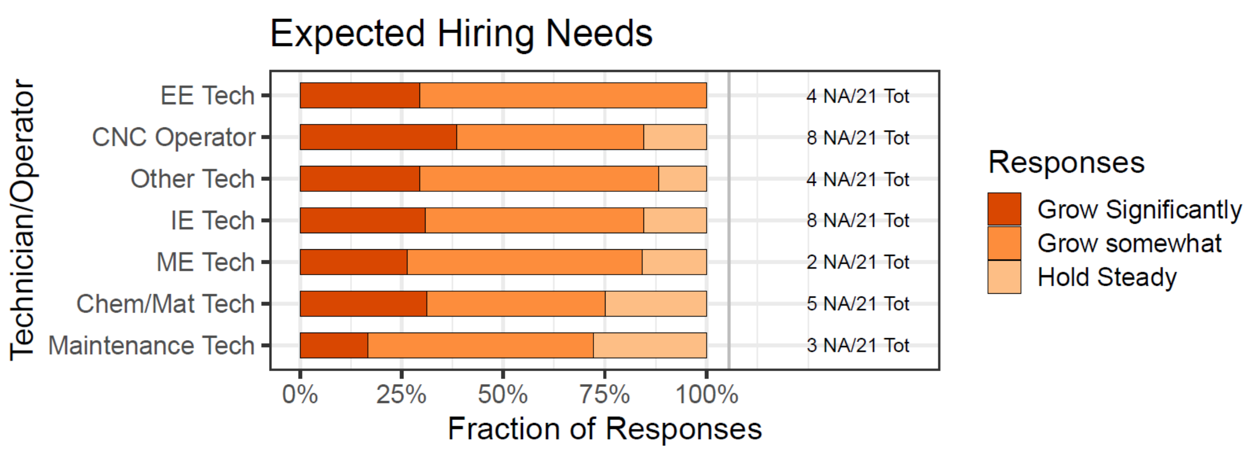

Figure 2. The technical worker occupations studied were classified according to future demand growth in the FHE industry. Number of respondents, n =21. Fraction of 'Not Applicable' responses at the right of the bar. Firms indicated that other technical worker would likely be a failure analysis technician or warehouse packer.

The demand for each position can be summarized as follows:

Strong Growth	Moderate Growth	Hold
• Electrical Engineering Technician	• CNC Tool Operator • Other Technical Production Worker • Industrial Engineering Technician • Mechanical Engineering Technician • Chemical/Materials Technician • Maintenance and Support Technician	

Workforce Demand Projections

An econometric analysis was performed to understand the growth trends in the FHE industry by estimating the expected number of positions and openings within the industry. This projection was based on three sources of data: forecasts for the overall economic activity within the U.S. FHE industry, estimates of worker intensity per dollar of economic activity within the represented sectors, and interview responses about specific staffing levels and anticipated growth in demand for specific occupations.

Estimates of economic activity within the U.S. FHE industry were assembled from three sources of market intelligence including industry statistics from the Global Market Post(Global Market Post 2021), a market research report by Global Industry Analysts, Inc. (Global Industry Analysts Inc 2021), and the Bureau of Labor Statistic's *Projections Overview and Highlights, 2019-2029* (Dubina et al. 2020). From these sources of information, we estimate the FHE industry within the United States currently generates approximately $3.2B of revenue and is projected to grow at a rate of approximately 13% per year. (To be more conservative, we use this rate of growth only for the first five years of our analysis. For the latter five years, we assume 60% this rate of growth.) Estimates of workforce intensity (i.e. workers per dollar of revenue) are based on analysis of BLS data for the hybrid industry that is used here to represent the FHE industry.

Note: in the balance of this section, in the interest of simplicity, we refer to technical middle-skilled positions. As was detailed earlier in this document, our analysis includes only specific occupation types. For middle-skilled occupations, the primary omission is information technology positions.

As shown in Figure 3, we estimate that currently there are ~1,000 technical middle-skilled positions in the U.S. FHE industry with that figure growing to just under 2,500 positions by the end of the decade (Figure 3a). The expected growth coupled with expected

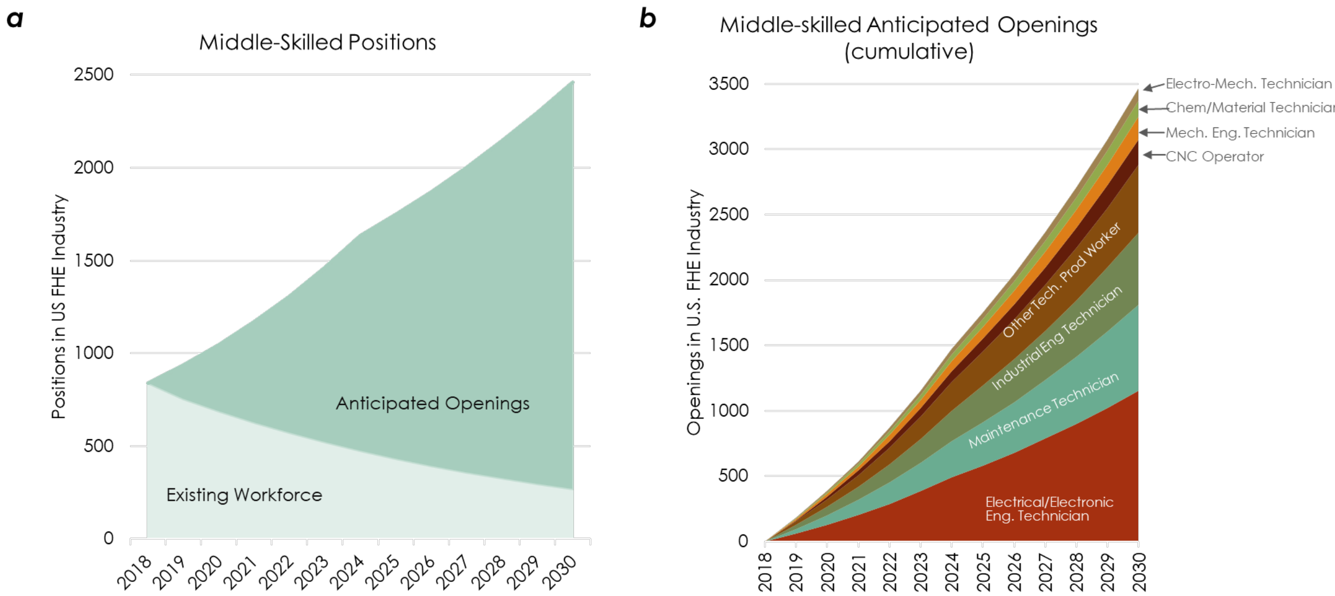

Figure 3. (a) Shows an overview of trends for middle-skilled workers in the FHE industry (b) Provides details by position. Results are based on expected demand growth, industry growth, and retirement rate.

departures from the existing workforce (i.e., retirements and separations into other occupations) would lead to nearly 3,300 middle-skilled skilled technical openings over the decade.

These estimates translate into a need of about 300 new middle-skilled workers per year. If a typical community college program graduates 15 middle-skilled learners with these skills per year, the country will need more than 20 programs focused on the needs of the FHE industry to meet the expected industry demand for middle-skilled workers.

Mapping these number to a Massachusetts context, we estimate approximately 100 total openings in these positions for this sector within the state. This includes about 10 middle-skilled openings per year within the state, easily supporting an educational program to train middle-skilled technical workers for the state's FHE industry.

Hiring Challenges

Question *Filling this type of position is ....*

Hiring is a significant challenge for most firms (Figure 4) and many small- and medium-sized firms explained that they often lose their skilled workers to larger firms. When asked about how long it typically takes to hire for these positions, most positions require at least 30-60 days to hire with >50% indicating more than 60 days for CNC operators, industrial engineering technicians, and chemical/materials technicians. Respondents indicated that there is a larger supply of Bachelors-level workers but not enough workers at the technician-level, driving firms to hire overqualified workers for technician roles. Many shared that they believe there is a labor shortage and the pandemic has only made hiring more difficult. These results suggest a low supply of technical middle-skilled workers as well as a challenge of attracting and retaining workers in this industry.

In comparing the demand and hiring results, all positions were found to be difficult to hire for and are positions expected to grow in the future. Among the group, electrical engineering technicians stood out as being in particularly high demand and also more difficult to hire compared to the other positions studied. Results recommend an emphasis on training and attracting electrical engineering technicians to meet the demand of the FHE industry.

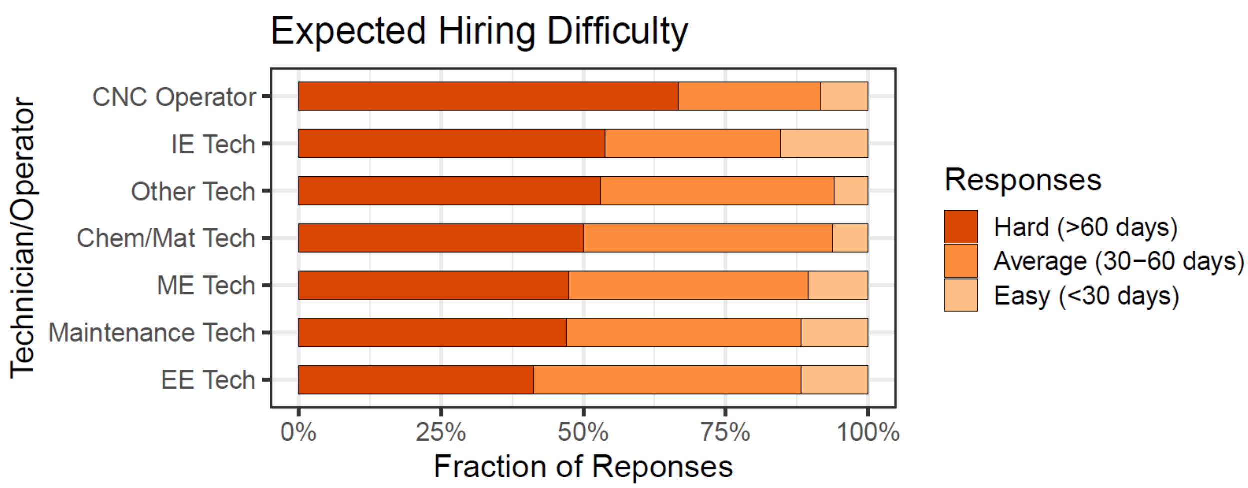

Figure 4 The difficulty of hiring middle-skilled positions was assessed for the FHE industry (n=21). Most positions were found to be difficult to fill.

The hiring difficulty for each position can be summarized as follows:

Considerable hiring effort	Moderate	Nominal
• CNC Operator • Industrial Engineering Technician • Other Technical Production Worker • Chemical/Materials Technician • Mechanical Engineering Technician • Maintenance and Support Technician		

• Electrical Engineering Technician		

Training Effort Required

Question
New hires typically require training that is …

The amount of on-the-job training for each occupation was also evaluated by respondents as extensive, some, or basic orientation only. Respondents indicated that the training required for all of the occupations studied is extensive, on-the-job training (see Figure 5). At some smaller firms, extensive training is desired but the firms do not have the time or resources to train to that level. At larger firms, there is a minimum of ~2 months training until workers are proficient around 3-6 months. While some training is company specific, respondents suggested additional or improved training in the following areas:

- Lean manufacturing
- Roll-to-roll manufacturing
- Soldering
- Automation
- Chemical safety
- Quality control
- CAD/PLM systems
- GDT requirements
- Surface mount technology placement

Many respondents shared a recommendation for improved relationships between training centers/community colleges and equipment vendors. An emphasis in training basic programming is also of interest to many firms in the FHE supply chain. Specific to printed electronics, firms recommend training in wet chemistry inks and solvents as well as profiling of different components.

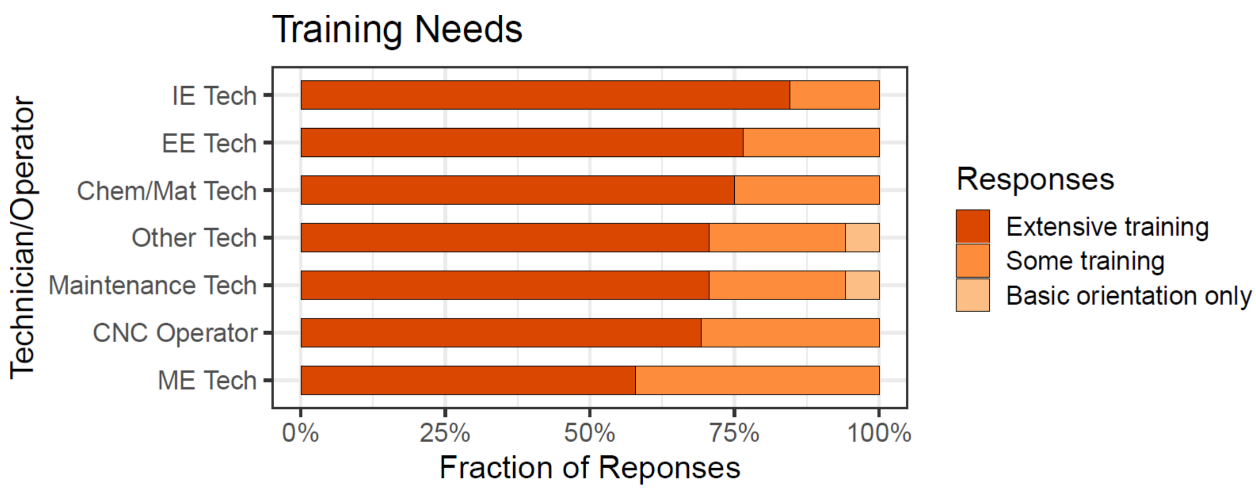

Figure 5 The training required for each position was assessed as extensive, some training, or basic orientation only (n=21). All positions require extensive training (>50% of the responses).

In comparing the training effort results to the hiring challenge results, we observe that all of the middle-skilled positions are difficult to hire and also require additional specialized training for new hires.

Industry Recognized Certification Program

Question How do you feel about the following statement: "Industry-Recognized Certifications and Credentials would be useful for the advanced FHE manufacturing industry."

During the interviews, the firms were asked to rank how they felt about job-specific industry-recognized certification and credentialing programs to assist with hiring from strongly disagree to strongly agree (Figure 6). The goal of these programs would be to aid in identifying qualified candidates and to provide opportunities for more workers. Most respondents (71%) either strongly agreed or agreed with the statement that industry specific credentials would be useful for the FHE industry. Several respondents (19%) disagreed and the remaining respondents indicated that they were neutral regarding certification programs.

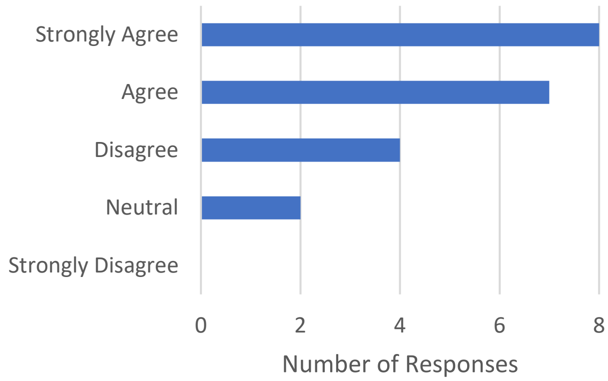

Figure 6 Reactions regarding certification and credentialing programs to improve hiring in the FHE industry.

For those that disagreed, they felt that credentialing programs do not give applied or practical experience. Others felt that certificate programs were a barrier to entry because it can take some time to get into the programs and can be costly. Instead, respondents recommend apprenticeships or a job-sharing model where students are in class for one week and then at a company gaining hands-on experience the next week. On the other hand, respondents that agreed felt certificates are desired but not required and are an absolute value add. Specifically, firms would value a printing technology certificate, a certificate on the basics of environmental health and safety, a programming certificate, and/or a certificate on printed electronics competencies such as inks, motion, and reliability requirements. Credentialing or certificate programs in these areas could help shorten training time significantly.

Skills required for In-Demand Positions

Results from the semi-structured interviews underscore the demand for middle-skilled workers, hiring challenges, and training gaps across all positions studied. The training gaps for each occupation were explored in detail for 8-10 specific skills where respondents were asked to rank the skill level for existing workers, new hires, and the importance of the skill in five years compared to today. The research team identified skills that were classified as high priority or moderate priority. High priority skills are those that have a large gap between existing workers and new hires and were also ranked as having high future importance. Moderate priority skills are those with either a large gap or were ranked as much more important or skills that fell in the mean range of the data for both categories. For those skills that were not ranked as high or moderate priority, the research team recommends these skills be re-evaluated for inclusion in the curricula for that occupation.

There were a sufficient number of responses (n>=5) to characterize five positions including mechanical engineering technician, electrical engineering technician, industrial engineering technician, chemical/materials technician, and CNC tool operator. Since there are significant training gaps for these workers, we highlight opportunities to improve training programs for the future.

Table 4 Occupation descriptions for the five positions with a sufficient number of responses.

Occupation Title	Description
Mechanical Engineering Technicians (SOC Code 17-3027.00)	Apply theory and principles of mechanical engineering to modify, develop, test, or calibrate machinery and equipment
Electrical Engineering Technicians (SOC Code 17-2023.00)	Apply electrical and electronic theory and related knowledge, usually under the direction of engineering staff, to design, build, repair, adjust, and modify electrical components, circuitry, controls, and machinery for subsequent evaluation and use by engineering staff in making engineering design decisions.
Industrial Engineering Technicians (SOC Code 17-3026.00)	Apply engineering theory and principles to problems of industrial layout or manufacturing production. May perform time and motion studies on worker operations in a variety of industries to establish standard production rates or improve efficiency
Chemical/Materials Technician (SOC Code 19-4031)	Conduct chemical and physical laboratory tests to assist scientists in making qualitative and quantitative analyses of solids, liquids, and gaseous materials for research and development of new products or processes, quality control, maintenance of environmental standards, and other work involving experimental, theoretical, or practical application of chemistry and related sciences.
CNC Tool Operators (SOC Code 9161.00)	Operate computer-controlled tools, machines, or robots to machine or process parts, tools, or other work pieces made of metal, plastic, wood, stone, or other materials. May also set up and maintain equipment.

Mechanical Engineering Technician

Survey responses for mechanical engineering technicians are shown in Figure 7. Recommendations for training of mechanical engineering technicians based on these results are summarized in Table 5.

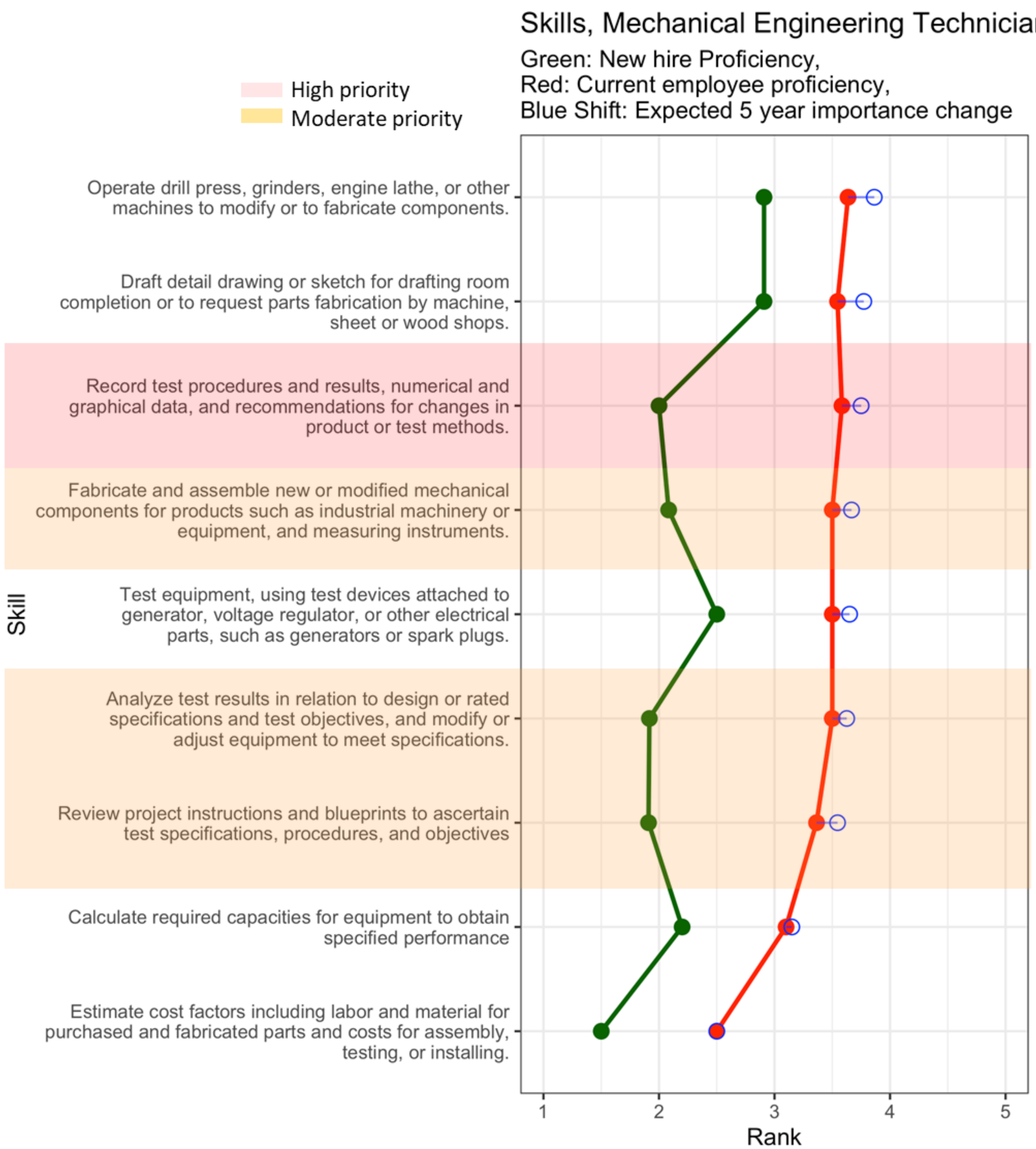

Figure 7. The gaps and expected future importance of skills for mechanical engineering technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 5. Recommended changes in the training of mechanical engineering technicians in the FHE industry. The red skills are those that are high priority and the orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on…	Recommend changes in product or process design	Record test procedures and results, numerical and graphical data, and recommendations for changes in product or test methods.
Improve training on…	Fabrication methods	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.
	Understand, evaluate, and maintain quality	Analyze test results in relation to design or rated specifications and test objectives, and modify or adjust equipment to meet specifications.
		Review project instructions and blueprints to ascertain test specifications, procedures, and objectives
Maintain training/evaluate training on…	Operate specific equipment	Operate drill press, grinders, engine lathe, or other machines to modify parts tested or to fabricate experimental parts for testing.
	Drafting for fabrication	Draft detail drawing or sketch for drafting room completion or to request parts fabrication by machine, sheet or wood shops.
	Understand, evaluate, and maintain quality	Test equipment, using test devices attached to generator, voltage regulator, or other electrical parts, such as generators or spark plugs.
	Estimate system capabilities and costs	Calculate required capacities for equipment to obtain specified performance
		Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.

Electrical Engineering Technician

Survey responses for electrical engineering technicians are shown in Figure 8. Recommendations for training of electrical engineering technicians based on these results are summarized in Table 6.

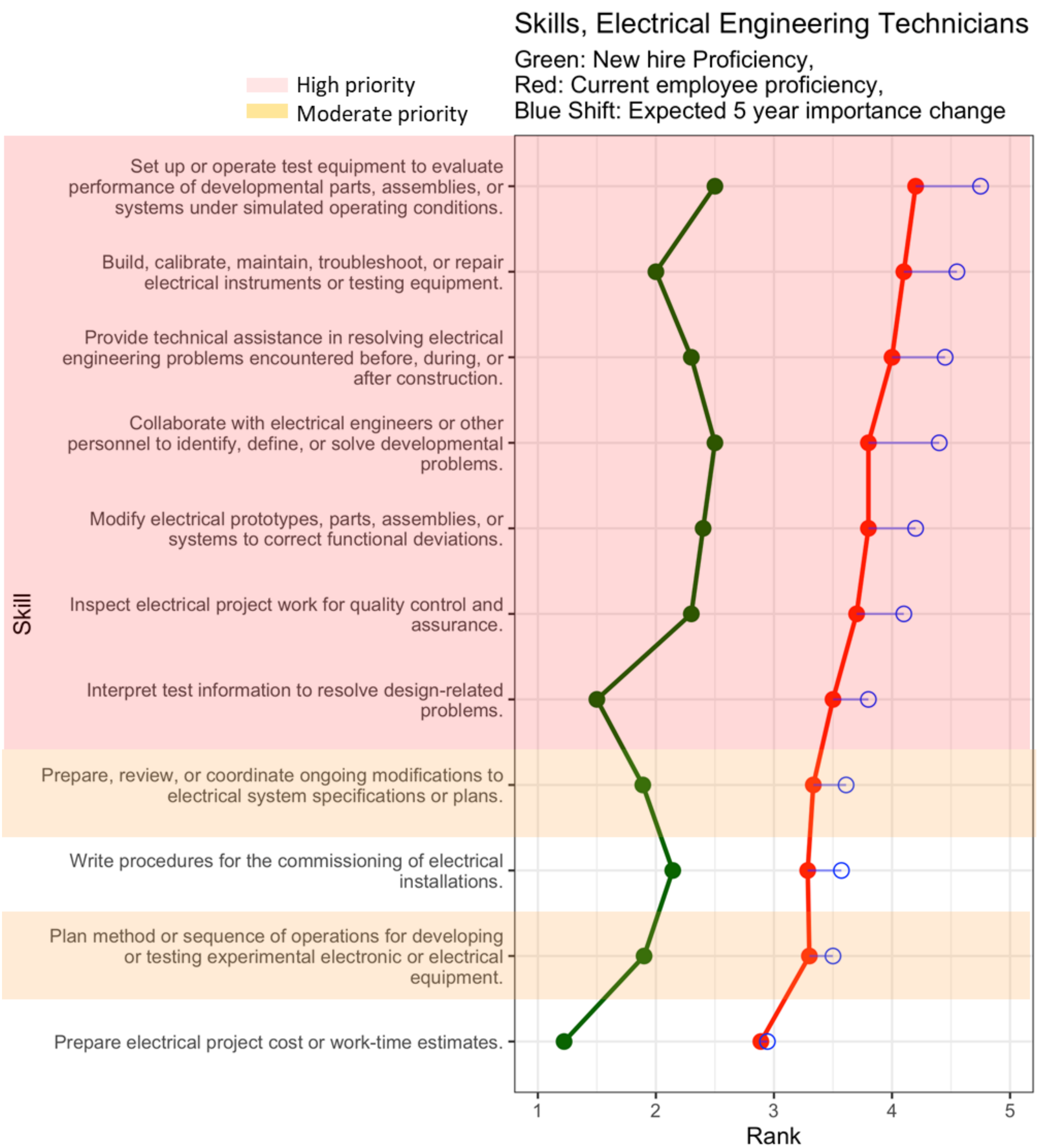

Figure 8. The gaps and expected future importance of skills for electrical engineering technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 6. Recommended changes in the training of electrical engineering technicians in the FHE The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on…	Diagnose and resolve process or product problems	Set up or operate test equipment to evaluate performance of developmental parts, assemblies, or systems under simulated operating conditions.
	Build and maintain electrical instruments or testing equipment	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.
	Collaborate to improve design or troubleshoot problems	Provide technical assistance in resolving electrical engineering problems encountered before, during, or after construction.
		Collaborate with electrical engineers or other personnel to identify, define, or solve developmental problems.
	Diagnose and resolve process or product problems	Modify electrical prototypes, parts, assemblies, or systems to correct functional deviations.
		Inspect electrical project work for quality control and assurance.
	Develop and execute standard testing procedures Develop and execute standard testing procedures	Interpret test information to resolve design-related problems.
Improve training on…		Prepare, review, or coordinate ongoing modifications to contract specifications or plans.
		Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.
Maintain training/evaluate training on…	Manage electrical system specifications	Write procedures for the commissioning of electrical installations.
	Estimate project or process cost	Prepare electrical project cost or work-time estimates.

Industrial Engineering Technician

Survey responses for industrial engineering technicians are shown in Figure 9. Recommendations for training of industrial engineering technicians based on these results are summarized in Table 7.

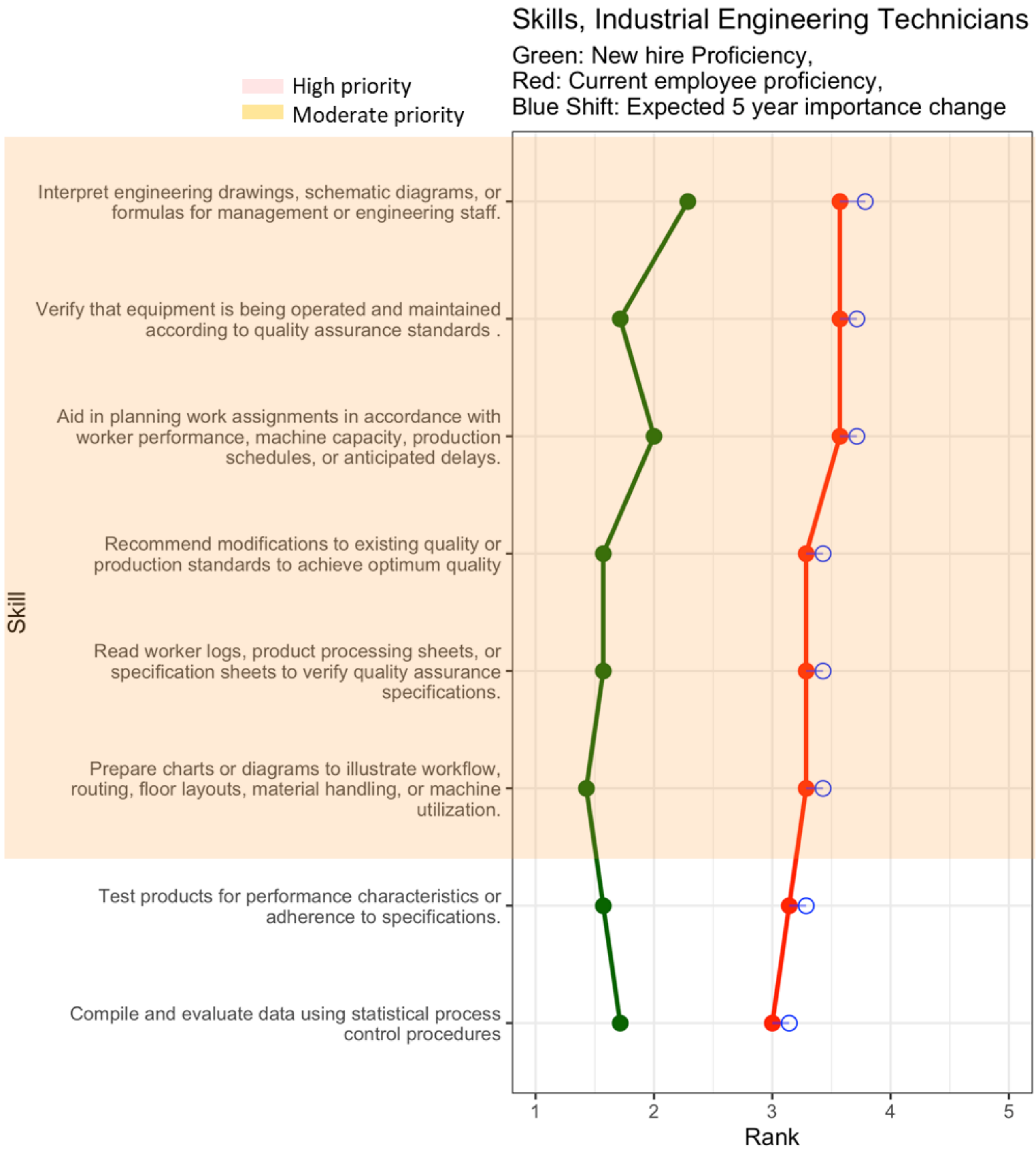

Figure 9. The gaps and expected future importance of skills for industrial engineering technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 7. Recommended changes in the training of industrial engineering technicians in the FHE industry. The red skills are those that are high priority with a large gap and high importance in the future. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Improve training on…	Communication with engineering and management	Interpret engineering drawings, schematic diagrams, or formulas for management or engineering staff.
	Maintain product and process quality assurance standards	Verify that equipment is being operated and maintained according to quality assurance standards.
	Recommend operational & procedural changes	Aid in planning work assignments in accordance with worker performance, machine capacity, production schedules, or anticipated delays.
		Recommend modifications to existing quality or production standards to achieve optimum quality
	Maintain product and process quality assurance standards	Read worker logs, product processing sheets, or specification sheets to verify quality assurance specifications.
	Communication with engineering and management	Prepare charts or diagrams to illustrate workflow, routing, floor layouts, material handling, or machine utilization.
Maintain training/evaluate training on…	Test, analyze and respond to process data	Test products for performance characteristics or adherence to specifications.
		Compile and evaluate statistical data to determine and maintain quality and reliability of products.

Chemical/Materials Technician

Survey responses for chemical/materials technicians shown in Figure 10. Recommendations for training of chemical/materials technicians based on these results are summarized in Table 8.

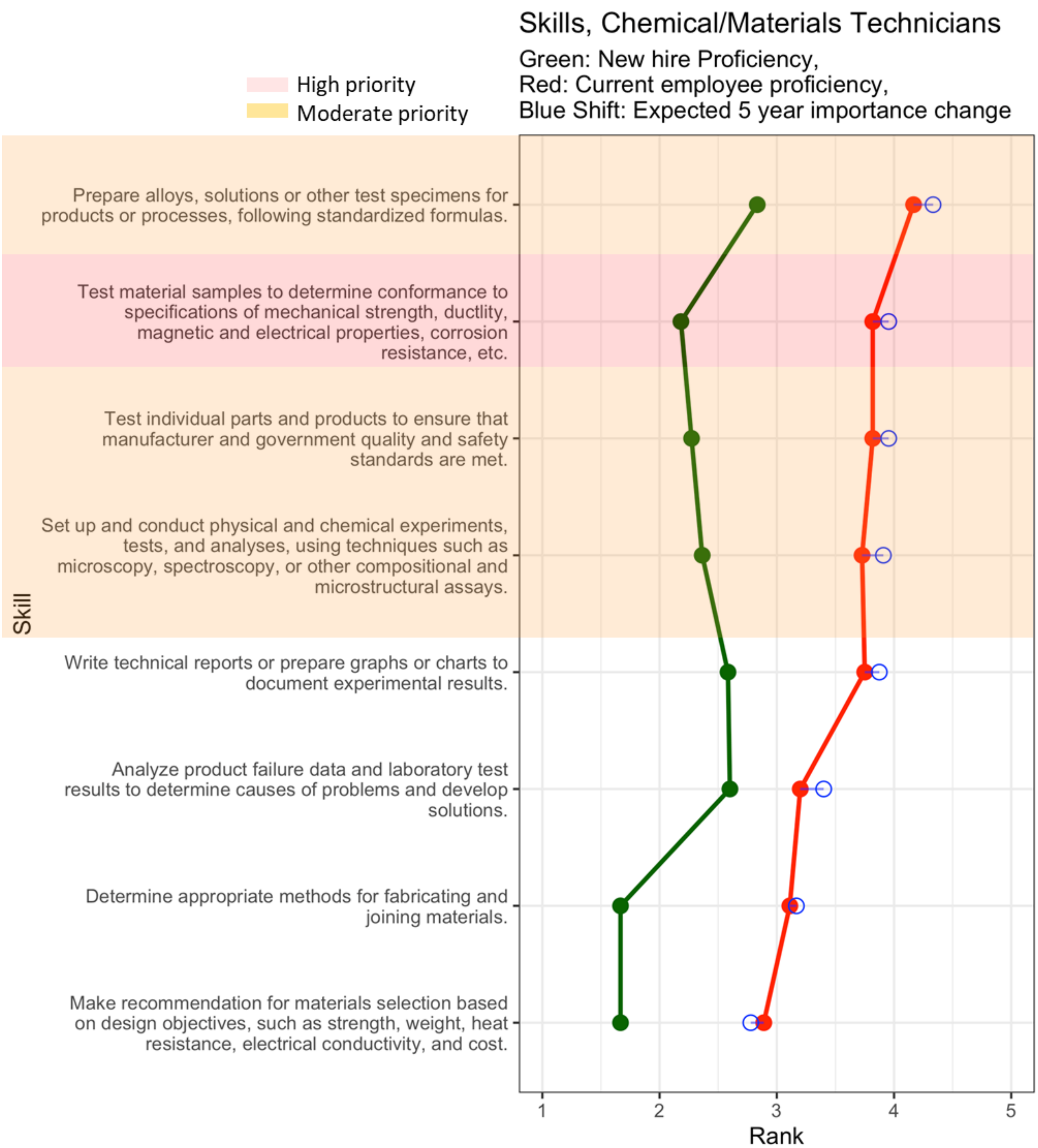

Figure 10. The gaps and expected future importance of skills for chemical/materials technicians are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 8. Recommended changes in the training of chemical/materials technicians in the FHE industry. The red skills are those that are high priority with a large gap and high importance in the future. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on…	Material testing	Test material samples to determine conformance to specifications of mechanical strength, ductlity, magnetic and electrical properties, corrosion resistance, etc.
Improve training on…	Set up and conduct experiments following quality and safety standards	Prepare chemical solutions for products or processes, following standardized formulas, or create experimental formulas.
		Test individual parts and products to ensure that manufacturer and government quality and safety standards are met.
		Set up and conduct physical and chemical experiments, tests, and analyses, using techniques such as microscopy, spectroscopy, or other compositional and microstructural assays.
Maintain training/evaluate training on…	Assess test results and identify root cause	Write technical reports or prepare graphs or charts to document experimental results.
		Analyze product failure data and laboratory test results to determine causes of problems and develop solutions
	Lab maintenance	Maintain, clean, or sterilize laboratory instruments or equipment.
	Chemical or physical lab tests and result assessment	Conduct chemical or physical laboratory tests to assist scientists in making qualitative or quantitative analyses of solids, liquids, or gaseous materials.
	Assess test results and identify root cause	Write technical reports or prepare graphs or charts to document experimental results.
		Analyze product failure data and laboratory test results to determine causes of problems and develop solutions
	Identify methods for fabricating and joining	Determine appropriate methods for fabricating and joining materials.
	Materials selection	Make recommendation for materials selection based on design objectives, such as strength, weight, heat resistance, electrical conductivity, and cost.

CNC Tool Operator

Survey responses for CNC tool operators are shown in Figure 11. Recommendations for training of CNC tool operators based on these results are summarized in Table 9.

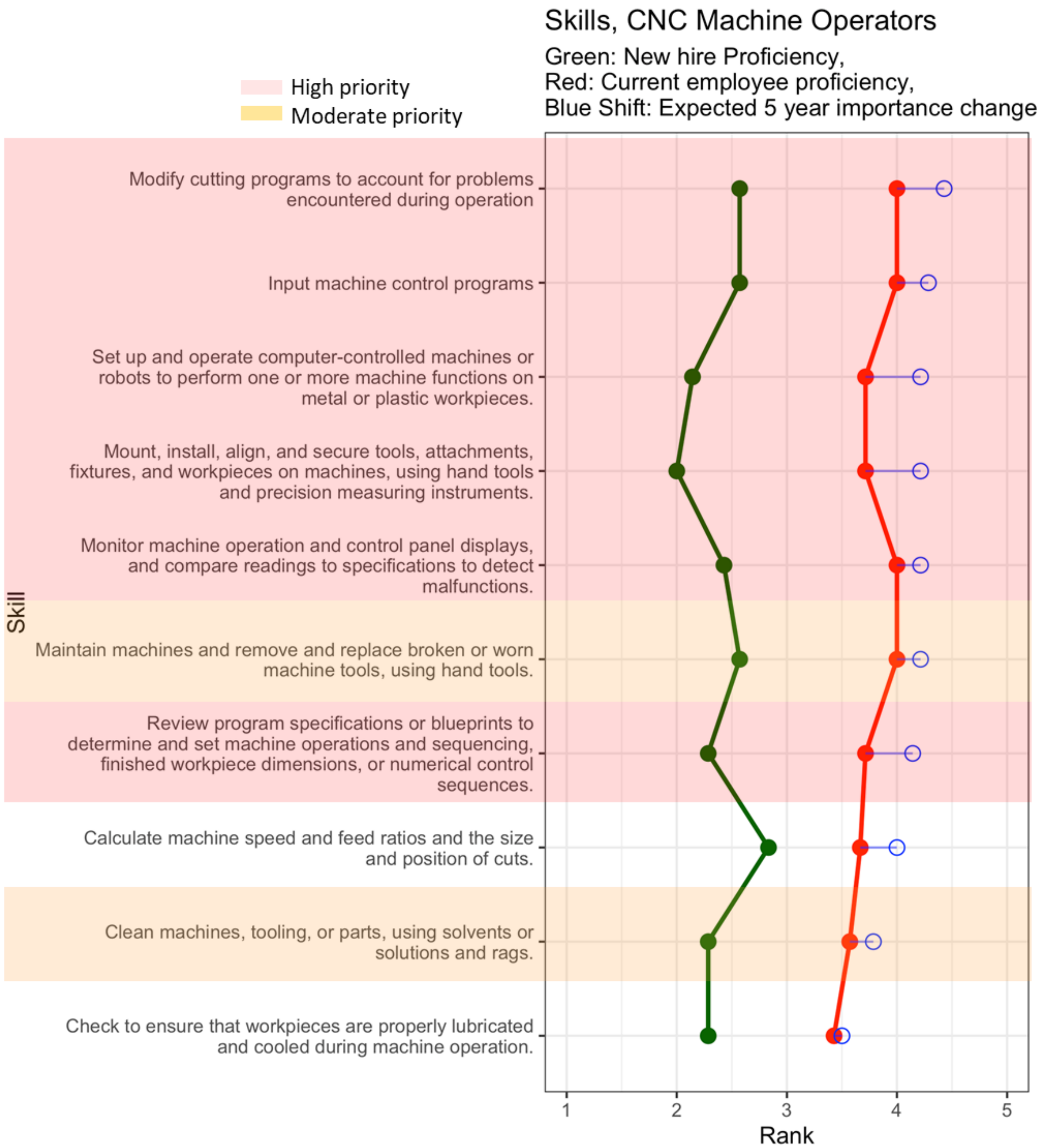

Figure 11. The gaps and expected future importance of skills for CNC tool operators are shown with high priority skills highlighted in red and moderate priority skills highlighted in orange.

Table 9 Recommended changes in the training of CNC tool operators in the FHE industry. The orange skills are those that are ranked as moderate priority and therefore have a skill gap and are also important in the future.

Recommendation	Skill	Full Skill Description
Emphasize training on…	Monitor and maintain machines	Modify cutting programs to account for problems encountered during operation
		Input machine control programs
		Set up and operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic workpieces.
		Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.
		Monitor machine operation and control panel displays, and compare readings to specifications to detect malfunctions.
	Assess specifications or blueprints	Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.
Improve training on…	Machine operation and maintenance	Maintain machines and remove and replace broken or worn machine tools, using hand tools.
		Clean machines, tooling, or parts, using solvents or solutions and rags.
Maintain training/evaluate training on…	Calculate machine speeds and feed ratios	Calculate machine speed and feed ratios and the size and position of cuts.
	Machine operation and maintenance	Check to ensure that workpieces are properly lubricated and cooled during machine operation.

Identifying the high priority skills gaps

Across all positions, there were 15 skills that were classified as high priority – exhibiting both high future importance and a significant skills gap (i.e., the gap between the proficiency of new hires are the level of proficiency needed in the future). These skills and their skills gap are shown in Figure 12 where the blue dot indicates the future proficiency needed and the green dot represents the proficiency of current new hires.

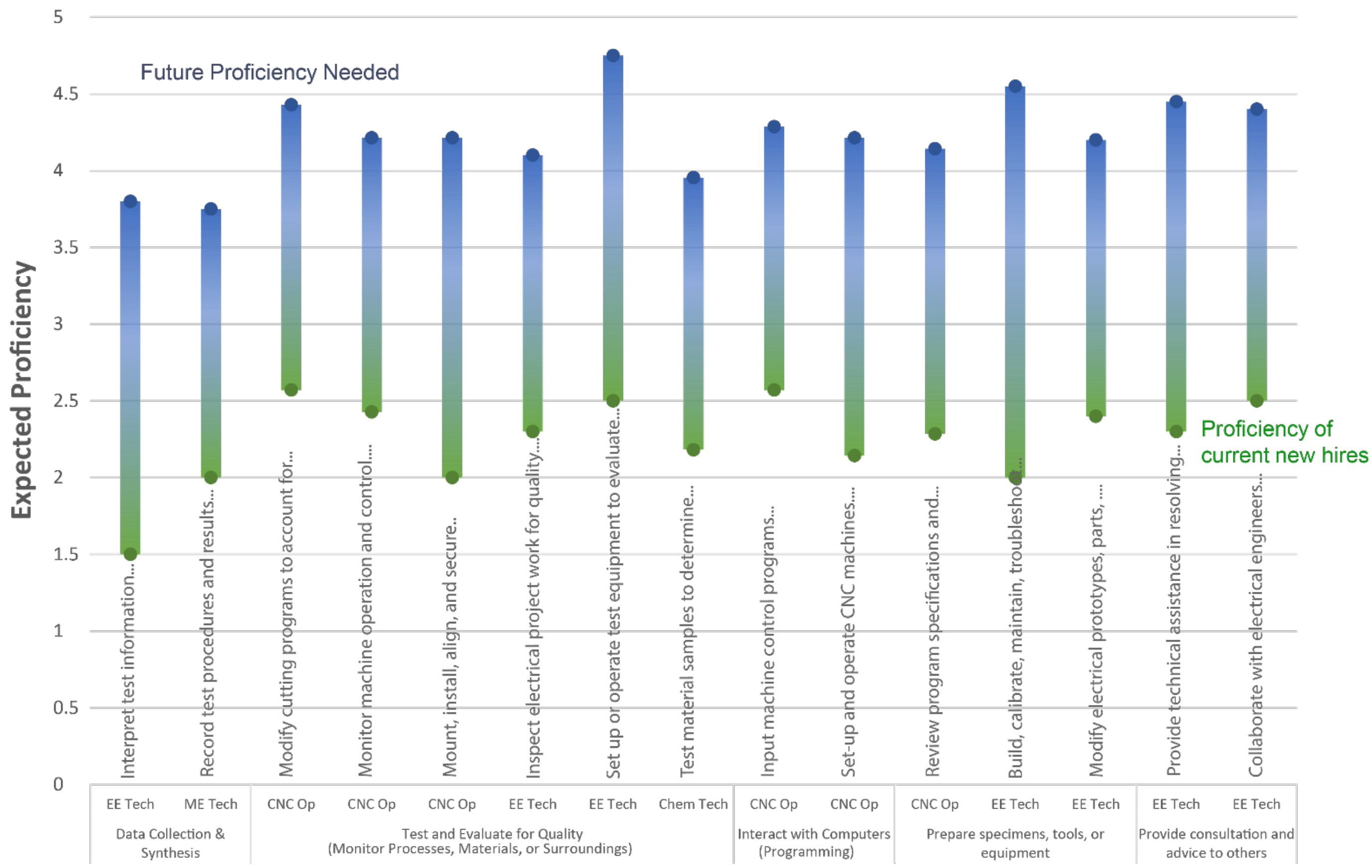

Figure 12 High priority skills across all positions studied in the FHE industry. The green dot represents the proficiency of current new hires and the blue dot represents the future proficiency needed for the middle-skilled level.

These high priority skills are all associated with one of five generalized skill categories. These are:

- Data Collection & Synthesis
- Test and Evaluate for Quality (Monitor processes, materials, or surroundings)
- Interact with Computers (Programming)
- Prepare specimens, tools, or equipment
- Provide consultation and advice to others

Notably, this same set represent four of the five most important generalized skills (see section Identifying Important Common Skills). Firms regularly emphasized the importance of data management, computer, and troubleshooting skills (i.e. data collection and synthesis, interact with computers, provide consultation, and monitor processes) for technicians in this emerging field.

Emerging and Human skill needs

Along with assessing current technical skills for each position, respondents also were asked to consider the importance of specific emerging and human skills for middle-skilled technical workers. Emerging skills were identified through two approaches – review of the workforce development literature and analysis of the BGLI database.

As was noted earlier, delays in access to the BGLI database precluded results from that database from informing the design of the interview template. As such, here we describe the analysis of the BGLI databased for the FHE industry first and then present the results of the industry survey on the importance of the emerging skills identified in the literature (see Figure 14).

Real-Time Skills Analysis from Burning Glass Labor Insight™ (BGLI)

The comparison of the two datasets found that ~80% of the skills and technologies highlighted by the BGLI database (at least 5% of postings for all positions) were present within the O*NET characterization of the focal occupations. Those that were not present were classified as one of the following:

- Emerging skill, tool, or technology: The real-time database captured an emergent skill or technology that has not been updated in the O*NET database.
- Value-added human skill: A human skill that is not specifically captured in the survey conducted here or within the O*NET database. (e.g., customer service or sales skills for technicians) but that is valuable in this industry.
- Value-added cross-training: Skills that are outside of the definition of the specified occupation but which represent valuable additional skills for some employers. (e.g., industrial engineering skills for mechanical engineering technicians)
- Context-specific skills: Skills that are valuable to particular employers because of the specifics of their operations, market, or other business conditions (e.g., HVAC or packaging design skills for mechanical engineering technicians)

The real-time labor market intelligence analytics data complements the O*NET database because it enables the identification of emerging trends in technical skills and knowledge and software skills and technologies in the FHE industry. For each of the relevant positions present in BGLI, the most frequently observed skills are shown in Figure 13. Specifically, Figure 13a shows all skills present in at least 5% of postings for the electrical engineering technicians including both those included in the O*NET framework (dark red columns) and those that are not. To better focus on uniquely identified skills, Figure 13b, c, and d, plot only the skills absent in O*NET for the electrical/electronic (EE), mechanical (ME), and industrial (IE) technicians.

Figure 13 The most frequently observed skills in the BGLI for mechatronics technicians categorized as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific. The skills that were not found in ONET are also shown for each of the positions in b-d.

**Full skill names include: Predictive/Preventative Maintenance, Electronics Industry Knowledge, Programmable Logic Controller Programming, Electrical Diagrams/Schematics, Hardware Experience, Electrical Distribution Systems, Computer Hardware/Software Knowledge, Personal Protective Equipment (PPE).*

Overall, a majority of the technical skills from the BGLI database are well represented in the O*NET database. For electrical/electronic engineering technicians and mechanical engineering technicians, hydraulics was the emerging technical skill found in more than 5% of postings. Cross-training skills that are common and complement conventional disciplinary training include knowledge of other industries such as industrial, electrical, industrial operations, and others. Skills that are context specific across all positions include soldering, welding, HVAC, and plumbing knowledge.

Emerging and Human Skill Interview Results

Because importance was evaluated identically for both emerging and human skills, these results are presented together in Figure 14 and summarized in Table 10. Blue text is used to distinguish human from technical skills.

Emerging skill needs

Along with assessing technical skills for each position, respondents also were asked to consider the importance of emerging skills over the next five years. This same set of skills was presented to respondents for each of the technical occupations. The importance of each of the emerging skills is shown for the operator and technician occupations (see Figure 14).

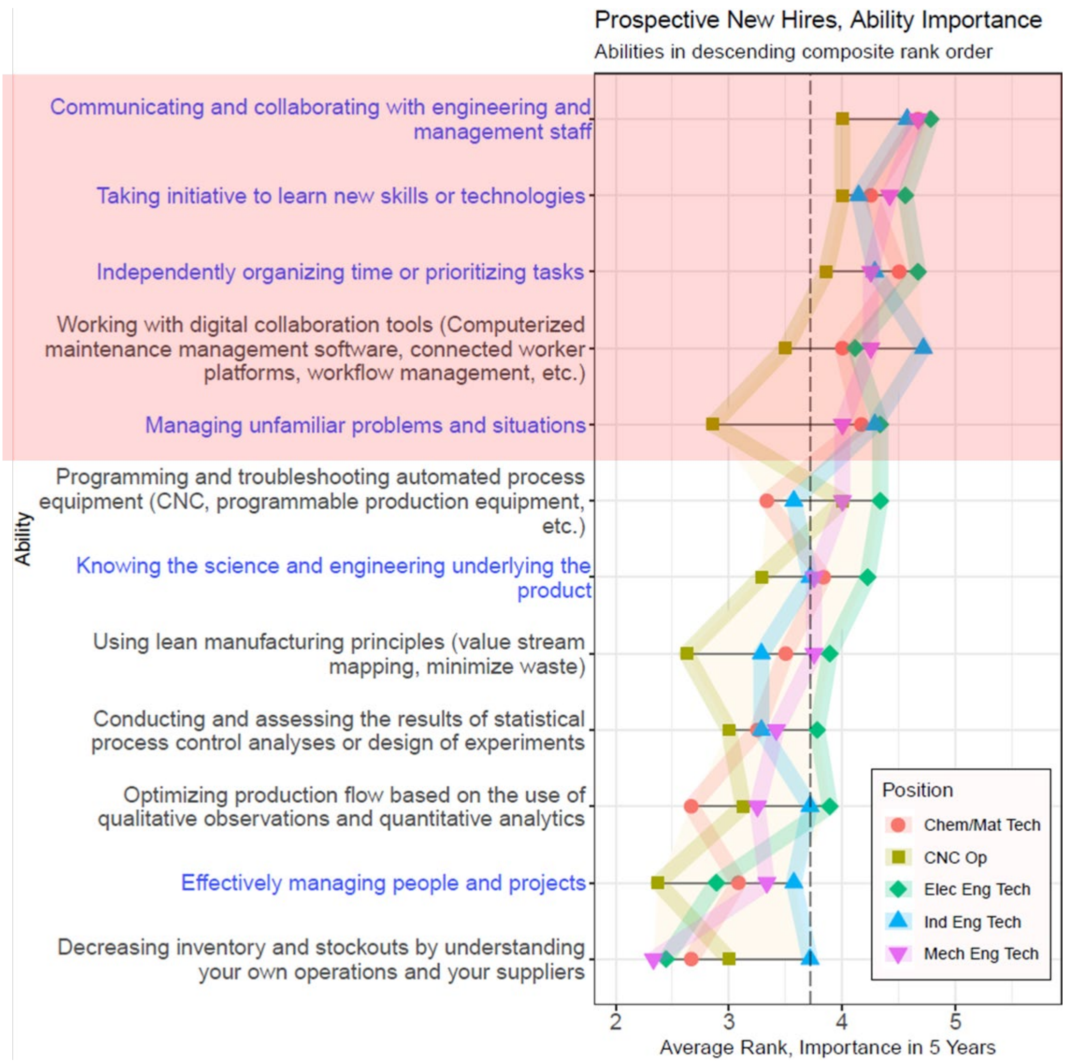

Figure 14 The expected importance of emerging skills was ranked as much less important than now, less important than now, as important than now, more important than now, and much more important than now. The first four skills, highlighted in red, are those that are important across all the positions studied. The remaining skills have varying levels of importance that are specific to each position. Skills in blue represent emerging human skills.

Table 10.Recommendations for emerging skill training across all technicians (red) and for job-specific roles.

Emphasize training for…					Full Skill Description
EE	ME	IE	CNC	Chem /Mat	Communicating and collaborating with engineering and management staff
X	X	X	X	X	Taking initiative to learn new skills or technologies
X	X	X	X	X	Independently organizing time or prioritizing skills
X	X	X	X	X	Working with digital collaboration tools (Computerized maintenance management software, connected worker platforms, workflow management, etc.)
X	X	X		X	Managing unfamiliar problems and situations
X	X		X		Programming and troubleshooting automated process equipment (CNC, programmable production equipment, etc.)
X	X			X	Knowing the science and engineering underlying the product
X	X				Using lean manufacturing principles (value stream mapping, minimize waste)
X					Conducting and assessing the results of statistical process control analyses or design of experiments
X		X			Optimizing production flow based on the use of qualitative observations and quantitative analytics
		X			Effectively managing people and projects
		X			Decreasing inventory stockouts by understanding your own operations and your suppliers

These results indicate that all technician training programs for flexible hybrid electronics should put an emphasis on: 1) communicating and collaborating; 2) taking initiative to learn new skills or technologies; and 3) independently organizing time or prioritizing skills.

FHE firms explained that while these skills can be difficult to teach in a classroom setting, practical experiences such as apprenticeships or internship programs are invaluable. Other emerging skills that respondents emphasized for future technicians include analysis of product failure, recommendations for quality improvement, and statistical process control. Skills such as decreasing inventory stockouts and effectively managing people and projects were expected more for engineers than technicians.

Troubleshooting was found to be one of the most critical skills for all technicians and operators. While some firms don't use troubleshooting as the determining factor for technician hiring at the moment, many firms feel that it is a skill growing in importance and will be vital to the job as technology advances and roles change. For example, firms expect technicians to be able to describe their approach for problem-solving such as debugging a non-functioning component or system. Respondents shared that technicians that have hobbies of assembling and building are the best candidates for technician roles (e.g. fixing cars). Most firms assess the ability to troubleshoot during the interview process to determine whether technicians can think themselves out of a box. Several firms bring technicians in as contractors first to assess performance on the job to determine whether the technician is able to troubleshoot before extending a permanent position. The interview results underscore the value of troubleshooting in the FHE industry.

Critical thinking skill needs

When trying to define what is meant by critical thinking, one definition is "the ability to analyze evidence and facts to form a judgment"(Gambrill 2005). More practically, we can classify these judgments with the following levels of critical thinking:

1. Perceiving the issue – What should I measure or observe to know that a problem exists?
2. Hypothesizing about problem cause – What might be causing the problem?
3. Developing a framework for hypothesis testing – How can I confirm my hypothesis?
4. Inferring whether tests confirm the hypothesis - Does the test suggest that my hypothesis was right?
5. Communicating the outcome – How (and to whom) do I report on what has happened?

Respondents were asked to identify what level of critical thinking is expected of technicians. Responses were grouped by engineering technician positions and other technical workers shown in Figure 15.

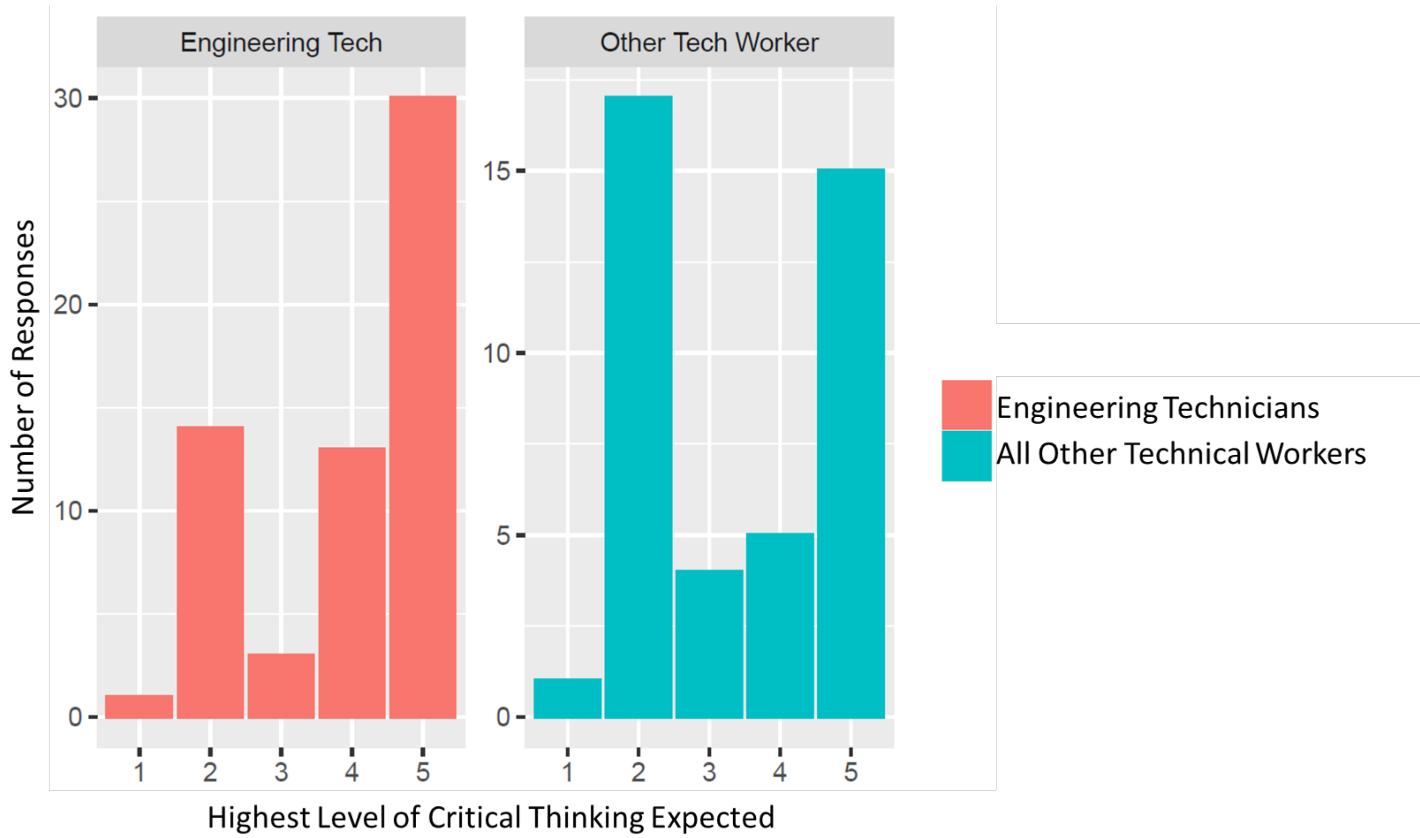

Figure 15. Respondents valued critical thinking skills for all occupations studied. However, most respondents expect a higher level of critical thinking for engineering technicians. While there are respondents that expect the highest level for other technical workers as well, a majority of respondents expect other technical workers to cause hypothesize

FHE firms shared that technicians are critical to solving problems since they are on the manufacturing front line and therefore become very sensitive to problems and develop an intuition on the causes of problems over time. While some firms don't expect technicians to be able to have critical thinking skills at first, they do expect them to be able to develop these skills with time. At a minimum, FHE firms expect all technicians to be able to cause hypothesize. However, there are firms that expect technicians of all types, especially engineering technicians, to be able to determine a problem, communicate that problem with the engineering team, and suggest solutions to the problem. Respondents emphasized that this process is collaborative and therefore it is vital that technicians are able to work with their colleagues to identify a problem and make decisions.

Results indicate that the majority of engineering technicians (71%) are expected to have competency in nearly all aspects of critical thinking (perceiving, hypothesizing, testing, and interpreting testing). Of the total number of responses, 49% of respondents expect engineering technicians to also be able to communicate the outcome of the process. Most other technical production workers are expected to only perceive the issue and hypothesize a cause (47%) while a third of the respondents expected these workers to be able to master all aspects of critical thinking.

A standard practice for technicians at FHE firms is using protocols to calibrate equipment and verify standards. As such, firms recommend that curriculum includes practice on operating machinery, looking at and interpreting data from the machine, detecting if a machine is calibrated to the acceptable level, and reporting the data to the team. The interpretation of data was emphasized across firms and it was recommended that technician training include basic statistics to enable better decision-making. Several firms suggested that virtual reality (VR) or augmented reality (AR) technology could also be leveraged to practice critical thinking and data interpretation with manufacturing simulations.

Identifying Important Common Skills

To understand the skills needed broadly at the middle-skill occupation level, the research team has identified skills that are both shared (common) and important across multiple occupations to enable training programs to be relevant for companies across the FHE supply chain. Figure 16 shows the twelve highest weighted average importance scores for the general task/skill (GTS) level ranked from highest to lowest.

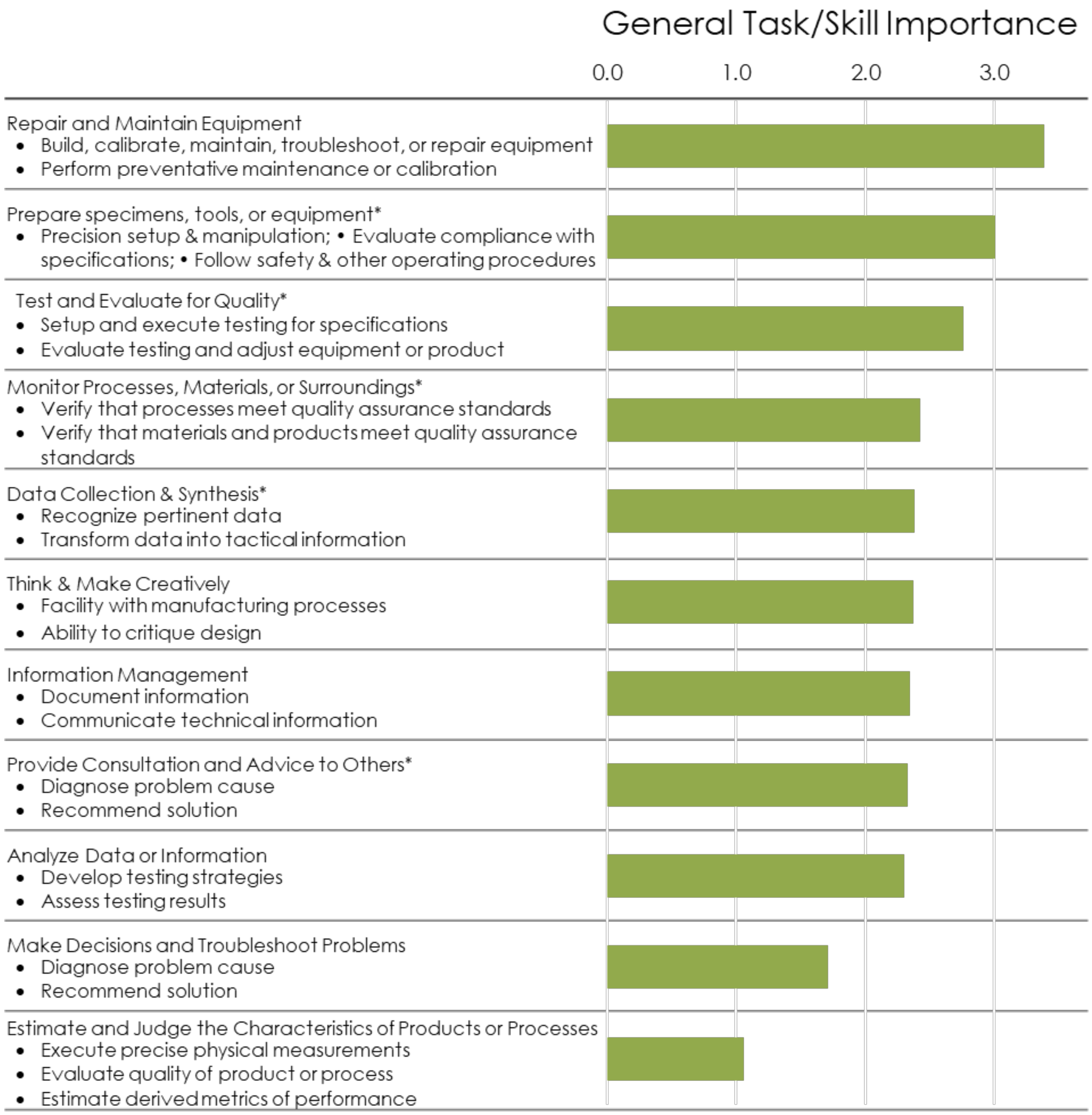

Figure 16 General Task or Skill ranked by weighted average importance of the skills within that class. Only GTS that are shared across at least two occupations are labeled as common and, therefore, included in this figure.

The top three ranked common skills include repair and maintain equipment, prepare specimens, tools or equipment, and test and evaluate for quality. These skills involve an understanding of the entire system from tools to each piece of equipment as well as knowledge of quality testing. The remaining skills emphasize critical thinking and communication and interpretation of technical information. Table 11 to Table 13 provide details on the underlying specific skills associated with these GTS. Details for all GTS are provided in the appendix.

Details on Common Skills

Table 11 shows the underlying categorization and score detail for the two highest ranked GTS, "Repairing and Maintaining Equipment" and "Prepare specimens, tools, or equipment." For repairing and maintaining equipment, there are physical skills required such as "using hand tools" or "build, calibrate, maintain…" But, there are also skills that require troubleshooting skills such as "troubleshoot or repair equipment." This skillset was especially important for electrical engineering technicians and CNC tool operators. For "Prepare specimens, tools, or equipment", the skillset requires physical skills such as preparing solutions, using hand tools, assembling parts, and operating equipment. This GTS was found in the electrical engineering technicians, chemical and materials technicians, CNC tool operators, and mechanical engineering technicians. Most of these skills require the physical workmanship to maintain and service equipment, the cognitive understanding of how the machine functions, and troubleshooting skills to understand how to address malfunctions

Table 11. Details of skill importance for General Task/Skill "Repairing and Maintain Equipment" and "Interacting with Computers" and their sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Repairing and Maintaining Equipment	3.4	Maintain electronic, computer, or other technical equipment.	3.7	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.7			X			
		Maintain tools or equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2						X
Prepare specimens, tools, or equipment	3.0	Assemble equipment or components.	3.7	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.7			X			
		Prepare specimens or materials for testing.	3.6	Prepare chemical solutions for products or processes, following standardized formulas, or create experimental formulas.	3.6				X		
		Disassemble equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2						X
		Position workpieces or materials on equipment.	2.9	Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.	2.9						X
		Set up equipment.	2.7	Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	2.6				X		
		Fabricate devices or components.	2.4	Operate drill press, grinders, engine lathe, or other machines to modify or to fabricate components.	2.5					X	
				Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.3					X	

Table 12 shows the details of the scoring for the third and fourth highest ranked GTS, "Test and Evaluate for Quality" and "Monitor Processes, Materials, or Surroundings." The GTS for test and evaluate for quality is common and important for electrical engineering technicians and mechanical engineering technicians. This skillset includes critical thinking skills and an understanding of quality assurance and testing methods including "verify part dimensions" or "test products for performance." The next GTS is common and important for industrial engineering technicians and CNC tool operators. The skillset of monitoring processes includes critical thinking skills and an understanding of quality assurance including "verifying quality assurance specifications" or "compare readings to specifications to detect malfunctions."

Table 12. Details of skill importance for General Task/Skill "Test and Evaluate for Quality" and "Monitor Processes, Materials, or Surroundings" and their sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Test and Evaluate for Quality	2.8	Test performance of equipment or systems.	3.1	Set up or operate test equipment to evaluate performance of developmental parts, assemblies, or systems under simulated operating conditions.	3.9			X			
				Test equipment, using test devices attached to generator, voltage regulator, or other electrical parts, such as generators or spark plugs.	2.2					X	
		Inspect completed work or finished products.	2.9	Inspect electrical project work for quality control and assurance.	2.9			X			
		Test characteristics of materials or products.	1.7	Test products for performance characteristics or adherence to specifications.	1.7		X				
Monitor Processes, Materials, or Surroundings	2.4	Monitor equipment operation.	2.7	Monitor machine operation and control panel displays, and compare readings to specifications to detect malfunctions.	3.2						X
				Check to ensure that workpieces are properly lubricated and cooled during machine operation.	2.2						X
		Monitor operations to ensure adequate performance.	2.4	Verify that equipment is being operated and maintained according to quality assurance standards .	2.4		X				
		Monitor operations to ensure compliance with regulations or standards.	1.9	Read worker logs, product processing sheets, or specification sheets to verify quality assurance specifications.	1.9		X				

Table 13 details the final important common skill "Data Collection & Synthesis." For data collection & synthesis, cognitive processing of specifications and blueprints is necessary as well as an understanding of underlying "knowledge of electronic theory and components." This skillset was particularly important for engineering technicians and CNC tool operators.

Table 13. Details of skill importance for General Task/Skill "Data Collection and Synthesis" and its sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Data Collection & Synthesis	2.4	Read documents or materials to inform work processes.	2.4	Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.	2.8						X
				Review project instructions and blueprints to ascertain test specifications, procedures, and objectives	2.1					X	

Results Summary

Semi-structured interviews with operations managers in the flexible and hybrid electronics (FHE) industry from twenty-one firms across the U.S. were conducted to identify workforce needs within the FHE supply chain. The interviews were focused on middle-skilled technical occupations (except for information technology occupations). Firms emphasized the skills gaps, hiring and training challenges, and the importance of specific technical and human skills relevant to the FHE industry.

Firms expect increasing demand for all middle-skilled technical workers evaluated in this study, especially for electrical engineering technicians While only a few firms (14%) identified mechatronics technicians as relevant in their operation, those firms expected significant growth in openings for mechatronic technicians.

An econometric analysis was performed to understand the growth trends in the FHE industry by estimating the expected number of positions and openings within the industry. Data from the US Bureau of Labor Statistics, market intelligence reports, and survey responses were used to project both anticipated positions and openings. We estimate middle-skilled positions within this industry to grow from around 1,000 today to 2,500 by the end of the decade. This translates to over 3,300 cumulative openings for middle skilled technical workers or around 300 new middle-skilled workers per year. Assuming a typical training program graduates about 15 students per year, the US would need more than 20 programs to meet the demand of this industry. In a Massachusetts context, we estimate around 100 total openings in these positions for this sector. This translates to about 10 middle-skilled openings per year, indicating the need for an educational program to train middle-skilled technical workers for the state's FHE industry.

Respondents indicated significant hiring challenges for all technical, middle-skilled workers as well as the need for extensive on-the-job training across the board. The occupation that exhibited the most significant hiring and training challenges and that was broadly employed across firms was the electrical engineering technician.

Emerging and human skill importance was evaluated for each position including a critical thinking needs assessment. An emerging technical skill that was emphasized across all positions was working with digital collaboration tools. Human skills are also growing in importance for technicians in the FHE industry. In particular, interview responses indicate that the following skills should be emphasized in training:

- Communicating and collaborating with engineering and management staff
- Taking initiative to learn new skills or technologies
- Independently organizing time or prioritizing skills

FHE firms shared that technicians are critical to solving problems since they are on the manufacturing front line and therefore become very sensitive to problems and develop an intuition on the causes of problems over time. While some firms don't expect technicians to be able to have critical thinking skills at first, they do expect them to be able to develop these skills with time. Results indicate that the majority of engineering technicians (71%) are expected to have competency in nearly all aspects of critical thinking (perceiving, hypothesizing, testing, and interpreting testing). Of the total number of responses, 49% of respondents expect engineering technicians to also be able to communicate the outcome of the process. Most other technical production workers are expected to only perceive the issue and hypothesize a cause (47%) while a third of the respondents expected these workers to be able to master all aspects of critical thinking.

We highlight the specific technical skills that are both increasingly important and exhibit skills gaps for five occupations: mechanical engineering technicians, electrical engineering technicians, industrial engineering technicians, chemical/materials technicians, and CNC tool operators.

Because the interviews focused on skills described in the Bureau of Labor Statistics O*Net dataset, it was possible to not only identify job-specific skills but also to use the taxonomy within that dataset to aggregate survey responses to more generalized classes of skills (referred to as General Task/Skill, GTS).

Looking across all middle-skilled positions, the top five generalized skills that are expected to be the most important for middle-skilled workers in the FHE industry are:

- Repair and Maintain Equipment
- Prepare specimens, tools, or equipment*
- Test and Evaluate for Quality*
- Monitor Processes, Materials, or Surroundings*
- Data Collection & Synthesis*

To get a better understanding of where training resources would be best applied, we also examined whether important skills also exhibited a significant skills gap (difference between competency of new hires and that required by industry). As shown in Figure ES 4, four of the most important GTS categories of skills were also frequently flagged as exhibiting a significant skills gap.

An emphasis in training these skills that exhibit significant training gaps, importance, and are common among multiple positions would add value to the FHE workforce. Data collection and synthesis as well as interacting with computers suggests improved training in data management as well as programming to perform multiple functions. Preparing specimens, tools, or equipment involves the ability to follow operating procedures and safety guidelines and attention to detail. Technicians in the FHE industry should also improve knowledge of quality, attention to detail, and knowledge of testing.

For middle-skilled workers in the FHE industry, the analysis of generalized skills points to the growing importance of the abilities to operate, maintain, and troubleshoot equipment, to program computers and equipment, ensure quality standards, and to collect and synthesize data.

The results from this study demonstrate the growing opportunity for technical careers in the FHE industry across the U.S. and areas of improvement for the training and skills development for those pursuing FHE careers.

Appendix

Literature review and gap analysis

Past efforts to characterize skills gaps and fulfill workforce needs have been successful in increasing employment opportunities specifically for middle-skilled workers. In Pennsylvania, a National Science Foundation (NSF) grant provided funding to develop community college programs in the area of nanofabrication (Hallacher, Fenwick, and Fonash 2002) through professional development workshops for educators and new curricula for students. Through these efforts, community college graduates from targeted nanofabrication programs received more than seven job offers on average upon graduation. There were also regional benefits of new nanofabrication facilities locating to Pennsylvania as a result of the increased workforce and skill development of Pennsylvania community college graduates. In an NSF funded workshop for additive manufacturing (AM), stakeholders evaluated the current state, workforce needs, and future trends to inform research and education and training for the upcoming workforce (Huang et al. 2015) . Their findings suggest the university-community college partnership model can enable a well-trained AM workforce through sharing of lectures, knowledge via educator workshops, web resources, and laboratory spaces for hands-on training. Participants in the workshop recommended future funding opportunities through America Makes, the NSF, and other federal agencies for AM education and curricula development. With support for feeder programs, a stable workforce of well-trained, low-cost, entry-level technicians will continue to grow (Foy and Iwaszek 1996). In addition to curricula development, internship opportunities will also be necessary for the up-and-coming workforce to obtain the on-the-job experience necessary to fill these critical gaps (Hardcastle and Waterman-Hoey 2010).

While curricula have been developed for emerging manufacturing areas in the past (e.g. nanofabrication), this is the first development of a roadmap method to assess workforce gaps and needs across several advanced manufacturing industries. This research provides a method to classify emerging advanced manufacturing industries, identify companies within the industry, and leverage industry expertise to inform workforce development needs. In BLS, these emerging manufacturing industries are organized broadly, and as a result, the industries are not immediately apparent. To address these limitations, we've developed a systematic, data-driven method for classifying advanced manufacturing industries and an industry stakeholder informed education roadmap on current priority and future accelerating jobs and training needs. The education roadmap will provide recommendations for community college, certificate programs, and instructors on how to upgrade their photonics curricula and matriculate more competitive technician candidates, for targeted hiring in photonics industry clusters across the US. This method is performed in four steps: 1) classification of emerging advanced manufacturing industries, 2) survey development leveraging industry expertise, 3) survey assessment by experts, and 4) survey distribution, response analysis and recommendations. To demonstrate the method for classifying and assessing employment needs for an advanced manufacturing industry, the method is applied to a case study of the photonics industry.

Detailed Methods

To characterize workforce needs within advanced manufacturing industries we have relied primarily on interviewing firms within that industry. Development and deployment of the semi-structured interview followed a process involving four major steps.

Discern emerging advanced manufacturing industries

The discernment process aims to identify a sufficiently large sample of firms that are representative of the advanced manufacturing sector of interest and to identify how these firms are currently classified in some relevant industrial classification system. This classification system will be referred to as the discernment system. This information will play two roles in subsequent analyses. First these firms will be the target of surveys and interviews. Second, the classifiers associated with these firms will be used to estimate employment intensity from BLS databases.

The first step in this classification process was to identify firms that are representative for the industry of interest. We refer to these firms as archetypes. This is an inherently manual, expert-based process. For the FHE industry, archetype firms were identified through a number of methods, including querying member listing from relevant professional associations[5] and expert elicitation. Once archetypes were identified, they were queried within the discernment system. The most common economic activity type (EAT) codes associated with those firms within the discernment system were cataloged. This set of codes serves as one definition of our industry of interest and were used to identify a larger set of similar firms.

[5] In this case, we specifically queried the membership roster of NextFlex, a Manufacturing USA institute based in San Jose, CA.

To leverage data catalogued by the US BLS, firms must be identified using the North American Industrial Classification System (NAICS)(Dalziel 2007). If the discernment system is not NAICS (as it was not in our case study here), then it is necessary to create an empirical mapping between the two systems. Here we do this by using the discernment system to identify a larger set of firms of the same type as the archetypes and then identifying the prevailing NAICS codes used to characterize those firms.

The North American Industrial Classification Systems (NAICS)

Industry classification systems reflect a country's economic output, trade, and employment (Dalziel 2007). The NAICS is a framework that is used widely for firm classification. NAICS was developed in 1997. It captures a large number of business types including those in the service industry (BLS). In the NAICS system, firms are identified using their production processes and the codes are updated every five years to reflect changes in industry titles and descriptions. The industries and sectors are classified with two to six digits, where the higher number of digits represents a greater detailed classification of the industry.

While the NAICS system may be more representative than its predecessor, the SIC system, many researchers have found limitations in classifying industries based on their production processes (Kile and Phillips 2009). For instance, Dalziel (2007) explains that eight non-diversified communications equipment manufacturers are classified in four separate industries and two separate sectors despite being major competitors. Other limitations include addressing the rapid changes in technology advancements. While there are many different types of software companies, all firms that develop software are classified with the same code, 511210, Software Publishers (Dalziel 2007). In classifying emerging industries, such as those in the advanced manufacturing space, it can be challenging to identify the boundaries of the industry and assign a NAICS code that is accurately representative of a firm's activities. For example, when searching the NAICS database for "photonics", the NAICS code assigned is 541715, Research and Development in the Physical, Engineering, and Life Sciences (except Nanotechnology and Biotechnology). Although photonics can be classified under this code, botany and agricultural research also share this classification. This shows yet another limitation of the NAICS system; the NAICS codes are often too broad to capture the specifics of an emerging industry. As a result, it can be difficult to capture the current employment statistics for an advanced manufacturing industry and understand the existing workforce gaps.

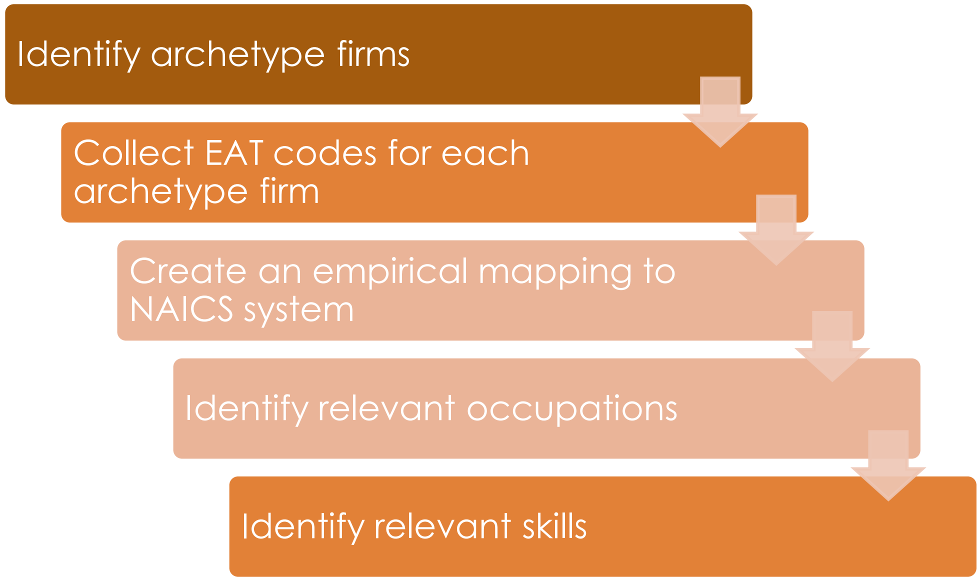

Figure 17 5-step process for discerning emerging advanced manufacturing industries.

The global FHE industry is expected to reach $44.8 billion by 2026 (Global Industry Analysts Inc 2021)). Table 14 lists eight companies that were identified as archetypes for the FHE industry.

EAT codes for several industrial classification systems were collected for each archetype firm using the D&B Hoovers business database (Dun and Bradstreet 2020). Here we elected to use the D&B Hoovers Proprietary SIC 8-digit Code (SIC8) classification system (Cramer 2017), an expansion of the original SIC system, to discern the industry. Table 14 shows the SIC8 and NAICS EAT codes for the archetype firms. If a primary and secondary code are provided, both codes are listed. This process was repeated for all the archetype companies for the industry to help develop a description of the firms based on the industrial classification codes.

Table 14 FHE industry classification archetype examples

Company	US Standard Industrial Classification – DB Hoovers Expanded Version (SIC8)	North American Industrial Classification System (NAICS)
Croda	28990000 – Chemical preparations, nec	325998 -- All Other Miscellaneous Chemical Product and Preparation Manufacturing
Lux Semiconductors	36740000 – Semiconductors and related devices	334413 – Semiconductor and Related Device Manufacturing
DuPont	28210200 – Thermoplastic materials	325211 – Plastics Material and Resin Manufacturing
SI2 Technologies	35990000 – Industrial machinery, nec	333999 – All Other Miscellaneous General-Purpose Machinery Manufacturing
Human Systems Integration	38290000 – Measuring and controlling devices, nec	333249 - Other Industrial Machinery Manufacturing
Flex	36720000 – Printed circuit boards	334519 – Other Measuring and Controlling Device Manufacturing
Analog Devices	36740200 – Integrated circuits, semiconductor networks, etc.	334413 – Semiconductor and Related Device Manufacturing
Averatek	36720000 – Printed circuit boards	334418 – Printed Circuit Assembly (Electronic Assembly) Manufacturing

Using the D&B Hoovers companies database, we identified the 395 unique firms with more than 20 employees that are classified by one of the 8 SIC8 codes. These firms are classified into one of seven NAICS codes. These three codes are listed in Table 15. Occupation data available from the BLS is organized in a truncated version of NAICS, with most industries organized at the three- or four-digit level. As such, Table 15 also lists the three BLS equivalent codes that capture this same scope for the FHE industry.

Table 15. Most common NAICS codes for firms identified as in the FHE industry. These codes capture 85% of firms identified.

NAICS Code	NAICS Description	BLS Equivalent Code
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	325000
333999	All Other Miscellaneous General-Purpose Machinery Manufacturing	3330A1
334413	Semiconductor and Related Device Manufacturing	334400
325211	Plastics Material and Resin Manufacturing	325000
334519	Other Measuring and Controlling Device Manufacturing	334500
333249	Other Industrial Machinery Manufacturing	3330A1
334418	Printed Circuit Assembly (Electronic Assembly) Manufacturing	334400

In summary, we discern the FHE industry as firms classified as one of the 82 codes within the SIC8 system which maps to the four BLS equivalent industrial classification codes 3330A1, 334400, 325000, and 334500. Effectively, we are defining the industry of interest as a hybrid of these industries. This hybrid industry description, will be used to identify relevant occupations.

Posit Relevant Occupations and Skills

Identify Relevant Occupations

To leverage the extensive surveying knowledge embedded within the O*NET database(U.S. Department of Labor 2020), we use the BLS equivalent NAICS codes to identify a relevant set of occupations for our industry of interest.

Specifically, occupation codes were identified using a combination of the 2018 National Employment Matrix (NEM) (U.S. Bureau of Labor Statistics 2018) and the O*NET database. Using this dataset, we identified occupations that met the following criteria:

- Associated with the industry of interest (as defined by the codes identified previously)
- Technical in nature (see next paragraph)
- Primarily held by middle-skilled workers (see two paragraphs down)
- Represented more than 0.1% of the workforce across the defined industry

The definition of technical work is inherently subjective. For our purposes here, we limit our search to jobs associated with the Standard Occupational Classification (SOC) codes listed in Table 16. That includes occupations involved in mathematics, architecture, engineering, life, physical, and social sciences, installation, maintenance, repair, and production. Computer related positions were excluded because in early test interviews we learned that skills for those positions would not be influenced by the specific industry.

Table 16. Standard Occupational Classification codes considered in this study.

Standard Occupation Classification Code (2-digit level)	Class Name
15-0000	Computer and mathematical occupations (excluding 15-1: Computer occupations)
17-0000	Architecture and engineering occupations
19-0000	Life, physical, and social science occupations
49-0000	Installation, maintenance, and repair occupations
51-0000	Production occupations

Middle-skilled workers are often defined as those with an education level that is greater than a high school diploma and less than a Bachelor's degree (Fuller and Raman 2017). Occupations are always held by workers with a range of education. For this research, we define middle-skilled occupations to be those for which both greater than 30% of the workforce is middle skilled and less than 50% of the workforce is either lower-skilled or upper-skilled.

Based on these definitions, we identified 18 relevant middle-skilled positions associated with the FHE industry. To facilitate survey data collection, these were grouped into eight representative positions, as shown in bold in

Table 17. This set includes five types of engineering technicians – electrical / electronic, electro-mechanical, industrial, mechanical, and chemical– as well as technical maintenance personnel (e.g., mechanics, electricians), computer-numerical-controlled machine operators, and machinists.

Table 17. Focal occupations that were evaluated in this study. Bold titles represent representative occupations that were served as proxy for the subsequent specific occupations.

Occupation	Standard Occupation Classification Code
Middle-skilled	
Electrical and electronics engineering technicians(representing)	
Electrical and electronics engineering technicians	17-3023
Electrical and electronics drafters	17-3012
Electro-mechanical technicians	17-3024
Industrial engineering technicians(representing)	
Industrial engineering technicians	17-3026
Aerospace engineering and operations technicians	17-3021
Mechanical engineering technicians(representing)	
Mechanical engineering technicians	17-3027
Mechanical drafters	17-3013
Chemical/materials technicians (representing)	
Chemical technician	19-4031
Materials scientist	19-2032
Maintenance and Support Technicians (representing)	
Industrial machinery mechanics	49-9041
Maintenance workers, machinery	49-9043
HVAC mechanics and installers	49-9021
Mobile heavy equipment mechanics, except engines	49-3042
Electrical & electronics repairers, commercial & ind. equipment	49-2094
Computer-controlled machine tool operators(representing)	
Computer-controlled machine tool operators	51-4011
Computer numerically controlled machine tool programmers	51-4012
Other Technical Production Worker (representing)	
Machinists	51-4041
Tool and die makers	51-4111

Identify Relevant Skills

For each identified occupation, an associated set of competencies (skills) and tools was developed from the U.S. Department of Labor O*Net database, an online tool for career exploration and job analysis (U.S. Department of Labor 2020). The O*Net database uses a hierarchical taxonomic approach to organize tasks and skills. (Peterson et al. 2001). The database was originally developed through survey methods to create a relational database of occupation attributes for the U.S. economy (Peterson et al. 2001)and helps create a common language for job descriptors. An example of tools and competencies collected is shown in Figure 18 for an Electrical Engineering Technician.

Electrical Engineering Technician

Competencies:

- Diagnose, test, or analyze the performance of electrical components, assemblies, or systems.
- Calculate design specifications or cost, material, and resource estimates, and prepare project schedules and budgets.
- Compile and maintain records documenting engineering schematics, installed equipment, installation or operational problems, resources used, repairs, or corrective action performed.
- Set up and operate standard or specialized testing equipment.
- Review, develop, and prepare maintenance standards.
- Install or maintain electrical control systems, industrial automation systems, or electrical equipment, including control circuits, variable speed drives, or programmable logic controllers.
- Design or modify engineering schematics for electrical transmission and distribution systems using computer-aided design (CAD) software.
- Supervise the construction or testing of electrical prototypes, according to general instructions and established standards.

Tools:

- Microcontrollers (e.g., Programmable logic controllers PLC)
- Electronic measuring probes (e.g., Probe stations)
- Multimeters
- Voltage or current meters (e.g., Analog current meters, Digital voltmeters DVM, Standing wave ratio SWR meters)
- Network analyzers
- Frequency analyzers (e.g., Spectrum analyzers)
- Frequency counters or timer or dividers (e.g., Microwave frequency counters)
- Reflectometers (e.g., Optical time domain reflectometers OTDR)
- Signal generators
- Development environment software
- Program testing software
- Analytical or scientific software

Figure 18 Competencies and tools associated with the job title electrical engineering technician.

Emerging Technical Skills

While the O*NET database provides valuable insight into the current technical skills needed for these occupations, the research team also wanted to get a sense of what skills are emerging as important within the FHE industry.

To accomplish this, we made use of two methods to identify potentially relevant emerging skills. The first method relied on discussions of the changing nature of work within the academic literature. Specifically, based on information within MIT Production in the Innovation Economy (PIE) survey (Weaver and Osterman 2017), the essential skills framework used by the Canadian government (Government of Canada 2015), and the Future of Work report (Autor, Mindell, and Reynolds 2020). Based on the authors' synthesis of these reports, we identified the following skills as potentially relevant and emerging for technical middle-skilled workers in manufacturing:

- Programming and troubleshooting automated process equipment (CNC, programmable production equipment, etc.)

- Conducting and assessing the results of statistical process control analyses or design of experiments
- Optimizing production flow based on the use of qualitative observations and quantitative analytics
- Using lean manufacturing principles (value stream mapping, minimize waste)
- Decreasing inventory and stockouts by understanding your own operations and your suppliers
- Working with digital collaboration tools (Computerized maintenance management software, connected worker platforms, workflow management, etc.)

The second method was to make use of a real-time labor market intelligence analytics database to identify emerging skills for each occupation. Burning Glass Labor Insight™ (BGLI) collects job posting data from job boards, firm websites, and job ad websites that represent more than 40,000 online resources and 3.4 million jobs (Burning Glass Technologies 2021). Duplicate postings are removed and natural language processing methods extract the in-demand occupations, skills, and credentials. Two approaches were used to identify relevant skills list from the BGLI database. It is important to note that while we did not specifically include tools and technologies in our interviews due to limited time; however, knowledge of in-demand tools and technologies can help inform trends in the FHE industry.

In the first approach, referred to as a keyword-based query, we attempted to identify relevant skills by querying middle-skilled posting associated with manufacturing and with the keywords representing the FHE industry. Specifically, we applied the filters shown in Table 18which yielded 451,683 job postings. Finally, we added a filter where the job title must include "technician" resulting in 147,958 postings. Comparison between these two queries (with "technician" and without), helped to highlight technician-specific skills and isolate skills that are typical for all types of middle skilled positions within the industry (e.g. Microsoft Office Suite).

Table 18 Filter criteria applied for relevant education levels and keywords in the Labor Insight™ database.

Criteria	**Filter Applied**
Time Period	07/01/2016-06/31/2021
Education	High school or vocational training or Associate's degree
Industry	Manufacturing
Keywords	Electronic(s), printed electronics, printed circuit board, flexible electronics, hybrid electronics, wearable devices
Location	Nationwide

Title includes	Technician

In a second approach, referred to as an employer-based query, we searched for relevant and current skills by querying postings specifically associated with the two middle-skilled technician positions identified within BGLI –industrial/mechanical engineering technician or general engineering technician – and with firms specifically known to be in the FHE industry. The filtering on employer and types of occupations as shown in Table 19, resulting in 446,091 job postings. To once again narrow the search and reduce noise in the dataset, the "technician" filter was added, reducing the number of postings to 1,534.

Table 19 Filter criteria applied for relevant employers and occupations in the Labor Insight™ database.

Criteria	Filter Applied
Time Period	07/01/2016-06/31/2021
Occupation(s)	General engineering technician or industrial/mechanical engineering technician
Employer	64 FHE firms
Location	Nationwide
Title includes	Technician

The top 200 technical skills and software skills were identified from both approaches and compared with the O*NET tasks, detailed work activities, tools (and examples), and technologies (and examples) associated with the three technician positions found in both databases: electrical engineering technicians, mechanical engineering technicians, and industrial engineering technicians.

To identify skills not represented in the O*NET database, we performed a two-stage assessment. First, an NLP tool, UDPipe in R (Wijffels 2021), was used to lemmatize the text of both the BGLI skills and the O*NET data and, then, to identify matches between the two. Matches and partial matches of at least 25% commonality were flagged for human evaluation. Based on this, skills or tools that were present in BGLI but not in O*NET were flagged to ensure all emerging skills, tools, and technologies are identified to inform curriculum development and training.

The O*NET database is a source of comprehensive job classification information with detail and context that is needed for in person interviews. The BGLI data is uniquely able to identify emergent skills and technologies in the field, but the information can require effort to contextualize given their brevity and occasional specificity. Overall, O*NET and Burning Glass Labor Insight™ complement one another in the skills gap analysis for the FHE industry.

Delays in accessing the BGLI database and the pressing need to deliver results in a timely manner, resulted in BGLI results not being available before interviews began. As such, for this report, we were unable to explicitly include emerging skills flagged by the BGLI analysis within industry interviews. While there were very few such skills that were absent from the survey questions, it is still important to identify them. As such, we call these out in Figure 19-Figure 21 and recommend that all programs monitor the importance of these skills to their local industry.

Electrical Engineering Technician

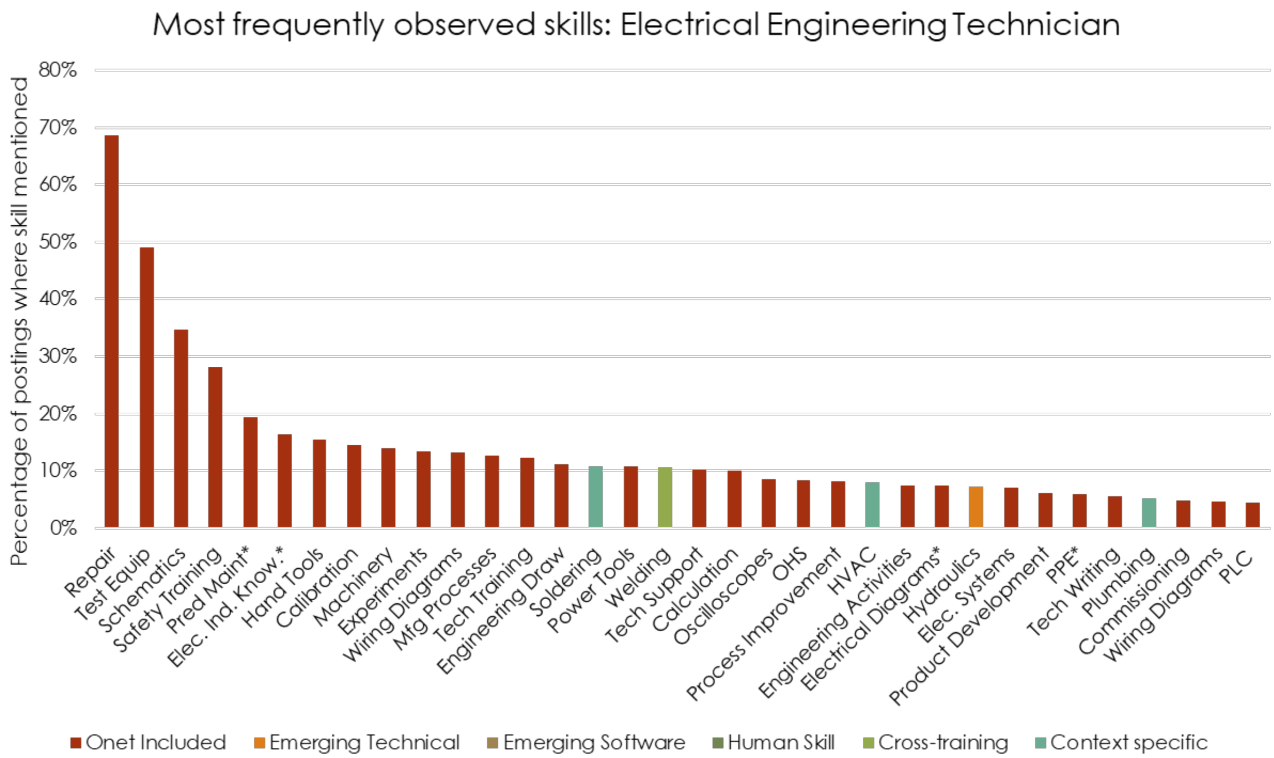

Figure 19 The most frequently observed skills for electrical engineering technicians classified as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific.

Table 20 Skills in at least 5% of postings for electrical engineering technicians from the employer and keyword approach. The maximum percentage of postings where the skill was mentioned was reported.

Skill	Skill Category	Percent of postings skill mentioned
Repair	ONET Included	69%
Test Equipment	ONET Included	49%
Schematic Diagrams	ONET Included	35%
Safety Training	ONET Included	28%
Predictive / Preventative Maintenance	ONET Included	19%
Electronics Industry Knowledge	ONET Included	16%
Hand Tools	ONET Included	15%

Calibration	ONET Included	15%
Machinery	ONET Included	14%
Experiments	ONET Included	13%
Wiring	ONET Included	13%
Manufacturing Processes	ONET Included	13%
Technical Training	ONET Included	12%
Engineering Drawings	ONET Included	11%
Soldering	Context Specific	11%
Power Tools	ONET Included	11%
Welding	Cross-training	11%
Technical Support	ONET Included	10%
Calculation	ONET Included	10%
Oscilloscopes	ONET Included	9%
Occupational Health and Safety	ONET Included	8%
Process Improvement	ONET Included	8%
HVAC	Context Specific	8%
Engineering Activities	ONET Included	7%
Electrical Diagrams / Schematics	ONET Included	7%
Hydraulics	Emerging Technical	7%
Electrical Systems	ONET Included	7%
Product Development	ONET Included	6%
Personal Protective Equipment (PPE)	ONET Included	6%
Technical Writing / Editing	ONET Included	5%
Plumbing	Context Specific	5%
Commissioning	ONET Included	5%
Wiring Diagrams	ONET Included	5%
Programmable Logic Controller (PLC) Programming	ONET Included	5%

Mechanical Engineering Technician

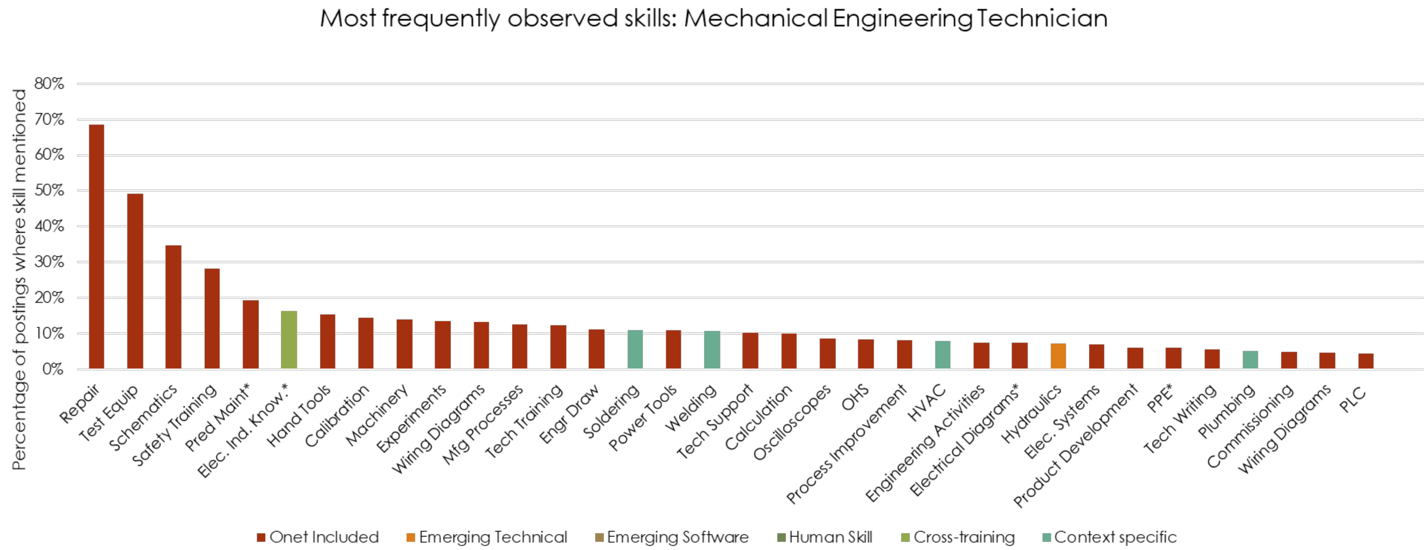

Figure 20 The most frequently observed skills for mechanical engineering technicians classified as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific.

Table 21 Skills in at least 5% of postings for mechanical engineering technicians from the employer and keyword approach. The maximum percentage of postings where the skill was mentioned was reported.

Skill	Skill Category	Percentage of postings skills mentioned
Repair	ONET Included	69%
Test Equipment	ONET Included	49%
Schematic Diagrams	ONET Included	35%
Safety Training	ONET Included	28%
Predictive / Preventative Maintenance	ONET Included	19%
Electronics Industry Knowledge	Cross-Training	16%
Hand Tools	ONET Included	15%
Calibration	ONET Included	15%
Machinery	ONET Included	14%
Experiments	ONET Included	13%
Wiring	ONET Included	13%
Manufacturing Processes	ONET Included	13%
Technical Training	ONET Included	12%
Engineering Drawings	ONET Included	11%
Soldering	Context Specific	11%
Power Tools	ONET Included	11%
Welding	Context Specific	11%
Technical Support	ONET Included	10%
Calculation	ONET Included	10%
Oscilloscopes	ONET Included	9%

Occupational Health and Safety	ONET Included	8%
Process Improvement	ONET Included	8%
HVAC	Context Specific	8%
Engineering Activities	ONET Included	7%
Electrical Diagrams / Schematics	ONET Included	7%
Hydraulics	Emerging Technical	7%
Electrical Systems	ONET Included	7%
Product Development	ONET Included	6%
Personal Protective Equipment (PPE)	ONET Included	6%
Technical Writing / Editing	ONET Included	5%
Plumbing	Context Specific	5%
Commissioning	Emerging Technical	5%
Wiring Diagrams	ONET Included	5%
Programmable Logic Controller (PLC) Programming	ONET Included	5%
Repair	ONET Included	69%
Test Equipment	ONET Included	49%
Schematic Diagrams	ONET Included	35%
Safety Training	ONET Included	28%
Predictive / Preventative Maintenance	ONET Included	19%
Electronics Industry Knowledge	Cross-Training	16%
Hand Tools	ONET Included	15%
Calibration	ONET Included	15%
Machinery	ONET Included	14%
Experiments	ONET Included	13%
Wiring	ONET Included	13%
Manufacturing Processes	ONET Included	13%
Technical Training	ONET Included	12%
Engineering Drawings	ONET Included	11%
Soldering	Context Specific	11%
Power Tools	ONET Included	11%
Welding	Context Specific	11%
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HVAC	Context Specific	8%
Engineering Activities	ONET Included	7%

Electrical Diagrams / Schematics	ONET Included	7%
Hydraulics	Emerging Technical	7%
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Product Development	ONET Included	6%
Personal Protective Equipment (PPE)	ONET Included	6%
Technical Writing / Editing	ONET Included	5%
Plumbing	Context Specific	5%
Commissioning	Emerging Technical	5%
Wiring Diagrams	ONET Included	5%
Programmable Logic Controller (PLC) Programming	ONET Included	5%

Industrial Engineering Technicians

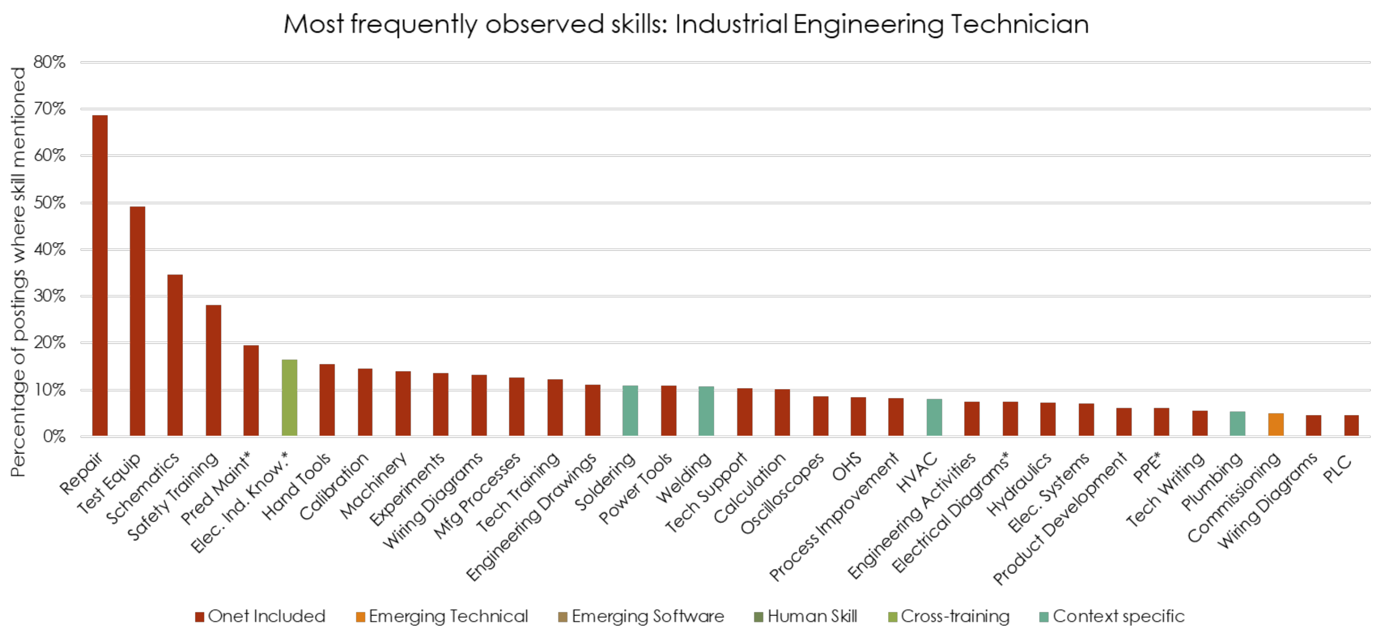

Figure 21 The most frequently observed skills for industrial engineering technicians classified as ONET included, emerging technical, emerging software, human skill, cross-training, or context specific.

Table 22 Skills in at least 5% of postings for industrial engineering technicians from the employer and keyword approach. The maximum percentage of postings where the skill was mentioned was reported.

Skill	Skill Category	Percentage of postings skills mentioned
Repair	ONET Included	69%
Test Equipment	ONET Included	49%
Schematic Diagrams	ONET Included	35%
Safety Training	ONET Included	28%
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Electrical Systems	ONET Included	7%
Product Development	ONET Included	6%
Personal Protective Equipment (PPE)	ONET Included	6%
Technical Writing / Editing	ONET Included	5%
Plumbing	Context Specific	5%
Commissioning	Emerging Technical	5%
Wiring Diagrams	ONET Included	5%
Programmable Logic Controller (PLC) Programming	ONET Included	5%
Repair	ONET Included	69%
Test Equipment	ONET Included	49%
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Electrical Systems	ONET Included	7%
Product Development	ONET Included	6%
Personal Protective Equipment (PPE)	ONET Included	6%
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Plumbing	Context Specific	5%
Commissioning	Emerging Technical	5%
Wiring Diagrams	ONET Included	5%
Programmable Logic Controller (PLC) Programming	ONET Included	5%

Human Skills: What about “Soft” skills?

The focus of this study was to assess the training gaps associated with specific applied skills for technical workers. This focus in no way implies that the research team believes that such technical skills are more important than other non-technical skills (also known as “soft” or human skills). Research was focused on technical skills for two reasons. First, our primary goal was to develop insights to shape training programs aimed to support the FHE industry. Such programs themselves focus on technical skills and, therefore, require feedback on the same. Secondly, the interview applied in this research was of a scale that taxed most respondents. As such, tradeoffs had to be made to limit its scope and content. As a result, this study explores only a limited set of human skills including a novel analysis of critical thinking.

Although they were not the focus of this study, it is important for training programs to recognize that human skills complement technical skills, enhance employability, and improve productivity (Schulz 2008; Rao 2014). Although both industry and academia are reaching consensus that employees need human skills in addition to the technical skills taught in most STEM training programs (Kumar and Hsiao 2007), there is no consensus on which human skills are most important or even how to frame and organize human skills.

A recent study by researchers at MIT’s Jameel World Education Lab attempts to bridge that gap by synthesizing more than 40 skills frameworks into the Human Skills Matrix (HSM). Their analysis found that communication and self-management skills were the most commonly identified important human skills. These were followed by creativity, problem solving, critical thinking, and teamwork. The HSM synthesizes this information into 24 non-technical skills that employees need to thrive (Stump, Westerman, and Hall 2020). These skills are grouped into four categories including Thinking, Interacting, Managing ourselves, and Leading. This framework was used to guide the selection of human skills studied here.

Specifically, we asked operations managers about the importance of these six human skills (as well as a detailed question about critical thinking) for middle-skilled manufacturing occupations:

- Effectively managing people and projects (Leading)
- Managing unfamiliar problems and situations (Thinking)
- Independently organizing time or prioritizing tasks (Managing ourselves)
- Communicating and collaborating with engineering and management staff (Interacting)
- Taking initiative to learn new skills or technologies (Managing ourselves)
- Knowing the science and engineering underlying the product (Thinking)

Critical thinking is widely cited as a skill that leads to success. Nevertheless, there are no established methods to characterize it. Here we define critical thinking as "the ability to analyze evidence and facts to form a judgment" (Gambrill 2005).To better characterize the role of critical thinking for technical middle-skilled occupations, we decompose the judgment process into the following sub-tasks:

1. Perceiving the issue – What should I measure or observe to know that a problem exists?
2. Hypothesizing about problem cause – What might be causing the problem?
3. Developing a framework for hypothesis testing – How can I confirm my hypothesis?
4. Inferring whether tests confirm the hypothesis - Does the test suggest that my hypothesis was right?
5. Communicating the outcome – How (and to whom) do I report on what has happened?

Respondents were asked to identify what aspect of critical thinking is important of technicians working at their facility.

Identifying Important, Common Skills

While it is valuable to understand the skills trends within individual occupations, in many cases, training programs or courses will need to be more broadly applicable, serving the needs of multiple types of learners. To that end, the research team has attempted to identify those skills that are both important and shared (common) among multiple occupations.

This was accomplished by making use of the hierarchical nature of the O*NET dataset from which occupation-specific skills were identified. To create the survey administered for this project, the research team identified occupation-specific skills from the list of Tasks within the O*NET dataset. In that context, Tasks are the most specific representation of occupation requirements. Tasks are related to more generalized classifications of skills as represented in Figure 22. Specifically, Tasks can be associated with many Detailed Work Activities which are each associated with only one Intermediate Work Activity which are themselves associated with only one General Work Activity. (To maintain a more consistent terminology in this report, we will refer to these classifications as Detailed Tasks/Skills (DTS), Intermediate Tasks/Skill (ITS), and General Tasks/Skills (GTS), respectively.)

Because of this hierarchical relationship, it was possible to compute an average skill importance at any level of aggregation. To do this, a weighting was assigned to each level of response for each specific skill (Importance will Grow Significantly = 5, Grow= 3, Hold = 1, Not important = 0). Then weighted averages of these importance levels were computed for each specific task or skill and the corresponding DTS, ITS, and GTS. For this set of occupations, the DTS level of aggregation did not provide useful insights. As such, it is not discussed further in the results section.

These weighted importance scores were then used to identify the most important GTS and ITS across all of the occupations considered in this survey. From these important skills we identify those that are shared by at least three occupations and refer to this set as important, common (as in shared) skills.

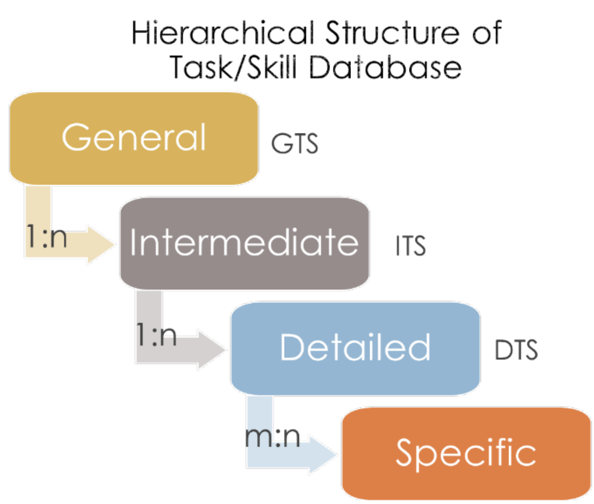


Figure 22. Hierarchical structure of the task/skill database used in this study. Survey respondents were asked about occupation specific (orange level) tasks or skill. 1:n indicates a one (parent) to many

(child) relationship. m:n indicates a many to many relationship. The hierarchies are defined within the O*NET database.

Semi-Structured Interview

Interview design

The interview is structured into four main sections:

5) firm characterization,
6) hiring and training challenges
7) workforce scaling, and
8) emerging skill needs.

In the first section of the interview, respondents were asked to identify the primary role that their firm plays in the FHE supply chain. Additionally, respondents were asked to estimate the firm's annual revenues and overall employment levels.

In the second section, respondents were asked to identify which of the focal occupations were relevant for their firm. Then for each relevant occupation they were asked whether

- Demand for that position would (Hold, Grow Somewhat, or Grow Significantly)?
- Filling an open position was (Easy, Average, or Hard)?
- In house training for new hires tends to be (Basic, Moderate, or Extensive training)?

In the final section of the survey, respondents were randomly assigned three relevant occupations. For each of these, they were asked to characterize the expected skill level for each position for their current technicians, the skill level of new hires for these positions, and rank the importance of the skills in 5 years compared to today. The categories for skill level included the following:

- Not applicable
- Aware of
- Familiar with
- Competent at
- Proficient with
- Mastery of

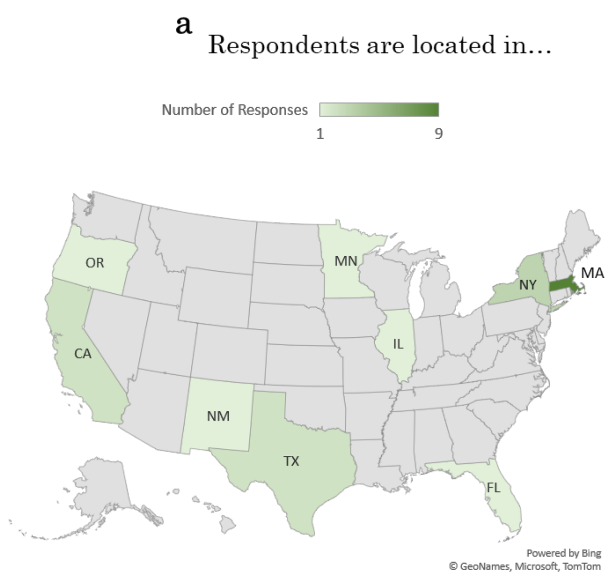
The expected importance ranks from much less important than now to much more important than now.

Semi-Structured Interview Process

The interview responses were captured in the Qualtrics online platform(Qualtrics XM 2021) and interviews were conducted with FHE firms mainly located in the New England area with some responses nationwide. Twenty-one responses where the respondent completed the entirety of the interview template were received and incorporated into the following results.

Respondent Demographics

Survey respondents came from a broad array of firms. As shown in Figure 23a, a majority of the respondents came from Massachusetts, with a few firms from other states. Firms ranged in size from as few as five employees to as many as 45,000. The median firm size was 70 employees. Annual revenue ranged from $3.5M to $95,000M with a median of $13M per year (Figure 23b).



b

	Annual Revenue (million USD)	Size of Firm (Headcount)
Median	$13	70
Mean	$9,202	4,000
Min	$3.5	5
Max	$95,000	45,000

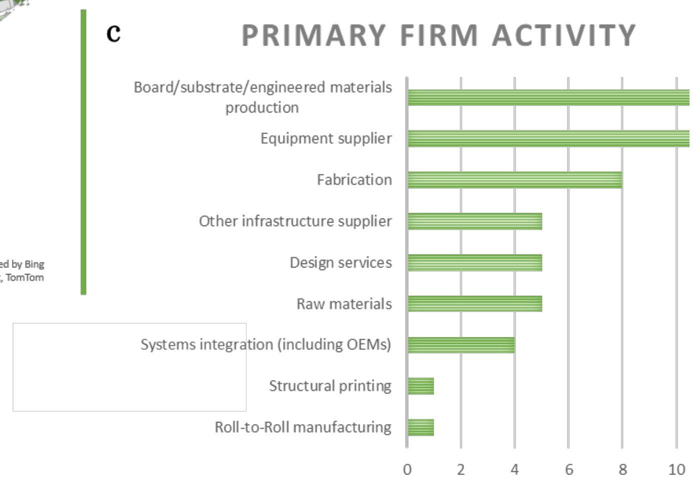


Figure 23. Distribution of respondent location, size, revenue, and primary supply chain activity.

Firms were asked to identify their role in the supply chain. There was a range of primary activities for each firm (see Figure 23c) with a majority focused on board/substrate/engineered materials production and equipment suppliers.

Common Important Skills

The following pages contain the details of survey responses for each specific skill organized by Intermediate Task/Skill (ITS) and by General Task/Skill (GTS). In the subsequent tables, occupation titles are abbreviated as listed in Table 23.

Table 23. Focal occupations that were evaluated in this study and abbreviated title used in GTS / ITS tables

Occupation	Abbreviation
Industrial engineering technicians	Ind Eng T
Electrical and electronics engineering technicians	ElecEng T
Mechanical engineering technicians	MechEng T
Chemical technicians	Chemical T
Computer-controlled machine tool operators	CNC Oper
Mechanical and mechatronics engineering technician	MechaTron T

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Repairing and Maintaining Equipment	3.4	Maintain electronic, computer, or other technical equipment.	3.7	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.7			X			
		Maintain tools or equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2						X
Prepare specimens, tools, or equipment	3.0	Assemble equipment or components.	3.7	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	3.7			X			
		Prepare specimens or materials for testing.	3.6	Prepare chemical solutions for products or processes, following standardized formulas, or create experimental formulas.	3.6				X		
		Disassemble equipment.	3.2	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	3.2						X
		Position workpieces or materials on equipment.	2.9	Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.	2.9						X
		Set up equipment.	2.7	Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	2.6				X		
		Fabricate devices or components.	2.4	Operate drill press, grinders, engine lathe, or other machines to modify or to fabricate components.	2.5					X	
				Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.3					X	

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Test and Evaluate for Quality	2.8	Test performance of equipment or systems.	3.1	Set up or operate test equipment to evaluate performance of developmental parts, assemblies, or systems under simulated operating conditions.	3.9			X			
				Test equipment, using test devices attached to generator, voltage regulator, or other electrical parts, such as generators or spark plugs.	2.2					X	
		Inspect completed work or finished products.	2.9	Inspect electrical project work for quality control and assurance.	2.9			X			
		Test characteristics of materials or products.	1.7	Test products for performance characteristics or adherence to specifications.	1.7		X				
Monitor Processes, Materials, or Surroundings	2.4	Monitor equipment operation.	2.7	Monitor machine operation and control panel displays, and compare readings to specifications to detect malfunctions.	3.2						X
				Check to ensure that workpieces are properly lubricated and cooled during machine operation.	2.2						X
		Monitor operations to ensure adequate performance.	2.4	Verify that equipment is being operated and maintained according to quality assurance standards .	2.4		X				
		Monitor operations to ensure compliance with regulations or standards.	1.9	Read worker logs, product processing sheets, or specification sheets to verify quality assurance specifications.	1.9		X				

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Data Collection & Synthesis	2.4	Read documents or materials to inform work processes.	2.4	Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.	2.8						X
				Review project instructions and blueprints to ascertain test specifications, procedures, and objectives	2.1					X	
Thinking & Making Creatively	2.4	Design electrical or electronic systems or equipment.	3.3	Modify electrical prototypes, parts, assemblies, or systems to correct functional deviations.	3.3			X			
		Design industrial systems or equipment.	2.3	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.3					X	
		Create visual designs or displays.	2.1	Draft detail drawing or sketch for drafting room completion or to request parts fabrication by machine, sheet or wood shops.	2.2					X	
				Prepare charts or diagrams to illustrate workflow, routing, floor layouts, material handling, or machine utilization.	2.0		X				
		Develop research plans or methodologies.	2.0	Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.	2.0			X			

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Information Management	2.3	Present research or technical information.	2.8	Write technical reports or prepare graphs or charts to document experimental results.	2.8				X		
		Document technical designs, procedures, or activities.	2.3	Record test procedures and results, numerical and graphical data, and recommendations for changes in product or test methods.	2.6					X	
				Write procedures for the commissioning of electrical installations.	1.8			X			
		Prepare documentation for contracts, applications, or permits.	1.9	Prepare, review, or coordinate ongoing modifications to electrical system specifications or plans.	1.9			X			
Provide Consultation and Advice to Others	2.3	Advise others on the design or use of technologies.	3.5	Provide technical assistance in resolving electrical engineering problems encountered before, during, or after construction.	3.5			X			
		Advise others on business or operational matters.	1.6	Recommend modifications to existing quality or production standards to achieve optimum quality	2.0		X				
				Review new product plans and make recommendations for material selection, based on design objectives such as strength, weight, heat resistance, electrical conductivity, and cost.	1.2						

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Analyzing Data or Information	2.3	Analyze biological or chemical substances or related data.	2.7	Conduct chemical or physical laboratory tests to assist scientists in making qualitative or quantitative analyses of solids, liquids, or gaseous materials.	2.9				X		
				Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	2.6				X		
		Analyze performance of systems or equipment.	2.1	Interpret test information to resolve design-related problems.	2.5			X			
				Analyze test results in relation to design or rated specifications and test objectives, and modify or adjust equipment to meet specifications.	2.2					X	
				Analyze product failure data and laboratory test results to determine causes of problems and develop solutions.	1.9						
				Compile and evaluate data using statistical process control procedures	1.4		X				

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Making Decisions and Troubleshooting Problems	1.7	Determine operational methods or procedures.	1.8	Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.	2.0			X			
				Determine appropriate methods for fabricating and joining materials.	1.6						
		Determine resource needs of projects or operations.	1.7	Calculate machine speed and feed ratios and the size and position of cuts.	2.5						X
				Calculate required capacities for equipment to obtain specified performance	1.5					X	
				Prepare electrical project cost or work-time estimates.	1.3			X			
Estimating and Judging the Characteristics of Products or Processes	1.1	Estimate project development or operational costs.	1.1	Prepare electrical project cost or work-time estimates.	1.3			X			
				Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.	0.8					X	

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Communicating with Supervisors, Peers, or Subordinates	3.3	Coordinate with others to resolve problems.	3.3	Collaborate with electrical engineers or other personnel to identify, define, or solve developmental problems.	3.3			X			
Interacting With Computers	3.1	Program computer systems or production equipment.	3.1	Input machine control programs	3.1						X
				Set up and operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic workpieces.	2.9						X
											X
Judging the Qualities of Things, Services, or People	2.9	Evaluate production inputs or outputs.	2.9	Monitor product quality to ensure compliance with standards and specifications.	2.9				X		
Performing General Physical Activities	2.6	Clean tools, equipment, facilities, or work areas.	2.6	Clean machines, tooling, or parts, using solvents or solutions and rags.	2.6						X

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Interpreting the Meaning of Information for Others	2.5	Explain technical details of products or services.	2.5	Interpret engineering drawings, schematic diagrams, or formulas for management or engineering staff.	2.5		X				
Organizing, Planning, and Prioritizing Work	2.4	Plan work activities.	2.4	Aid in planning work assignments in accordance with worker performance, machine capacity, production schedules, or anticipated delays.	2.4		X				
Evaluating Information to Determine Compliance with Standards	1.2	Assess compliance with environmental standards or regulations.	1.2	Review new product plans and make recommendations for material selection, based on design objectives such as strength, weight, heat resistance, electrical conductivity, and cost.	1.2						
Making Decisions and Troubleshooting Problems	1.7	Determine operational methods or procedures.	1.8	Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.	2.0			X			
				Determine appropriate methods for fabricating and joining materials.	1.6						
		Determine resource needs of projects or operations.	1.7	Calculate machine speed and feed ratios and the size and position of cuts.	2.5						X
				Calculate required capacities for equipment to obtain specified performance	1.5					X	
				Prepare electrical project cost or work-time estimates.	1.3			X			

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Photonic T	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper
Estimating and Judging the Characteristics of Products or Processes	1.1	Estimate project development or operational costs.	1.1	Prepare electrical project cost or work-time estimates.	1.3			X			
				Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.	0.8					X	

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