Quad Cities Manufacturing Innovation Hub Playbook Series

Additive Manufacturing

How to Use This Playbook

Each Quad Cities Manufacturing Innovation Hub playbook is created with the business growth needs of our area’s small and medium manufacturers in mind. By utilizing the information in the Additive Manufacturing Playbook, you are taking the first steps to creating a competitive advantage for your company by innovating in the face of disruptive technologies.

This playbook follows a logical flow to guide you as you learn more about additive manufacturing (see Fig. 1). Review the sections as they apply to your individual opportunities and resources, either in the order they’re presented or jump around to fit your immediate needs.

Figure 1: Additive Manufacturing Playbook Information Flow

This is your toolkit for plugging into the additive manufacturing innovation network right here in the Quad Cities.

Together, all eight of our playbooks work in concert to uplift our regional manufacturers and Department of Defense suppliers through increasing digital readiness; working together to accelerate the understanding and investment in emerging technologies; and foster a culture of innovation in the manufacturing industry. We encourage you to review the other playbooks (see appendix for more information) as well.

Whom can I contact at the Quad Cities Manufacturing and Innovation Hub with questions?
Email askthehub@quadcitieschamber.com, and a member of the Hub team will respond to your question.

About the Quad Cities Manufacturing Innovation Hub and Our Partners
The Quad Cities Manufacturing Innovation Hub assists businesses by offering services such as operational assessments, registry in a regional catalog of manufacturers and suppliers, trade and business-to-business events, access to national and international marketing, access to subject matter experts through the Chamber’s Critical Talent Network, connections to the Quad City Manufacturing Lab and national research, and training seminars targeted at key technologies.

More information on the Hub can be found online here.

This content was prepared as part of the Illinois Defense Industry Adjustment Program, a
partnership between the University of Illinois System, the Quad Cities Chamber of Commerce, and the Voorhees Center at the University of Illinois Chicago (UIC), with financial support from the U.S. Department of Defense, Office of Economic Adjustment (OEA). It reflects the views of the Quad Cities Chamber of Commerce and does not necessarily reflect the views of the OEA. For more information, please visit www.IllinoisDIA.org.

Additive Manufacturing in the Quad Cities: At a Glance

What is “additive manufacturing?”
Additive Manufacturing (often referred to as simply “AM”) is the process of adding layers of material (plastic, metal, concrete, etc.) upon one another to create a product. You may also hear it referred to as “3D printing,” though that term only encompasses some of the processes that can be used in additive manufacturing.

Why does additive manufacturing matter to the Quad Cities?
Additive manufacturing has the capacity to complement and augment current manufacturing processes in the future. In three to five years, manufacturers in our region will plan for additive manufacturing opportunities from product inception through design and production, in order to increase efficiencies, save money, and rapidly prototype.

What are the biggest opportunity areas locally?
Traditional tooling, small weldments, low production runs, complex parts, and repair parts will see significant disruption.

What are the business benefits of additive manufacturing?
Rapid innovation and prototyping, increased speed-to-market, lower tooling costs, unique designs, reduced part quantities, ability to embed sensors, multi-material designs, and a breadth of equipment to cover multiple applications. See more benefits in the Metrics section.

Where can I find help to get started?
Local experts from Western Illinois University, the Quad City Manufacturing Lab, and Eastern Iowa Community Colleges can help you find the right application of additive manufacturing that fits your needs. The Hub also holds periodic Additive Manufacturing User Group meetings (check the Chamber website for event details). Look to the resources section for more information.
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Understand the Technology
In the first section, we take a closer look at the variety of technologies that contribute to the collective term “additive manufacturing.” You’ll gain a better understanding of how AM
Additive Manufacturing is the process of adding layers of material (plastic, metal, concrete, etc.) upon one another to create a product. You may also hear it referred to as “3D printing,” though that term only encompasses some of the processes that can be used in additive manufacturing. According to a recent Industry 4.0 study by Boston Consulting Group, 34% of manufacturers have implemented additive manufacturing, with that number steadily on the rise as technologies become more mainstream, cost-efficient, and employees upskill.¹

Figure 2. Conceptual Comparison Between Subtractive and Additive Manufacturing²

![Subtractive manufacturing diagram](https://commons.wikimedia.org/wiki/File:Figure_1_-_Conceptual_Comparison_between_Subtractive_and_Additive_Manufacturing_(22327379300).jpg)

![Additive manufacturing diagram](https://commons.wikimedia.org/wiki/File:Figure_2_-_Conceptual_Comparison_between_Subtractive_and_Additive_Manufacturing_(22327379300).jpg)

Figure 3. 7 Types of Additive Manufacturing and Hybrid, According to ASTM F2792 Standards. Diagram created by Hybrid Manufacturing Technologies.

² [https://commons.wikimedia.org/wiki/File:Figure_1_-_Conceptual_Comparison_between_Subtractive_and_Additive_Manufacturing_(22327379300).jpg](https://commons.wikimedia.org/wiki/File:Figure_1_-_Conceptual_Comparison_between_Subtractive_and_Additive_Manufacturing_(22327379300).jpg)
<table>
<thead>
<tr>
<th>Alternative Names:</th>
<th>Description:</th>
<th>Strengths:</th>
<th>Typical Materials:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Metal Laser Cladding (DMLC), Direct Metal Laser Depositing (DMLD)</td>
<td>Powdered materials are selectively heated and melted using a laser or electron beam. The resulting molten pool is then recoated.</td>
<td>● High level of accuracy</td>
<td>Plastic, Metal, and Ceramic Powders, Plus Sand</td>
</tr>
<tr>
<td>Material Extrusion</td>
<td></td>
<td>● Allows for full laser processing</td>
<td></td>
</tr>
<tr>
<td>Directed Energy Deposition (DED)</td>
<td></td>
<td>● High productivity</td>
<td></td>
</tr>
<tr>
<td>Hybrid Additive Manufacturing Technologies (HABT)</td>
<td></td>
<td>● Uses a wide range of materials</td>
<td></td>
</tr>
<tr>
<td>Material Extrusion</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4. Additive Manufacturing Process: Laser Cladding Nozzle Diagram**

1 https://commons.wikimedia.org/wiki/File:Laser_Cladding_nozzle_configurations.jpg
Figure 5. Additive Manufacturing Technologies, infographic via 3D Hubs.4 Hi-resolution infographic available for download [here](https://www.3dhubs.com/what-is-3d-printing).

Glossary: Key Additive Manufacturing Terms
Please refer to the glossary in the appendix for definitions of key additive manufacturing terminology that is utilized in this playbook. Definitions provided for educational purposes as described by TEAMM (Technology Education in Additive Manufacturing and Materials), unless otherwise noted.

Additional Online Resources
There are many online resources for review to deepen your understanding of additive manufacturing technologies, processes, opportunities, challenges, and more. We’ve outlined a few below:

- **From MIT:** “Standard Terminology for Additive Manufacturing Technologies.” This terminology includes terms, definitions of terms, descriptions of terms, nomenclature, and acronyms associated with additive-manufacturing technologies in an effort to standardize terminology used by AM users, producers, researchers, educators, press/media, and others.
- **From GE:** “What is additive manufacturing?” (video). GE Aviation is revolutionizing the age-old rules of manufacturing and design. Learn how additive manufacturing, a 3D printing technology, frees engineers to design the perfect jet engine.
- **From Loughborough University’s Additive Manufacturing Research Group:** “The 7 Categories of Additive Manufacturing.” Although the term “3D Printing” is often used as a synonym for all additive manufacturing processes, there are any individual processes...
which vary in their method of layer manufacturing. Individual processes will differ depending on the material and machine technology used. Hence, in 2010, the American Society for Testing and Materials (ASTM) group “ASTM F42 – Additive Manufacturing”, formulated a set of standards that classify the range of additive manufacturing processes into seven categories.

- From UPS and the Consumer Technology Association (CTA): “3D Printing: The Next Revolution of Industrial Manufacturing.” This report details how the AM industry is expected to grow on the path to 2020. Researchers explore how AM will disrupt the manufacturing market, how it compares to traditional processes, its supply chain impact, and the technological advancements on the horizon. This report is highly visual, with many graphic frameworks and charts to help readers understand the impacts of AM.

Identify Opportunities
Additive manufacturing offers many opportunities to small and medium manufacturers in the Quad Cities (see Figure 6, below). Of the myriad of opportunities, the Hub has identified three key opportunity areas that will bring greatest benefit to our area’s small and medium manufacturers: tooling; repair parts and legacy components; and prototyping.

Figure 6, Applications of Additive Manufacturing by Use Case

Opportunity #1: Tooling
Utilizing additive manufacturing, you can make tools that are either impossible to machine (complex or novel geometries) using traditional subtractive methods, or extremely expensive to

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5 Wohler’s and Associates Report 2017
Machine. AM offers efficiencies in tooling production time, strength and durability in parts, higher quality finish, as well as the ability to combine multiple parts into one single print—all, of which, can positively impact return on investment over traditional manufacturing methods. Tooling with additive can be completed using a variety of materials, including nylon, fiber, and metals. Many manufacturers use AM to print one-off, custom parts as well to quickly solve in-house tooling issues as they arise.

Opportunity #2: Repair Parts and Legacy Components
As additive manufacturing is quick and flexible in its applications, many manufacturers use it to either update legacy components or efficiently replace parts in need of repair that would typically take much longer (and more investment due to set-up costs and large batch requirements) to cast a mold and print either in-house or overseas. By depositing new material using AM onto an existing part, it can not only create new use cases for tooling but also extend the lifetime of the part. If manufacturers do not have a 3D model of a legacy part or one in need of repair, there are local resources that can assist in 3D-scanning solid models, as well as taking measurements in order to remodel a part (see Education section).

Opportunity #3: Prototyping
Additive Manufacturing provides the opportunity to learn quickly, fail early, and move on to the next innovation due to its production speed and low cost in small-batch runs. Traditionally, manufacturers become comfortable with long lead times and large runs of parts, incrementally inspiring less in-house R&D and innovation over time as it doesn’t seem “worth the trouble” if it isn’t successful. AM offers ultimate flexibility for prototyping new ideas for innovation in tooling, repair parts, fixtures, legacy equipment, and more. And, with both materials and hardware technology costs decreasing, the opportunities presented by quick and easy prototyping, and immediate problem-solving, will only continue to grow.

Benefits and Use Cases of Additive Manufacturing Opportunities
As the cost of international logistics continues to rise, and additive manufacturing becomes more affordable, Quad Cities manufacturers have the opportunity to shift facilities and production back to U.S. and local locations. This offers many benefits to small and medium manufacturers, including lower inventory levels as products are made in smaller batches and closer to “on-demand,” and direct-to-consumer fulfillment opportunities.6

And, AM isn’t just for plastics, nylon, and polymers. The increase and pervasiveness of industrial metal AM also offers new opportunities to area manufacturers in decreasing costs and production time typically associated with metal tooling and repair parts. According to the, “Wohlers Report 2018: 3D Printing and Additive Manufacturing State of the Industry,” there has been an 875% growth in sales of metal AM machines over the past five years,7 and a 220% growth in the past two years alone8 (chart below). 135 companies are producing “industrial AM systems” globally, defined as costing more than $5,000, up from 97 in 2016.

6 http://info.plslogistics.com/blog/6-effects-3d-printing-has-on-supply-chains
7 http://www.machinedesign.com/3d-printing/metal-am-metal-additive-manufacturing-hits-critical-mass
Let’s examine the key benefits of utilizing additive manufacturing in each of the three opportunity areas previously identified. Below, you’ll also find a case example for each opportunity area that shows how a manufacturer was able to utilize AM to produce better results than traditional subtractive methods.

**Opportunity #1: Tooling**

- Works best with low volume production needs, complex parts, and those that would normally be of high cost to create using traditional manufacturing methods
- Surrogate parts created using AM allows employees to practice on lightweight versions before casting is complete on actual part. This can be beneficial for safety training; ergonomics; proofs of concept; and other technician training aids
- Significantly cut weight of tools to increase efficiency of operator setup time
- Minimized print time and material usage while maintaining strength of tool. This can translate to high cost savings

**Case Example:** John Deere significantly cuts tooling costs by using additive manufacturing to create a porous support structure. See table below for cost comparisons. Fused deposition modeling (FDM) tooling proved to be more cost-effective vs. traditional aluminum and medium-density fiberboard (MDF) tooling.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Mold Material</th>
<th>Tooling Cost Quoted</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Aluminum</td>
<td>$1,800</td>
</tr>
<tr>
<td>B</td>
<td>Aluminum</td>
<td>$4,000</td>
</tr>
<tr>
<td>C</td>
<td>Aluminum</td>
<td>$1,300</td>
</tr>
<tr>
<td>D</td>
<td>Aluminum</td>
<td>$2,500</td>
</tr>
</tbody>
</table>

**Case Example: 3D Systems Healthcare, Inc. 3D-prints nylon cutting guides to assist surgeons**

Oral, craniofacial, and orthopedic surgeons are all taking advantage of additive manufactured surgical guides in order to reduce operating room time, improve surgical outcomes, patient satisfaction, and surgeon and patient confidence. These patient-matched surgical guides require shorter lead time, small batch runs for complex molds, and greater cost efficiency than traditional manufacturing techniques. 3D Systems Healthcare, Inc. has seen an uptick in production of these guides utilizing its additive manufacturing machinery.9

**Opportunity #2: Repair Parts and Legacy Components**

- Part repairs can be made in-place to extend lifetime and/or create new use cases and upgrades to legacy components without the need for new castings
- More efficient in-house component repair than replacing through distributor
- Reduced waste generation during the repair process
- Improved product utilization during repair and remanufacturing
- Reduced replacement parts inventory, offering cost-savings in times of low demand10

**Case Example: Siemens uses AM to repair burner tips more efficiently and with less waste.**

Siemens Power Generation Services (Siemens PGS) provides support, maintenance and repair services to customers operating rotating power equipment such as gas steam and wind turbines, generators, and compressors. Having identified the combustion system in gas turbines as one particular application whereby AM could improve customer value in spare parts repair and manufacturing, Siemens PGS has redesigned the burner “swirler” to make use of the design freedoms afforded by AM. Through using AM the burner tip can be repaired more quickly and with less waste. It is estimated that the repair time is 10 times quicker than the previous approach. Less waste is generated as little of the burner is now discarded; only the top 18 mm edge of the burner tip is removed prior to repair. Using AM also allows for much easier upgrading to the latest design and is a step toward the business’ future vision of spare parts being manufactured on-demand, closer to the customer’s location.11

**Machine Shop Remanufactures Broken Gear Teeth with AM**

As detailed in a full case study on its blog, Hansford Parts and Products partnered with the Rochester Institute of Technology (RIT) to remanufacture obsolete milling machine parts. Together, they developed a plan to use directed energy deposition to add metal onto the broken gear teeth of a 1966 Knapp rack milling machine. To execute the AM process, Hansford first imaged existing gear teeth to establish profile for CAM. They then removed the broken teeth, undercut the base diameter, and added material to strengthen the interface. From there, they milled the surface flat and fabricated a near-net shape tooth profile onto the shaft. Finally, they

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9 https://advancedmanufacturing.org/additive-mfg-reaches-production-scale-medical/
measured micro-hardness to determine it a match for original teeth and machined the final tooth profile and operated it in the rack mill.\footnote{12}

The gear shaft with a new 3D-printed tooth. (Image via Hansford Parts and Products.)

**Opportunity #3: Prototyping**

- Cost-effectively test the function of a design, geometry, and fit-up with other parts before waiting the average 20-week lead time to cast and manufacture a tool. Prototyping can be done using in-house AM equipment or partnering with a local innovation lab (see resources section for details).
- Test product markets to better understand what customer want and get in front of them faster.
- Test manufacturing process, including assembly and tooling/fixtures. Print a mock-up before buying an expensive tool.
- Use prototypes during discussions with suppliers as surrogates for discussion, planning, verification, and sales purposes.
- Prototype large parts in multiple pieces using AM to ensure each part fits into manufacturing process without error.

**Case Example: DePuy Spine uses AM to speed prototyping of complex surgical tools**

DePuy Spine makes more than 70 brand-name products with more than 10,000 product codes that are distributed globally. Using a single DMLS-machine from EOS in their own shop, DePuy Spine processed 2,000 prototype parts — benders, extractors, surgical screws, clamps, reduction devices and others — in the first year of use alone. This has accelerated the development of its medical instruments according to the consulting doctors’ requirements rather than manufacturability using traditional methods. Delivery times for surgical prototype tools have shrunk from several months to less than one week. The flexibility of CAD designs makes it easy to adjust to new requirements, and in-house production has saved DePuy Spine time and

\footnote{12} https://hpproc.com/hansford-rit-partner-remanufacture-obsolete-milling-machine-parts/
Build the Business Case and Begin Implementation

In this section, we’ll outline the steps to take in implementing additive manufacturing within your company, beginning with awareness and change management, through establishing partnerships and building use cases that will save you time and money. We understand that the idea of implementing AM is completely different from traditional subtractive manufacturing processes that you may be accustomed to, and that the prospect of this degree of change to your business model is daunting and frightening. It is our hope that, through the following content and previous look at the benefits of AM, you’ll feel more comfortable exploring how you can utilize these technologies to bring production back in-house, into the region, and create new solutions for your customers.

Change Management: Building the Case Requires Data and a “Test-and-Learn” Approach

For most small and medium manufacturers, the prospect of adopting AM seems risky, as it bucks the status quo and requires learning new equipment, technologies, and procedures to remain profitable. Only through experimentation, learning, and failing fast, can you quickly gain new expertise and experience that will benefit your company in years to come.

It’s tempting to allow your self-defense mechanism to take over when faced with new technologies. It’s natural for leaders to practice self-preservation to protect their role, team, and the future of the company at-large. However, it is in new technologies, like additive manufacturing, that are shifting the very structure of the manufacturing industry—beyond the Quad Cities. New business models are emerging, and the only way to survive is to be proactive in your adoption of AM in ways that fit into your production methods.

There are many ways for you to get started along the path to utilizing AM. Use the change management tips below to make the case for change and immediately begin proving results:

- **Understand the business value of additive manufacturing and set goals accordingly.** Use our metrics section as well as your own data research to set realistic expectations of how you will measure the impact and success of integrating AM into your existing manufacturing processes. This will help in resource planning if you’re measuring the right benchmarks out of the gate. Focus on one or two main use cases first before adding complexity to your production process and supply chain.
- **Focus on getting every employee on board with the benefits of AM through peer education.** Get all stakeholders involved from the beginning via one-on-one conversations with leaders and all-company meetings to drive the vision. Make them as knowledgeable as you possibly can, taking ownership of AM initiatives. Innovative companies like GE promote “reverse mentoring” to foster understanding, create mutual empathy, and promote collaborate between disparate generations and team members. In reverse mentoring scenarios, a younger colleague mentors a more tenured employee as a way of getting everyone up-to-speed quickly with AM technologies and benefits.

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13 https://www.eos.info/press/customer_case_studies/depuy-spine
Keep communication lines open during the trial-and-error portion of AM experimentation. Employees should understand that it’s okay to fail, and fail fast, if it’s part of a learning process that eventually leads to prototyping successful equipment, product, and tooling runs. This mindset must be led from the top-down within your company in order for employees to feel like they can experiment and innovate in order to achieve efficiencies in AM. Breed risk-taking early.

Part of change management also lies in understanding and planning for the challenges you will encounter in integrating AM into your existing operations. Below are three challenges we’ve identified through our research and conversations with area manufacturers. Become familiar with the potential roadblocks so you can steer clear of their hindrances early on.

- **Longer print times**: Depending on your application of AM, it may take longer to print an entire run of parts or tools due to the speed of the 3D-printer. For this reason, AM is best suited for small-batch runs and prototyping for many manufacturers.

  However, progress is being made on this front, as MIT is making headlines for attaining new speeds in AM. Its new desktop 3D printer is 10 times faster than commercial counterparts. Anastasios John Hart, associate professor of mechanical engineering at MIT, explains, “If I can get a prototype part, maybe a bracket or a gear, in five to 10 minutes rather than an hour, or a bigger part over my lunch break rather than the next day, I can engineer, build, and test faster.”

- **Frequent firmware updates**: The software utilized to communicate with AM machinery requires regular updates in order to perform correctly. You’ll need to plan for hardware and software resource allocation accordingly within your facilities.

- **Costly metal printing filaments and powders**: Though the cost of smaller 3D-printers that output plastic or other polymer parts is declining, the cost of utilizing AM for metal parts is still quite steep. Manufacturers must conduct a cost/benefits analysis of printing efficiency, cost, labor, batch size, and delivery against traditional methods (either internally or outsourced). The feasibility of using AM for metal materials will vary by project and is dependent on cost structure.

**Processes and Frameworks for Implementing Additive Manufacturing**

Integrating AM into your existing manufacturing processes requires a strategic approach. Utilize the workflows and frameworks below to jumpstart your efforts.

**Workflow 1: Additive Manufacturing Planning and Deployment Strategy**

1. **Diagnose**: Assess your current state of AM knowledge and create a vision for where your company should be in its use of AM in three to five years.
2. **Define**: Define your strategy and timeline for achieving your vision. Include resource planning and goals and metrics to define success.
3. **Deploy**: Develop and pilot priority initiatives to test AM capabilities and use cases.

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**Footnotes**

1. [MIT news article](http://news.mit.edu/2017/new-3-d-printer-10-times-faster-commercial-counterparts-1129)
2. Workflow adopted from Altimeter Group, a Prophet Company’s approach to jumpstart digital transformation.
Embed new capabilities, and upgrade necessary technologies and infrastructure.

4. **Determine**: Measure impact against predefined benchmarks and iterate on future AM uses. Continue this process iteratively.

**Workflow 2: Tools Chain to Create a Process for Additive Manufacturing**

From Reinshaw: AM must be underpinned by an effective process chain with user-friendly design tools and a range of post-processing and metrology before the parts it makes can be used. Information must flow up and down the chain to link processes together.

![Diagram of a process chain for additive manufacturing]

**Resources Needed: Technology and Staffing**

Resources required to implement AM within your manufacturing facility will vary by the use cases you’ve established for the technology. For example, utilizing AM for rapid prototyping will yield a different cost structure for hardware, software, and staffing than planning to use AM as a replacement for all tool casting. As previously outlined, you must create a strategic plan for how AM will augment or replace your current manufacturing processes in the recommended opportunity areas of tooling, repair and legacy parts, and prototyping before jumping the gun and purchasing a series of 3D printers, updating software, and hiring unnecessary talent.

Use this general checklist to assist in the process of planning for your hard and soft costs in AM:

- **Hardware**: The machinery you purchase will depend on how you plan to use AM within your manufacturing facility. Refer to the glossary to review the types of AM that are best suited for various use cases. Once you have decided on how you will utilize the machine, and what type of AM is best suited for your needs, begin the research process of purchasing one or more machines. Refer to the Regional Assets section for recommendations on local partners and vendors. Also review offerings from EOS, Stratasys, and Reinshaw—all reputable hardware vendors used by many local manufacturers, innovation labs, and EOMs.

  America Makes also offers the Senvol Database, a comprehensive database of industrial additive manufacturing machines and materials. Users are able to search the database by more than 30 fields, such as machine build size, material type, and material tensile strength. Access the database here to aid in your selection process.

• **Software**: AM begins with a CAD model, which often means there will be a small learning curve for engineers and designers in transitioning into the software specific to your AM machine. There are many modeling programs that can be used for AM and feature sets depend on your intended use. Use the framework below to begin deciding which software is right for your application(s) and continue research online.

The American Society of Mechanical Engineers (ASME) has published a draft standard for additive manufacturing data files, to improve manufacturing efficiency with precise methods of controlling product definition. RapidReady offers a comprehensive assessment and summary of the [draft standard here](http://www.padtinc.com/blog/the-focus/the-additive-manufacturing-software-conundrum). ASME Y14.46-2017 can be ordered by downloading a digital PDF here. During the one-year trial and comment period (ending November 2018), interested parties may submit suggestions for revision. ASME expects the new standard, when approved, will greatly help anyone involved in mechanical design, drafting, quality assurance and supply-chain management working with additively manufactured parts and assemblies.

• **Figure 7: Seven sub-categories of AM software**

![Figure 7: Seven sub-categories of AM software](http://www.padtinc.com/blog/the-focus/the-additive-manufacturing-software-conundrum)

• **Employees and Hiring**: Assess your current employees for skillsets in CAD/CAM to determine if expertise is applicable and transferrable to your AM software choices. Most manufacturers have in-house talent that is ready and able to augment their current skills. However, some local small and medium manufacturers have opted to hire new employees with engineer and design expertise specific to AM in order to speed up the implementation process, as well as inject new, passionate approaches to innovation within the company. Work with the education partners listed later in the playbook to find inexpensive design and engineering talent either freshly graduated or as a temporary intern (with, ideally, intent to hire).

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17 http://www.padtinc.com/blog/the-focus/the-additive-manufacturing-software-conundrum
“Quick Wins” to Get Started with Additive Manufacturing

Take a page from the playbooks of local manufacturers like John Deere, Trackside Solutions, Ossian, and more that are already up-and-running with AM by following a few of their tips to jumpstart your use of the technology:

- **Start with brainstorming potential applications in tooling.** What can you make that’s low volume, and expensive to make traditionally? Also consider what would require otherwise complicated or impossible geometry using traditional methods—those are your immediate opportunity areas!

Utilize the worksheet below in Fig. 8 ([available for high-resolution download here](https://3mf.io/faq)) from Joran Booth to guide you through the process of designing parts for AM that will fit your needs and achieve your goals. It was created to quickly reduce the number of printing and prototyping failures. The 3MF (3D Manufacturing Format) Consortium also aids engineers in making better designs for AM. 3MF is an industry consortium working to define a 3D printing format that will allow design applications to send full-fidelity 3D models to a mix of other applications, platforms, services and printers. Its goal is to provide a specification that eliminates the issues with currently available file formats, and allows companies to focus on innovation, rather than on basic interoperability issues.

*Figure 8. Design for Additive Manufacturing Worksheet from Joran Booth*

- **Gain experience through service bureaus.** At the end of this playbook, we offer local
educational and partnership resources. Depending on your AM applications, it’s likely you’ll be able to make use of others’ assets during your planning and consideration phases. This will help you build the business case if you need to “sell” the idea of AM to leadership within your company.

- **Talk to machine resellers** to better understand the pros and cons of each machine you’re considering purchasing. They’ll be able to tell you the ideal applications for each machine, material needs and tolerances, and if it fits with your production needs. Before making a large purchase, experiment with a cheaper 3D plastic printer. Get them in the hands of your engineers to begin rapidly innovating in real-time.

- **Reach out to people in the community**, You’ve already taken the first step by reviewing the Quad Cities Manufacturing and Innovation Hub playbook. This playbook was drafted based on the input of our AM “Tech Team,” a group of local manufacturers that are currently implementing AM. You’re invited to attend any of our AM User Group meetings and Hub Huddles as well to network with other manufacturers and learn straight from the source how they’re using AM to augment or replace existing manufacturing processes to save time and money. Go to the Quad Cities Chamber of Commerce events web page for upcoming meeting information and registration.

**Metrics for Success: How to Measure Impact**

When setting your objectives for AM, you’ll need to tie goals to business impact using metrics for success. Without measuring and benchmarking the performance of AM against traditional manufacturing, it will be more difficult to consistently improve processes, assess weaknesses, and secure future resources.

- More efficient and rapid prototyping
- Increased efficiency of flow paths
- Production time reduction
- Higher precision and more uniform cooling patterns
- Decreased production and output time
- Reduced post-processing time and resources
- Increased component stability
- Greater accuracy and repeatability
- Decreased materials costs
- Increased customer value
- Increased product sales in either volume or price-point
- Competitive advantage in innovation
- … and more, depending on your specific AM application

The National Institute of Standards and Technology’s (NIST) Material Measurement Lab contributes to the measurement methods, standards, data, and models required to realize the full promise of additive manufacturing. AM-Bench, its additive manufacturing benchmark data test and set, results can be found here. As detailed in Quality Magazine, AM-Bench engages multiple companies to build the same part using the same starting materials, while multiple computer modelers try to predict the finished parts’ chemical and physical properties, which NIST material science experts measure. The final results are available to any company to compare how their own modelling efforts perform against NIST’s data. New builds, predictions, and tests recur.
Find Help with Regional Assets and Partners

In delivering this additive manufacturing playbook, among the seven other playbooks provided by the Quad Cities Manufacturing and Innovation Hub, our goal is to connect you to local resources you need to learn about and implement new technologies that will impact your business and our region in the future. In this section, you’ll find suppliers, educators, innovation labs, consultants, and more Quad Cities assets to help you succeed. Additionally, we’ve outlined national and global resources in some categories if local resources do not exist and/or the national resource is reputable and used often by local manufacturers.

Suppliers: Hardware

**RP Support and Sales America**
http://www.rpsupportamerica.com/
RP Support America, Inc. is a premier mobile service provider specializing in the support and service of stereolithography 3D printers. RP Sales America, Inc. is the exclusive U.S. distributor for the UnionTech™ RSPro equipment line, which brings a fresh dimension to stereolithography 3D printing in the North American market. Recently, RP Support and Sales has also diversified with the addition of Rise printers that use a proprietary fuse deposition modeling technique at a lower price point and complexity.

**Stratasys**
http://www.stratasys.com/
Stratasys, Ltd. is a manufacturer of 3D printers and 3D production systems for office-based rapid prototyping and direct digital manufacturing solutions. It solutions include a powerful and diverse range of materials to help maximize the benefits of additive manufacturing at every stage of research, product development and production; 3D printers that include FDM and PolyJet technologies; Thingiverse and GrabCAD communities with access to more than 5 million free design components and 3D printable files; Stratasys Direct Manufacturing delivers parts on demand; and Stratasys Strategic Consulting analyzes business impact and guides adoption.

**EOS**
https://www.eos.info/en
Eos e-manufacturing solutions provides quality, high-end AM solutions Founded in 1989, EOS is a pioneer and world leader in the field of Direct Metal Laser Sintering (DMLS) and provider of highly productive AM systems for plastic materials. EOS has developed Micro Laser-Sintering (MLS) Technology for the e-manufacturing of miniaturized parts.

**Reinshaw**
Reinshaw is a metal 3D printing systems manufacturer and solutions provider for a wide range of...
Industries worldwide. Its solutions range from systems, metal powders, ancillaries, and software. Reinshaw’s advanced metal AM systems are designed to fulfill a range of industry applications where durability, customized parts and precision are key. Industries include dental, medical, mold tooling, automotive, industrial tooling, aerospace, and creative.

**Markforged**
[https://markforged.com/](https://markforged.com/)
In 2014, Markforged launched the world’s first and only carbon fiber composite printer, enabling designers and engineers to create same-day strong, reliable parts. Markforged printers allow for fast innovation with parts made of Onyx, Continuous Carbon Fiber, Stainless Steel, or any of its 11 other materials.

**Suppliers: Software**
Refer to software vendors listed earlier in the playbook. AM software is typically provided in conjunction with hardware components and/or distributed online through a cloud-based service.

**Educational Resources**
In the creation of this playbook, as well as the AM User Group meetings, the Quad Cities Manufacturing and Innovation Hub is proud to partner with two local higher education facilities: Eastern Iowa Community College and Western Illinois University. Both offer unique AM training/certification or technology innovation solutions for local manufacturers:

**Eastern Iowa Community Colleges (EICC)**
**Contact: Brad McConnell, Pro/E/Drafting | bemcconnell@eicc.edu**
EICC is focused on training at the technician level to assist small and medium manufacturers in building and hiring talent that is capable of implementing AM programs and operating equipment effectively. By teaching 3D modeling techniques focused on accuracy, EICC is training engineering technicians, welding, CNC machining, and mechanical design. Through a grant with the National Science Foundation, it’s also undergoing development of a curriculum (launching in 2018, see preview in Fig. 9 below) focused solely on additive manufacturing that includes job safety; CAD file procedures; AM machine setup; building AM parts; performing part post-processing; troubleshooting and maintenance; and administrative duties. If you have an immediate AM project need, contact Brad McConnell to connect with current EICC students to assist.

*Figure 9: Additive Manufacturing Occupational Profile. Foundation for EICC curriculum.*
Western Illinois University (WIU)

Contact: Bill Pratt, Director/Professor of QC Engineering || WF-Pratt@wiu.edu

WIU enables area manufacturers to innovate in AM by showcasing the technologies and the solutions they can provide. From hosting AM User Group meetings, to providing facility and equipment tours, to working directly with EOMs like John Deere, the goal of WIU is to transfer knowledge to the manufacturer or other end user after providing hands-on education into the potential use cases. WIU can provide site-specific considerations for large-format 3D printers, in addition to other R&D services that allow manufacturers to “try before they buy” AM equipment. AM is not currently part of the WIU curriculum, though students may work with 3D printing as part of their engineering classes as well as in internships with the Quad Cities Manufacturing Lab (see below for more information).

Black Hawk College: Trade and Technical Career Program

Engineering Technology Manufacturing Track and CNC Manufacturing Certificate || More Information
Black Hawk College trade and technical grads learn to create, repair, install and troubleshoot—all skills that make them highly attractive to local industry recruiters. These programs cover a wide range of training in technical and trade-related fields and vary in time and duration. Students interested in a technical career can tailor their course selection in many areas, including basic science, mathematics, and applied disciplines in manufacturing, as noted in the above recommended track and certificate.

MIT xPRO Online Course
Additive Manufacturing for Innovative Design and Production || More information
An 11-week online course on the fundamentals, design principles, applications, and implications of additive manufacturing. The course is tailored for manufacturing professionals, from engineers to executives. It presents the technical foundation of AM, how to design parts for AM using advanced digital tools, and equips learners with the knowledge and confidence to select and evaluate applications of AM across the product life cycle.

Innovation Labs and Partnership Networks
Iowa State University’s Center for Industrial Research and Service (Ames, Iowa)
http://www.ciras.iastate.edu/
The Center for Industrial Research and Service (CIRAS) is part of the College of Engineering and the Office of Economic Development and Industry Relations at Iowa State University. Since 1963, CIRAS has been partnering with Iowa companies and communities on R&D and prototyping using in-house AM equipment. CIRAS experts believe metal additive manufacturing technology has the potential to revolutionize how Iowa businesses make parts and tooling. In addition to helping area manufacturers in learning new methods of design and new ways to manufacture using AM, its machines will allow companies to cut costs and reduce the time needed to bring new products to market.

Quad City Manufacturing Laboratory (Rock Island, Ill.)
http://qcml.org/
The Quad City Manufacturing Laboratory (QCML) is a non-profit 501 (c) (3) organization headquartered at Rock Island Arsenal in Rock Island, Illinois. QCML performs research, development, and technology transfer in advanced materials and manufacturing processes such as 3D Metal Printing and Laser Cladding, Spark Plasma Sintering (SPS), Friction Stir Welding (FSW), Solid Modeling, 3D Scanning, Robotics, and Hot Isostatic Pressing (HIP). Some of the materials that QCML has worked with include: titanium alloys, metal matrix-carbide composites, Inconel alloys, aluminum alloys, magnesium alloys, steel alloys, MgAlB14 (BAM), silicon carbide, and silicon nitride.

QCML, aligned with WIU, is a national resource for research and development of advanced materials and manufacturing technology for commercial and military applications. QCML has the capabilities to design processes and equipment to suit its customer’s needs. It was recently involved with is constructing a custom metal powder bed fusion that incorporates open-source technologies. Contact QCML to assist with your metal prototyping process using their AM equipment before investing in your own solutions.

QC Co-Lab (Davenport, Iowa)
The QC Co-Lab is a makerspace established in March of 2010 to promote the sciences, technology, engineering, art, and music. The makerspace contains dedicated project rooms including industrial and electrical workshops, a library, a classroom, and an AV studio. The QC Co-Lab facility is open 24-hours a day, seven days a week, to dues-paying members of the organization. The QC Co-Lab is available for non-members as well for special events, workshops, and tours can be arranged.

TechWorks (Waterloo, Iowa)
http://techworkscampus.com/
The TechWorks Campus is a 30-acre advanced manufacturing, research and development, innovation, education, commercial and manufacturing center. Located in downtown Waterloo, the campus is comprised of 20 acres of development sites and 300,000 square feet of flex space and is a place for innovation and development.

TechWorks Campus provides AM research, development, and training through its alignment with higher education institutions Hawkeye Community College and the University of Northern Iowa. University of Northern Iowa's Technology Department operates its Additive Manufacturing Center. Private companies and students utilize this center for advanced product development and research. UNI and HCC have partnered to provide design and engineering services and training for students in the Additive Manufacturing Design Lab.

Consulting

One Vision Consulting
Contact: Glenn Dugan, Consultant and Trainer || glenn@1visionconsulting.com
One Vision Consulting’s Glenn Dugan has 35 years of corporate engineering and management experience in large, medium and small organizations, worldwide in scope. He has extensive project management experience in design and development, manufacturing, and R&D environments. Contact One Vision Consulting for AM group training, team building project and discussion, group facilitation, staff mentoring, and assessing and engaging people's strengths around additive manufacturing.

Special Thanks
The Additive Manufacturing Playbook was created with the contributions, time, and talent of many members of our manufacturing community. We'd like to extend a special thanks to:

- Glenn Dugan, One Vision Consulting
- Eric Faierson, QCML
- Eric Johnson, John Deere
- Brad McConnell, EICC
- Mike Ossian, Ossian Inc.
- Bill Pratt, WIU
- Jeremy Vos, RP Sales and Support America
- Brad Zust, Trackside Solutions
**Appendix**

**Glossary: Key Additive Manufacturing Terms**
Definitions provided for educational purposes as described by TEAMM (Technology Education in Additive Manufacturing and Materials), unless otherwise noted.

**3D Printer**: machine used for 3D printing.

**3D Scanning**: method of acquiring the shape and size of an object as a 3-dimensional representation by recording x,y,z coordinates on the object’s surface and through software the collection of points is converted into digital data.

**Build Cycle**: single cycle in which one or more components are built up in layers in the process chamber of the machine.

**Build Platform**: of a machine, any base which provides a surface upon which the build is started and supported throughout the build process.

**Build Surface**: area where material is added, normally on the last deposited layer which becomes the foundation upon which the next layer is formed.

**Computer Aided Design (CAD)**: The use of computers for the design of real or virtual objects. The Quad Cities Manufacturing and Innovation Hub also offers a technology playbook dedicated to CAD/CAM [that can be found here](#).

**Computer Aided Manufacturing (CAM)**: Typically refers to systems that use surface data to drive CNC machines, such as digitally-driven mills and lathes, to produce parts, molds, and dies. The Quad Cities Manufacturing and Innovation Hub also offers a technology playbook dedicated to CAD/CAM [that can be found here](#).

**Fused Deposition Modeling (FDM)**: Making of thermoplastic parts through heated extrusion and deposition of materials layer by layer. A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.

**Prototype Tooling**: Molds, dies, and other devices used to produce prototypes; sometimes referred to as bridge tooling or soft tooling.

**Rapid Tooling**: In machining processes, the production of tools or tooling quickly by subtractive
manufacturing methods, such as CNC milling, etc.

Selective Layer Sintering (SLS): Thermoplastic powder is spread by a roller over the surface of a build cylinder. The piston in the cylinder moves down one object layer thickness to accommodate the new layer of powder. Here, a piston moves upward incrementally to supply a measured quantity of powder for each layer. A laser beam is then traced over the surface of this tightly compacted powder to selectively melt and bond it to form a layer of the object. The fabrication chamber is maintained at a temperature just below the melting point of the powder so that heat from the laser need only elevate the temperature slightly to cause sintering. The process is repeated until the entire object is fabricated. After the object is fully formed, the piston is raised to elevate it. Excess powder is brushed away and final manual finishing may be carried out.

Stereolithography (SL): Process used to produce parts from photopolymer materials in a liquid state using one or more lasers to selectively cure to a predetermined thickness and harden the material into shape layer upon layer. Once one layer is completely traced, it's lowered a small distance into the vat and a second layer is traced right on top of the first. The self-adhesive property of the material causes the layers to bond to one another and eventually form a complete, three-dimensional object after many such layers are formed. Stereolithography is the most widely used rapid prototyping technology.

STL: A file format native to the stereolithography computer-aided drafting (CAD) software that is supported by many software packages; it is widely used for rapid prototyping and computer-aided manufacturing.

Subtractive Manufacturing: making objects by removing of material (for example, milling, drilling, grinding, carving, etc.) from a bulk solid to leave a desired shape, as opposed to additive manufacturing.

Tool, Tooling: A mold, die, or other device used in various manufacturing and fabricating processes such as plastic injection molding, thermoforming, blow molding, vacuum casting, die casting, sheet metal stamping, hydroforming, forging, composite lay-up tools, machining and assembly fixtures, etc.