Asset Map

Additive Manufacturing Opportunities

Northeast Ohio

July 2016

Prepared for:

Fund for our Economic Future

Prepared by:

Youngstown Business Incubator

Team NEO

MAGNET

America Makes

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INTRODUCTION

I. INTRODUCTION

A. Scope of Work

The purpose of this study, the *Asset Map of Additive Manufacturing Opportunities in Northeast Ohio* (Asset Map) is to create a clear vision for the integration of the Additive Manufacturing (AM) supply chain in northeast Ohio. A primary component of this vision is the ability to capitalize on the technology advancements being generated by America Makes, the national accelerator for AM and 3D printing (3DP).

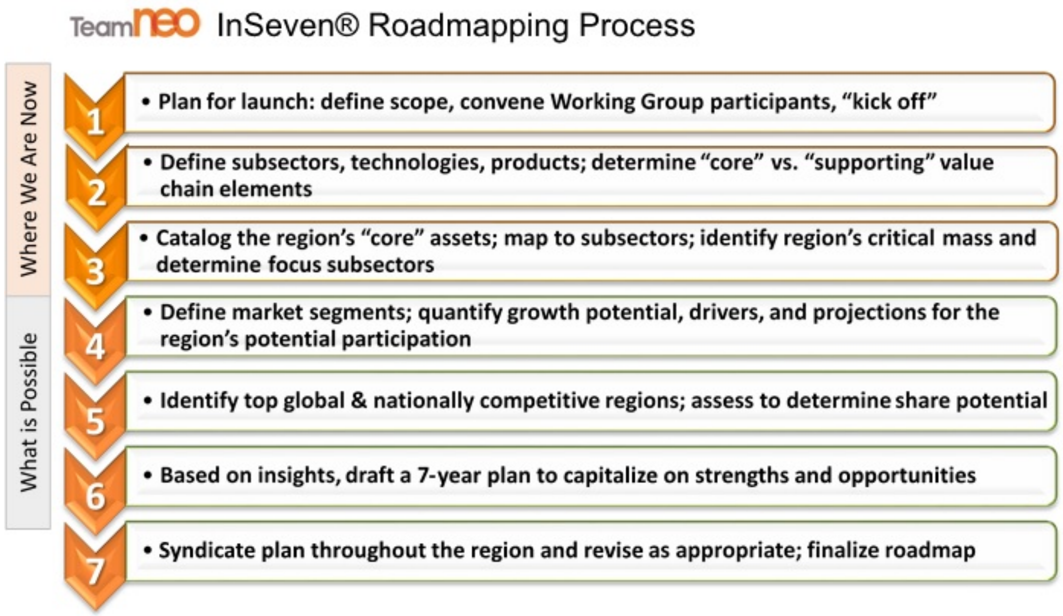
To this end, a project team was assembled in November 2015. The team, which is comprised of members of the Youngstown Business Incubator (YBI), Team NEO, MAGNET, and America Makes, began the process of road mapping the regional commercialization landscape to identify AM opportunities.

Objectives include:

- maximizing ongoing AM research and development
- generating new industry applications of AM
- stimulating regional entrepreneurial activity
- driving business and economic growth throughout the northeast Ohio AM supply chain

The road mapping process employed is the InSeven© model. This model is designed to identify key regional strengths as the basis of long-term cluster-development opportunities surrounding those assets.

Figure A: Team NEO InSeven® Road Mapping Process



B. Advisory Council

An Advisory Council consisting of stakeholders throughout the region was established to guide all Asset Map activities. Advisory Council members include representation from prominent end-user companies, key supply chain participants and leading academic institutions. The role of the Advisory Council has been to provide: a plan structure; market and technical guidance; connections to market participants; consistent engagement during development of the work product; and review of all plan outcomes and recommendations.

Figure B: Advisory Council, Asset Map of AM Opportunities

Council Members	**Company**	**Value Chain**
Tracy Albers, President	rp+m	Production/Design
John Baliotti, Director of Marketing and Business Development	Formerly of The ExOne Company	Equipment Manufacturer
John Barnes, Vice President of Advanced Manufacturing and Strategy	Alcoa Titanium & Engineered Products	Materials
Barb Ewing, Chief Operating Officer	Youngstown Business Incubator	R&D
Tim Fahey, Vice President of Industry and Innovation	Team NEO	R&D
Rob Gorham, Director of Operations	National Center for Defense Manufacturing and Machining	R&D
Tracy Green, Vice President, Strategic and Institutional Development	Lorain County Community College	Workforce/R&D
Mark Horner, VP Business Development	The Technology House	Production
Anthony Hughes, Founder and President	The Lanterman Group	Design/Commercialization/Workforce

Howard Kuhn, Senior Technologist	Formerly of the ExOne Company	Equipment Manufacturer
Aaron LaLonde, Principal Materials Engineer	Swagelok	Design/Production/End-User
Brandon Lamoncha, Sales Manager, Solution Provider	Humtown Products	Production
Rich Lonardo, Principal Consultant	Defense and Energy Solutions, LLC.	R&D
Georgette Nelson, Leader, Additive Programs at General Electric	General Electric	End-User/Production
Dave Pierson, Senior Design Engineer	MAGNET	R&D/Design/Engineering/Production
Julie Michael Smith, Executive Vice President, Executive Director, Advanced Methods in Innovation	AST2 (Applied Systems and Technology Transfer)	Workforce/Design/Production/R&D
Evan Spirk, Product Design Manager; John Spirk, Co-Founder, Co-President	NottinghamSpirk	Design
Darrell Wallace, Assistant Professor/Owner	Youngstown State University/Assimilogic	R&D

C. Process

The first stage of the project included an extensive review of previously completed roadmaps and AM market analyses, in order to accurately assess the existing AM landscape, as well as existing and future market opportunities. The defined market opportunities were then used to develop a value chain model which was populated by market participants existing in northeast Ohio. From that value chain, key segments were selected, and more than fifty voice-of-the-customer (VOC) interviews were conducted among resources that represent the core assets of the region.

VOC interviews rely on direct interactions with end-users and key supply chain assets; for this reason, the VOC method was deemed most effective for the identification of key use cases and the determination of near and long-term AM opportunities.

Interviews were also conducted with leading industry resources from surrounding regions. The information gathered has been useful in assessing northeast Ohio's competitive positioning. Based on these interviews, a set of recommendations for support of AM growth in northeast Ohio was developed.

The remainder of this report has been organized into seven sections:

- Value of the Work
- The Additive Manufacturing Landscape and Market Opportunity
- Competitive Analysis
- Asset Inventory
- Voice-of-the-Customer Interviews
- Business Use Cases
- Outcomes and Recommendations

VALUE OF WORK

II. VALUE OF WORK

The opportunity AM presents within northeast Ohio includes building on the already robust manufacturing base to aid the region's ability to remain competitive. There is also a direct opportunity for companies and end-users who design and produce using AM technologies to positively impact their bottom line through production efficiencies, reduction in time to market, and market development.

The ultimate outcome of the roadmapping work is to identify growth and commercialization opportunities to help the region retain and grow jobs and advance the region's competitiveness.

It has been determined that by defining the regional AM value chain and identifying economic use cases of merit, we can facilitate successful adoption of the technology and market entry into value chain gaps by in-region companies and original equipment manufacturers (OEMs). A robust regional AM value chain and ecosystem should enable in-region companies to better contend with global competition and capitalize on the technology, bringing benefits directly to the materials suppliers, fabricated metal products manufacturers, and plastic products manufacturers that are abundant in northeast Ohio.

Additionally, this work would benefit OEMs and end-users whose finished products would incorporate AM produced parts. Economic development organizations in northeast Ohio, such as MAGNET and YBI, could benefit through increased awareness and demand for the technology, generating greater wealth creation within their target regions. The area's institutions of higher education with AM curriculum could benefit significantly as they are better able to link their research to industry. Entrepreneurs will especially benefit as they gain access to services, value chain partners, and know-how to help them launch their businesses.

A. Why Northeast Ohio?

Northeast Ohio has an advantaged position for capitalizing on the transformational effect AM will have on manufacturing economies. The region's industrial legacy includes 273,000 manufacturing workers– 62 percent above the national average – a foundation which holds vast potential for accelerating regional and national growth within the AM cache of technologies. The existing fabric of manufacturers, end-use markets, regional economic development and entrepreneurial support organizations, professional associations, and higher education makes northeast Ohio a hotbed of current and potential AM capabilities.

- The presence of America Makes in northeast Ohio provides engineering resources, a prototyping center, research and development opportunities, a cadre of AM experts, access to the national AM community and a significant body of IP. The presence of the flagship program for the National Network for Manufacturing Innovation in the region is a unique asset that can and should be leveraged by the state of Ohio and regional economic development agencies in their efforts to attract and retain companies to northeast Ohio.

- Companies primed to feed and utilize the AM supply chain including 1,900-plus metal fabrication establishments and more than 800 plastic processors, together employing more than 100,000 people.
- End-use markets, which are a part of northeast Ohio's driver industry cache, include the aerospace, medical/dental, and automotive industries. These industries were responsible for 62 percent of AM system sales worldwide in 2014. Aerospace, medical/dental, and automotive account for 478 establishments in northeast Ohio and over 38,000 jobs in the region.
- The connecting fabric of regional organizations dedicated to company and entrepreneurial growth includes YBI's expertise as an incubator and in technology-based economic development; Team NEO's expertise in private/public collaboration and regional innovation cluster development; MAGNET as the pre-eminent center for manufacturing growth in northeast Ohio; BioEnterprise in biotech business formation, recruitment, and acceleration; JumpStart's support of diverse entrepreneurs, high growth companies and the ecosystems that support them; and county economic development organizations, such as the Stark Development Board and Team Lorain County.
- Private sector organizations and national associations located in northeast Ohio with expressed interest in AM include ASM International, the world's largest association of metals-centric materials, engineers, and scientists; SME (formerly known as the Society for Manufacturing Engineers), dedicated to advancing and educating the manufacturing industry; Alliance for Working Together (AWT), a consortium of 75+ manufacturing companies working on the sustainability of manufacturing in the community; and the Lanterman Group, a consulting firm focused on integrating additive manufacturing practices into existing businesses.
- Significant workforce, intellectual property (IP) and R&D capabilities from higher education including Lorain County Community College's (LCCC) Smart Center; Cuyahoga Community College's Digital Design and Manufacturing Technology curriculum; Case Western Reserve University's (CWRU) Additive Manufacturing Studio in think[box]; and Youngstown State University's (YSU) Center for Innovation In Advanced Manufacturing (CIAM).

The Additive Manufacturing Landscape
And Market Opportunities

III. THE AM LANDSCAPE AND MARKET OPPORTUNITIES

A. Global AM Landscape and Market Opportunities

Additive manufacturing is forecasted to remain on a sizeable global growth trajectory over the next several years. Industry analysts Wohlers Associates estimated in 2015 a global market of more than $5.2 billion for direct products and services, with an additional $1.8 in indirect revenue from in-house production, for a total market of $7 billion. This represents a 25 percent compound annual growth rate (CAGR), with most analysts predicting similar growth through 2020. While the range of market revenue projections varies from $7 billion to $21 billion in 2020, the consensus among industry experts is that growth will be significant and steady.

Wohlers Associates further segments the current worldwide market for products and services to include:

- Revenue from systems and materials estimated at $2.4 billion in 2015. Of this, $1.5 billion is sales of AM printing machines and systems, and $770 million due to sales of AM materials.
- Revenue from services estimated at $2.8 billion in 2015, of which $1.7 billion is attributed to service bureaus.
- Revenue of $2 billion in OEM indirect revenue from in-house production. Indirect OEM revenue is common in tooling and fixture applications where companies use 3DP-dies, molds and tools to satisfy their own manufacturing needs.

Globally, Asia-Pacific, the U.S., and Western Europe are expected to increase their combined share of global spending on 3D printing from 59.2 percent in 2014 to 70 percent by 2019, according to International Data Corporation (IDC). China is projected to become the leading market for 3D printing hardware and services by IDC. Estimates also vary when measuring the North America and U.S. market, ranging from an $814 million 2014 North American market estimated by BCC Research, to a $1.5 billion U.S. market estimated by IBISWorld in 2014, based on regional sales of commercial and industrial printers. With 40 percent of the installed machine base in North America, actual 2015 revenue could range as high as $1.9 billion from services and indirect revenue, while North American share in machine manufacture and materials was much lower.

Applications

1. Direct Parts Production: Though holding the largest promise for market disruption and economic impact, direct parts production (end-user parts) remains the smallest segment of the end-use printer market. Analysts, including McKinsey and Piper Jaffrey, estimate that direct part production accounts for less than 30 percent of additive manufacturing production.

   The leap from using AM technology mainly for product design and prototyping to actual volume production has been eagerly anticipated. However, catalysts for mass production remain slower to evolve then many in the market had anticipated, creating an environment where it is still too early in the near-term to capitalize on mass production. Challenges lie in operationalizing 3D printing throughout multiple areas of the organization and sustaining the technology internally for a number of reasons, including cost, time, design mindset, and leadership vision.

   However, there are some segments of the market that have become competitive in replacing conventional processes. Industries at the forefront of direct part production are aerospace and biomedical. For example, GE is 3D printing 19 fuel nozzles for each LEAP aircraft engine, and 90 percent of the plastic shells for in-the-ear hearing aids are created via additive manufacturing.

2. Prototyping: AM is still most commonly used for prototyping, which includes, for the purposes of this study, prototypes for fit and assembly, presentation models and visual aids. Estimates range from 48 percent to 70 percent of 3D printing is used for prototyping, which is a critical step in the new product development process, enabling the more rapid creation and optimization of designs and the further integration of the design and manufacturing processes.

3. Tooling: Tooling is, by its nature, a low-volume / high variability production process. It is also the single largest cost component of most mass produced products. Some additive manufacturing processes have been demonstrated to be effective at producing viable tooling for applications including molding, casting, and forming. Current applications are generally limited to expendable molds (as in green sand casting) or low-volume production tooling in molding and light-gage forming applications. This has opened up the opportunity for manufacturers to produce components cost effectively at much lower production volumes than previously possible. This has significant implications for increasing innovation through lower fixed capital costs and shorter design iteration cycles.

AM tooling is also more readily integrated into the existing manufacturing ecosystem. AM tooling yields components that are manufactured by traditional processes and that are made from traditional materials. Thus, they are able to be incorporated into the traditional supply chain without additional barriers.

At the recent SME RAPID 2016 conference, an annual conference dedicated to the acceleration of AM, market researchers from the University of Tennessee-Knoxville Oak Ridge National Library (UTK-ORNL) estimated that the total global addressable market for tooling would grow to $68.7 billion by 2020. Unfortunately, this sizeable opportunity is offset by what researchers say will be a direct correlation between the off shoring of tooling and the loss of domestic manufacturing jobs. From 1997 to 2010, the volume of U.S. tooling imports grew from $1.3 billion to $4.8 billion, with a corresponding decline in domestic manufacturing jobs. Researchers project that an ideal target for reshoring a portion of this immense market is the low quantity, high customization, large area tooling. They estimate that the accessible market for AM tooling in the U.S. will be $8.8 billion by 2020. This is a sizable growth opportunity, as the 2015 market estimate for AM tooling in North America would be roughly $800 million, a 40 percent share of indirect revenue estimates.

Research & Development

Globally, several regions are focused on the expansion of 3DP technology across industries. These international efforts are sure to play a major role in international commercial competition and economic growth. National security is another critical focus, since the U.S. military is using 3DP technology to address a broad range of needs. A few applications include 3D printed weapons, uniforms with biometric sensors and the ability to produce spare equipment parts in remote locations.

According to Wohlers's analysis, North America and Europe lead the adoption of 3DP, holding 68 percent of the current market share. Emerging markets include South Korea, China, Japan, and Singapore, all of which have an extensive industrial base as well as strong government support in both funding and policy.

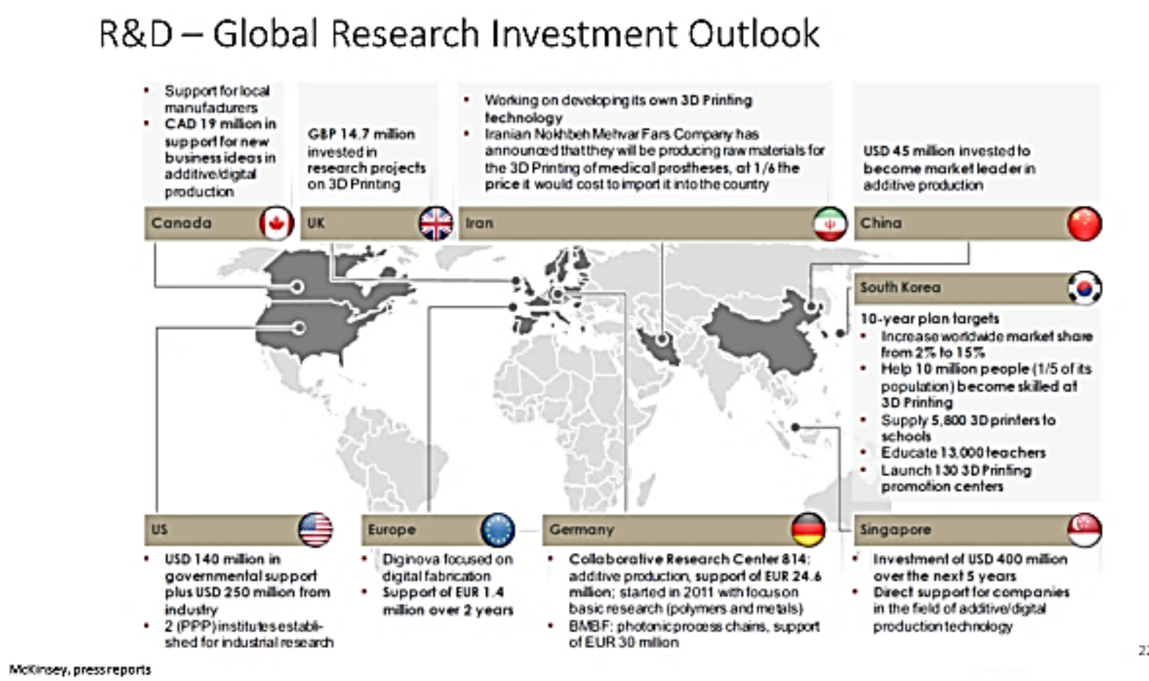
Several interesting and relevant lessons can be gleaned from the investments being made by those nations. For instance, South Korea is spending approximately 20 percent of its AM investment in training its workforce. Their strategic goals are very specific: deploy 5,000 printers in schools and train 13,000 teachers. Another specific South Korean goal is to create 130 "3D Promotion Centers." Singapore and China, on the other hand, have targeted an investment of $400 USD per person (over 5 years) and $45 USD per person respectively in an effort to become world leaders in AM production.

On a national level, the U.S. government, academia and the private sector all play a role in the development of AM technologies. According to the Science and Technology Policy Institute, the

United States began to fund AM research and development in 1986. Since that time, more than $200 million has been poured into AM research by the National Science Foundation (NSF). Other federal agencies have also been involved in AM research and development, including, but not limited to, the National Aeronautics and Space Administration (NASA), the National Institute of Science and Technology (NIST), the Department of Defense (DOD), and the Department of Energy (DOE).

Figure C below demonstrates the current status of research investments into AM made by all nations.

Figure C.



B. Ohio and Northeast Ohio AM Landscape and Market Opportunities

The Northeast Ohio AM Landscape

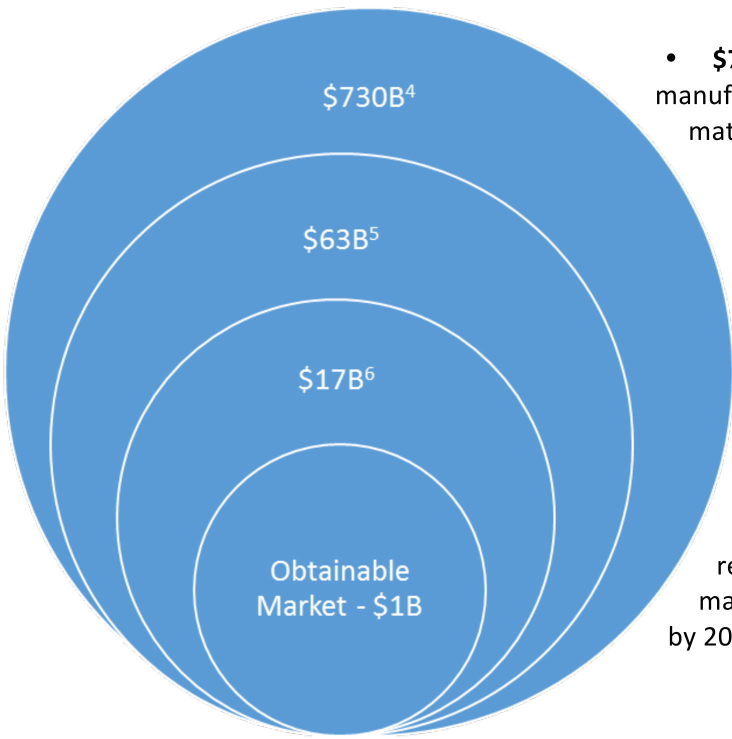
The Asset Map Project Team considered the magnitude of AM opportunities in northeast Ohio from multiple perspectives including tooling, materials, and research and development. In each case, the projected growth opportunities were comparably optimistic.

1. Tooling: The tooling industry has been identified as the greatest opportunity for near-term AM market growth in Ohio and in particular, northeast Ohio; 3DP equipment OEMs project the same. As previously noted, northeast Ohio has more than 400 plastics processing and 1,900 metals fabricating companies, with a combined total workforce of ~80,000 individuals. Accordingly, the regional tooling industry has the greatest potential

for early AM adoption and the greatest likelihood of sparking significant economic opportunity.

Figure D below illustrates the magnitude of impact that Ohio's AM tooling market could have on the state's manufacturing economy. As noted above, a recent study sized the US AM tooling opportunity at $8.8 billion in 2020. Ohio is 2nd in the US in tool, die & mold output with ~12 percent share. Thus, we estimate a market potential of >$1billion for AM tooling production in Ohio by 2020.

Figure D: Relative Magnitude of AM Opportunities for Tooling



- **$730 B** - Total U.S. Market for plastics manufacturing, metal fabrication and polymer materials industries
- **$63 B** - NEO Total Addressable Market for plastics manufacturing, metal fabrication and polymer
- **$17 B** - NEO Available Market: Specific segments of the northeast Ohio plastics manufacturing, metal fabrication and polymer materials industries identified by the project team as having a good opportunity for economic impact.
- **Obtainable Market – $1B** - Portion of the available market that can realistically be penetrated by additive manufacturing for tooling production in Ohio by 2020.

Sources: [4] Data from FirstResearch
[5,6]Data from Mergent Intellect

2. Materials: Materials spending for AM in 2015 was $765 million, a twenty percent increase over 2014, according to Wohlers. The primary material segments in AM are metals and plastics, along with a variety of composite materials, ceramics, sands, and hybrids.

   In 2015, the aerospace and medical device industries were the primary drivers in an 80 percent growth in metal usage, with that revenue reaching nearly $88 million. By all indications, the sale of metals for AM purposes will continue to grow at a healthy rate in 2016.

Polymer materials accounted for more than $550 million (or 71 percent) of all materials dollars spent in 2015. This represents an increase of 20 percent over 2014. The range of polymers available for AM vary by strength, color, transparency, rigidity, temperature, moisture resistance, and a number of other characteristics, but still are quite limited compared to those available for non-AM processes.

In 2015, the following polymer types were most frequently used in the AM process:

- *Photopolymers* dominated usage with nearly $350 million in sales
- *Laser sintered polymers* accounted for $191 million in material spending, which reflects a one-year increase of 25 percent
- *Polymer filament* spending accounted for $116 million

In northeast Ohio, materials represent a legacy strength and a key opportunity for growth as part of the future global value chain for AM. The northeast Ohio region has more than four times the concentration of materials industry jobs when compared to the rest of the U.S. More than 50 percent of all materials industry jobs in the State of Ohio are located in northeast Ohio, and 35 percent of those jobs are specific to the manufacturing of plastics. Primary materials producers employ over 40,000 workers in the region.

To date, that dominance in materials, especially polymers, for northeast Ohio has not translated to a corresponding share in AM materials. A key reason for this has been the closed materials model employed by the large machine OEMs, requiring use of their materials. This position is protected by patent portfolios for many of the AM polymer systems, limiting entry by traditional material suppliers. These barriers have started to erode as patents expire, but still limit innovation in the AM materials sector. Creating opportunities for new products to enter the market will require a significant disruption in the existing supply chain, as well the expiration of existing patents.

Industry experts agree that new, lower cost materials and access to a broader palette of material grades will spur more rapid adoption of new AM technology. Two striking advances in AM machine technology were introduced in 2015, and together they provide a glimpse into the AM materials transformation that lies ahead: the Hewlett Packard AM printer and the Carbon printer both use polymer materials and both offer open source opportunities. Both systems promise a tenfold increase in printing speed, which will significantly alter the breakeven volume for AM plastics part production. These advances could open up whole new market sectors for AM. For example, Carbon is actively working in the automotive sector with Delphi in Ohio and in consumer goods with Nike.

HP states that it is open to all material suppliers. Since the selection of polymer powders used by the HP AM printer is somewhat limited, northeast Ohio polymer compound producers could be able to capitalize on growth opportunities. (Current HP materials suppliers include Evonik, BASF, Arkema and Lehman & Voss.)

Carbon's machine is designed around proprietary thermoset polyurethane chemistry, but the company says that it is seeking polymer production partners for these materials as well as for other thermosets.

The materials opportunities created by HP and Carbon will help disrupt the closed sourcing model of AM original equipment manufacturers, 3D Systems and Stratasys, and thereby accelerate entry opportunities for Ohio polymer materials companies.

Targets for innovation in AM materials:

- *Polymer filaments:* Northeast Ohio has the key production facility for 3D Systems business in polymer filament production, as well as notable start-ups in this product group. Polymer manufacturer Lubrizol has developed novel TPU (thermoplastic polyurethane) filament products as well. As patents expire in this segment, collaboration of Ohio compounders with filament producers could penetrate.
- *Composite structures*: Impossible Objects in Illinois has developed a 3DP system that prints composite structures, using mats of carbon or glass impregnated with polymer. Ohio has strong composite material assets that could be focused on this opportunity.
- *Glass reinforced powders*: Owens Corning Europe offers glass reinforced powders for use in SLS processes. With US operations in Ohio, this could be an early growth opportunity in the state.

3. Research, Development, Engineering, and Design: In August 2012, America Makes, the National Additive Manufacturing Innovation Institute, was founded in Youngstown, Ohio, as a public-private partnership to accelerate the research and development (R&D) of AM and to successfully transition technology to the U.S. manufacturing industry. America Makes' federal partners include NSF, NASA, DOD, and DOE, as well as the Department of Education and the Department of Commerce.

As of February 2016, America Makes is engaged with more than 160 member organizations and has leveraged more than $100 million in public and private funds for research and develop projects. Northeast Ohio represents more than one third of the entire public post-secondary education system in the State of Ohio, including several with specific emphasis on supporting manufacturing and additive manufacturing education. Among these are Youngstown State University, one of the founding members of America Makes, the University of Akron with its strength in polymers, and Cuyahoga Community College, recipient of a $2.5-million Department of Labor award to establish AM education programs. Additionally, northeast Ohio is home to Case Western Reserve University, another founding member of America Makes and a world class research university. Expanding across the border into Pennsylvania, the regional strength of the TechBelt also includes strong, AM-centric programs at Carnegie Mellon University, the University of Pittsburgh, and Robert Morris University.

Among the most valuable products of this region are its engineering and technology graduates who support manufacturing companies across the country and around the world. Northeast Ohio's strength in this technology will only continue to add to the value of the area's graduates and the rate at which they are pulled out of the region to fill jobs around the country. Unfortunately, though Ohio is one of the most productive states in terms of college degrees per capita, it ranks 35th in the nation for residents with a college degree. The region's talent, particularly those with in-demand skill sets, is not well retained within the state.

Though northeast Ohio has a high density of manufacturing, it does not possess a high proportion of the associated engineering.   The ability to incorporate AM processes into the supply chain requires authority over design and process specifications. The overwhelming majority of manufacturers in the region are small, tiered suppliers who have little or no input to design. For the large corporations that do have a manufacturing presence in the region, most are strictly manufacturing arms with corporate engineering headquartered outside the region.

An anticipated by-product of AM adoption will be a migration of engineering talent away from the central corporate structure and closer to the point of manufacture. This would be consistent with an expected shift toward greater customization, faster design cycles, and higher complexities in manufacturing that will become increasingly common. Through that evolution, northeast Ohio will continue to be a critical supplier of engineering and technical workforce talent as well as a growing consumer of that talent.

4. Revenue and Job Growth Projections: The potential for AM market impact nationally is significant, yet AM products currently represent less than one percent of all manufactured products in the U.S. Even a 1 percent increase in manufacturing output due to AM would translate to a $1 billion impact in Ohio, as Ohio produces almost $100 billion in manufacturing output and is one of the top manufacturing workforce states in the country. As detailed above, the available market for AM tooling is expected to grow dramatically to $8.8 billion in the US by 2020, providing a $1 billion opportunity for Ohio. Projections for materials and direct part production services growth in the state must be more tempered in the short term, due to the barriers to entry detailed elsewhere in this report. Realistically, today Ohio produces at best $10-20 million of the $115 million filament segment of AM materials revenue, and almost none of the remaining segments in metals, photopolymers and LS polymer powders. Thus, only a few percent share of the estimated $2.5B total AM materials market in 2020 is realistic for Ohio, assuming closed systems and patent barriers persist through most of that timeframe. A major alliance to supply new open source systems could possibly alter that trajectory. Direct part production share is harder to predict, but certainly northeast Ohio's share today is just a few percent of the global $1.7 billion segment.

   Estimates of jobs in additive manufacturing prove to be difficult due to the variability of an emerging technology, and the proprietary nature of AM technologies. A report issued by the American Jobs Project, "Ohio Jobs Project," estimates Ohio's current market share of the 3D printer system manufacturing and 3D printing services industries at approximately 4 percent. The report argues that, if a concerted effort were made to expand the state's AM share to 10 percent over the next 15 years, Ohio could yield growth of over 4,400 jobs annually, with a corresponding 65,000 job-years gained over the next fifteen years. A job year is defined as one full-time equivalent job for one year. In northeast Ohio, the large number of plastics and metals fabrication companies suggest that the best opportunity for realization of this job growth is by more of these firms adopting AM for tooling applications in the short term and part production longer term.

COMPETITIVE ANALYSIS

IV. COMPETITITVE ANALYSIS

A. Benchmarking Northeast Ohio against Other Regions

A comparison between AM activity in northeast Ohio and other regions of the U.S. reveals that the AM industry remains relatively fragmented, with no one region monopolizing the resources or production at this time.

Leading competitors include:

1. *Pittsburgh:* Pittsburgh is becoming an AM technical hub for several reasons, including accessibility to the existing resources of Carnegie Mellon University, the University of Pittsburgh, Penn State University (PSU) and America Makes. The region boasts strong assets in software and robotics. Additionally, GE and Alcoa have recently established AM facilities in Pittsburgh. Alcoa, in particular, is using the strong metals industry of the tristate region as an opportunity to expand its AM metal powders production in Pittsburgh. Given Pittsburgh's adjacency and the complementary AM assets it holds with northeast Ohio, a collaborative TechBelt (stretching from Cleveland to Pittsburgh) strategy presents obvious benefits.
2. *San Francisco Bay Area***:** HP and Carbon, both innovators of AM machinery, have centered their business operations in the Bay Area. Carbon, cited the availability of venture capital and talent (software, Internet of Things (IoT) and electronics) as primary reasons.
3. *Texas:* Because the University of Texas at El Paso (UTEP) has fundamentally strong AM components, the University has been selected as the first America Makes satellite. Alcoa and Essentium, both major corporate players in the AM space, have also established operations in Texas. Hardware manufacturer Essentium has recently developed a novel microwave process.
4. *New England:* Strong biomedical participants and startups are drawing AM resources to New England: examples include Voxel8 and the U.S. headquarters of EOS, a major German direct metal laser sintering (DMLS) machinery leader.
5. *Michigan***:** The manufacturing infrastructure that developed as a result of the auto industry has attracted European AM players, including three German

machine manufacturing companies: Voxeljet, SLM and Envisiontec, whose work includes the manufacturing of a biological material printer.

6. *North and South Carolina:* The presence of 3D Systems in Rock Hill, South Carolina, along with major OEMs like Boeing, BMW and Volvo, have created a strong regional AM base.

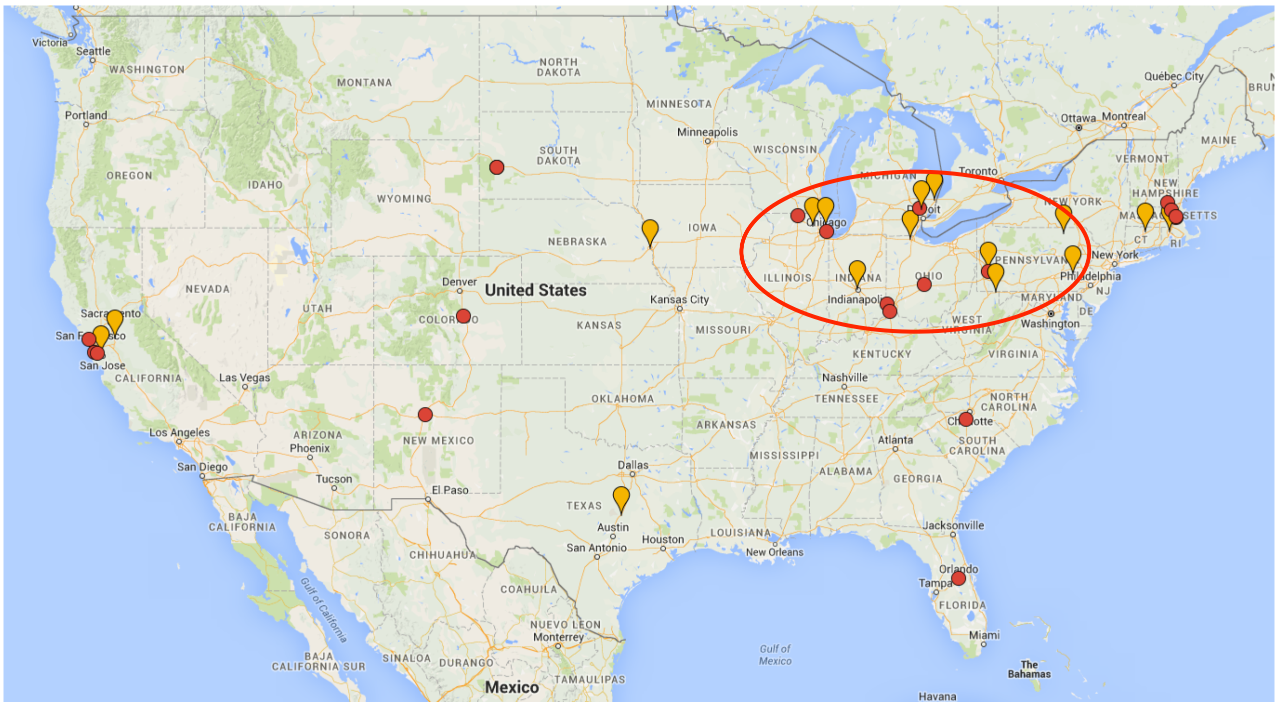
7. *Minneapolis:* The AM makeup of the City of Minneapolis is benefiting significantly from the U.S. headquarters of Stratasys, a world leader in 3DP, as well as the presence of the RedEye service bureau and a considerable medical technology base associated with over 36 biomedical technologies companies located with the city and a strong partnership with the University of Minnesota's Minneapolis campus.

8. *New York:* In 2012, Buffalo Manufacturing Works (previously known as the Buffalo Niagara Institute for Advanced Manufacturing Competitiveness) benefitted from an investment of $45 million as part of New York State Governor Andrew M. Cuomo's Buffalo Billion Investment Development Plan. That investment has spurred the development of AM facilities, equipment and talent acquisition. In 2014, Ohio-based EWI was selected as the operating partner for Buffalo Manufacturing Works.

Figure E below illustrates clusters of major commercial AM hardware and materials suppliers in the U.S. as of 2016. The map reveals tight clusters in California and New England and loosely-structured clusters throughout the Midwest. There appears to be no clear link between hardware and materials clusters anywhere in the U.S.

Figure E:

Major Commercial AM Clusters in Hardware and Materials



Northeast Ohio's central location among the relatively loose clustering of AM assets in the Midwest region suggests good opportunity for northeast Ohio to establish itself as a leader in providing central marketing and outreach campaigns for the entire Cleveland to Pittsburgh TechBelt region. In fact, it was the preexisting partnerships within this region that led to the federal designation of Youngstown (the geographic center of this area) as the host of America Makes. Northeast Ohio can establish this leadership role by initiating partnerships with neighboring regions that offer complementary assets. The May 2017 RAPID show that will be hosted in Pittsburgh, PA, provides one such near-term opportunity to establish a unified AM presence.

Assets Inventory

Northeast Ohio

V. ASSET INVENTORY

A. Northeast Ohio's AM Supply Chain

The study identified ~165 distinct companies and organizations directly involved in the AM supply chain. These assets were catalogued as having direct involvement in specific sectors of the AM supply chain; 35 companies were identified as having involvement in more than one sector. Following is a breakdown of the value chain segments identified as a result of the exercise:

1. *Materials:* 19 companies
    - polymers
    - metals
    - sands
    - other inorganic materials

    The region's AM materials assets include industry leaders 3D Systems, through its acquisition of Village Plastics in Norton, and Alcoa, through its acquisition of RTI International Metals in Niles. Lubrizol is another potential participant through its work on FDM filaments. A few start-ups in the region are also marketing FDM filaments.

2. *Systems/Systems Parts:* 15 companies
    - 3DP systems for industry and hobbyist use
    - manufactured parts for 3D printers (not necessarily AM produced)

    The fifteen participants in this segment include several startup companies manufacturing desktop 3D printers. Most notable of these is Maker Gear in Beachwood, selling desktop systems globally for several years. Lincoln Electric represents a significant new entrant in industrial metal printers, through its pioneering work in conjunction with CWRU and America Makes. The region also is home to system parts producers such as Strangpresse.

3. *Design/Engineering:* 14 companies
    - designing and engineering services specific to 3DP

    Northeast Ohio boasts strong design and engineering assets skilled in the use of AM. These include design houses such as NottinghamSpirk and SmartShape, service bureaus RP+M and The Technology House, as well as design capabilities within large regional manufacturers such as Parker Hannifin, Caterpillar, Swagelok, Diebold and Timken.

4. *Production:* 85 companies
    - applications include prototyping, tooling and direct parts production
    - service bureaus producing for others
    - end-user companies and manufacturers producing for themselves

    Parts production is clearly the strength of the region in AM, with 85 companies identified and probably many more than that are yet to be determined. The region is home to two very good service bureaus in rp+m and The Technology House. Dozens of metal fabricators, tool & die makers and plastic processors are using AM today or would like to learn how to apply it to their businesses.

5. *Post Processing:* 7 companies
    - processes include sealing, polishing and painting
    - service bureaus and manufacturers performing this in-house
    - companies offering this as a third-party service

    Post processing is an important step in AM part production. Most assets in the region are within the service bureaus and part manufacturers.

6. *Third Party Research & Development:* 18 organizations
    (This count does not include in-house R&D by manufacturers)
    - higher education institutions
    - government-funded organizations
    - industry organizations

    Northeast Ohio is exceptionally strong in this respect with America Makes providing funding and strategic leadership in development of manufacturing technologies, and CWRU, YSU, CSU and UA offering programs on AM design and engineering. CWRU's think[box] is a substantial dedicated AM teaching asset, and YSU's engineering curriculum offers some of the most focused AM training in the country.

7. *Workforce:* 19 organizations
    - formal education
    - certification
    - training and professional development

The region is also rich in workforce development programs, including a dedicated program at Cuyahoga Community College, and newer AM programs at Stark State and Lorain County community colleges.

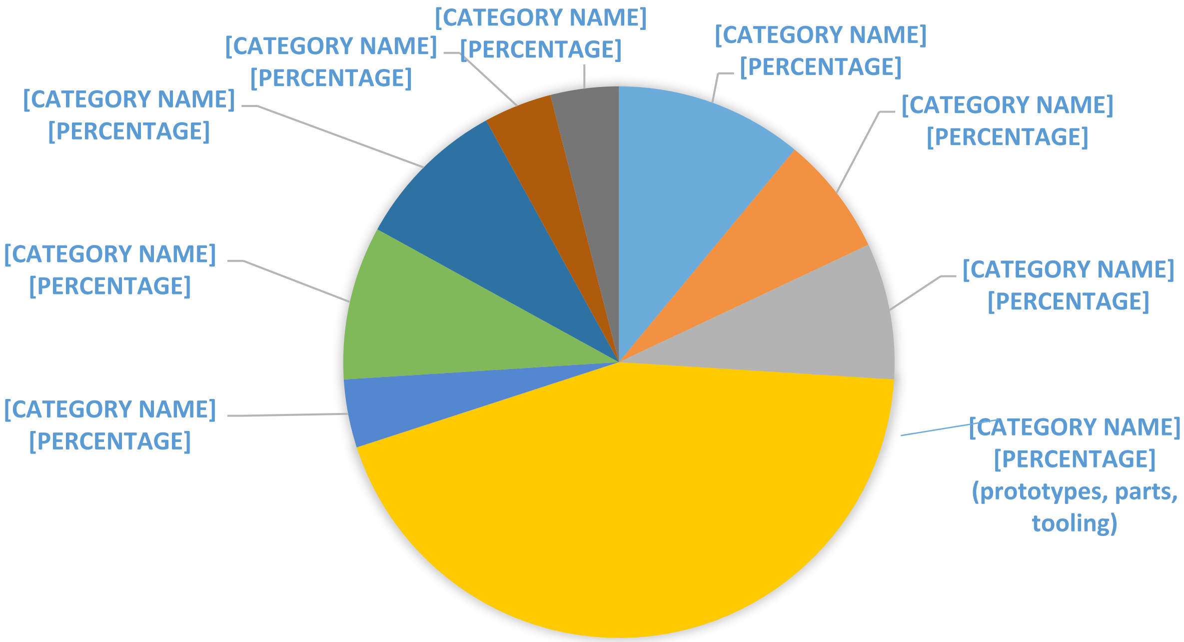
8. *Third Party Testing:* 9 companies
   - testing
   - measurement
   - inspection
9. *Value Added:* 3 companies
   - value-added resellers and servicers of equipment and systems
10. *Sourcing: 6 companies*

    (Generally not an in-house service)
    - production "middlemen," taking the prototype or production to a network of manufacturers, producers, designers

Software, while a very important component of the AM value chain, appears to be an under-represented sector in northeast Ohio.

Figure F below illustrates by percentage the assets that comprise each supply chain sector in northeast Ohio. The region's strengths are evident in the sectors of production, materials, design and engineering, R&D and workforce opportunities. These strengths were used to guide the Voice-of-the-Customer (VOC) interviews and analysis that follows in Section VI of this report, with a strong focus on identification of use case examples in part production.

FIGURE F: NEO VALUE CHAIN ASSETS - STRENGTHS



B. Investments in Northeast Ohio's AM Infrastructure

In addition to value chain assets, a region can achieve competitive advantage through well-placed investments in infrastructure. The most important of these in northeast Ohio is the location in Youngstown of America Makes, the federally funded NMII. Building from this core, the State of Ohio is well-positioned to garner significant economic gains should it leverage the AM assets already housed in the State; and effectively integrate those technologies into the existing manufacturing infrastructure.

Several existing state and regional initiatives are already in place in Ohio as detailed below:

1. *Economic Development:* Three economic development programs, the Ohio Development Services Agency, Ohio Third Frontier (OTF), Ohio Department of Higher Education, and JobsOhio have been investing in the advancement of AM across the State.
2. *Hybrid Manufacturing*: In 2014, the OTF's Advanced Manufacturing Program (AMP) provided funding which enabled YBI and YSU to create a hybrid manufacturing program called the Precision Printed Parts Network; additionally, the YBI's Accelerated Tooling Adoption Program (ATAP) is a result of that funding

initiative. Similar investments have been made at EWI in Columbus and the University of Dayton Research Institute.

3. *Marketing and Informational Materials:* JobsOhio has so far helped attract AM supply chain partners to the State by developing marketing and informational materials.
4. *Design and Production:* State support for the Manufacturing Extension Partnership (MEP) has enabled MAGNET to become a recognized national leader within the MEP system for AM design and production.
5. *America Makes:* The State of Ohio committed $2 million to match funds invested by the U.S. Department of Defense to establish America Makes.
6. *Startup AM Companies*: Startup AM companies receive support from the OTF Entrepreneurial Signature Program, and other JumpStart Entrepreneurial Network partners.
7. *Facilities and Equipment:* Funds from the Ohio Capital Appropriation Budget and Appalachian Regional Commission have been invested in YBI and YSU to establish facilities and purchase equipment that will advance AM activities in northeast Ohio.

VOICE-OF-THE-CUSTOMER INTERVIEWS

VI. VOICE-OF-THE-CUSTOMER INTERVIEWS

The future success of AM in northeast Ohio depends on the perceptions of regional manufacturing companies as much as it does on objective statistical analysis.

For this reason, more than fifty companies comprising northeast Ohio's AM value chain were interviewed during the course of this study. The objective was to obtain a relatively comprehensive picture of AM's integration into the regional manufacturing, design and training paradigm. Specific information regarding each participating company's perceptions and applications of AM were gathered, including: familiarity with or current applications of AM; perceived barriers to adoption; factors that would enhance business appeal; and preferred timeline of integration. General insights about training opportunities and end-user needs were also obtained.

Business use cases for each of northeast Ohio's AM supply chain sectors were also obtained, and the presentation of those summaries is included in Section VII of this study.

A. Parts Manufacturers: Voice-of-the Customer Interviews

The parts manufacturers that participated in the interview process consisted primarily of the following groups of metal and plastic processors, most of which also design or manufacture their own tooling and fixtures, since this manufacturing sector represents significant opportunities for regional AM growth. Independent tool and die shops were also contacted but none agreed to participate in the interview process. The two major service bureaus are not covered in this section, but are covered separately later in this report. The parts manufacturers interviewed included:

- Thermoplastic injection molders doing high volume production of bins, appliance and automotive parts, electrical fixtures, standby power, medical housings, telecom components and household goods, and including thermoplastic molders with integrated tool building;
- Thermoset compounds and molders that use compression and injection molding for large parts such as business machines, truck engine and exterior components, construction, electrical components, appliance parts and medical housings, and including molders of silicone elastomer parts;

- Metal fabrication shops that supply parts and tooling primarily for automotive, tires, medical devices and aerospace applications. Some of these act as subcontractors to regional machine shops that do mold assembly and act as direct suppliers to OEMs.

1. *Parts Manufacturers: Current AM Applications*

    - Prototyping is the primary use. FDM machines are commonly used to make demos for customers. Typical responses from this industry group include: “Engineering groups often have a small printer for prototypes, and sometimes for customer presentation.” They “use FDM internally to make prototypes for showing design to customers to get approval.” “We own 3D printer for prototyping to confirm design for mold production.” “We use FDM parts as a marketing tool to show parts or justify design improvements to customers.” Most manufacturers see great value in the use of AM machines for prototyping, shortening design cycles and improving customer response to new products and designs.
    - After prototyping, tooling and fixtures are the most common short term applications. Internal value is created when companies employ 3DP for tooling because it can enhance production efficiency and save cost, especially on design iterations. Some applications include producing jigs, fixtures and mold inserts. These uses require no customer approval or qualification, but create immediate ROI in production efficiency. Even those companies that rely completely on traditional manufacturing accept that value creation would result from incorporating AM. Applications were identified within all types of part manufacturers.
    - Metal AM processing machines (Direct Metal Laser Sintering) are not common among regional processors due to the high capital cost for entry. The existing DMLS manufacturers in the region run stainless, stainless alloys and Aluminum, but not titanium. Production part application examples involved part consolidation as a value creation element.
    - 3D printing of titanium has not been adopted for several reasons: inventory expense, capital needed to modify machines, need for argon tankage and safety concerns. Processors have no motivation to justify these expenses, since no volume applications are readily evident. Aerospace industry applications are not accessible as Tier 1 suppliers are backward integrated and produce their own 3D printed parts.
    - With this barrier to aerospace entry, metal AM processors have been more successful in tooling applications. Examples include tire molds and fixtures for medical device fabrication. Some expressed a clear interest in accessing more opportunities in biomedical uses.

- AM is not currently a viable finished part production option for most of the plastic injection molders that were interviewed, since they engage in the high-volume production of relatively large parts for automotive, appliance, housings, etc. Many recognize the value of AM tooling in small volume, higher value production, and would like to learn how to use AM to access this portion of the market. Some have considered the acquisition of companies that engage in AM for that purpose.
- Companies with limited familiarity with AM wanted to learn more about processes and capabilities for tooling, perhaps through events offered at America Makes.

2. *Parts Manufacturers: Barriers to AM Adoption*

- Most molders outsource full mold design/build due to lower labor costs in China, though regional material costs are comparable. These companies typically do have in-house CAD capabilities.
- Thermoset BMC/SMC is glass filled and abrasive, limiting the use of plastic tool inserts.
- Low complexity tools do not require the advantages offered by AM.
- In industrial applications with slow adoption cycles, a multi-cavity tool is partially finished, limiting the need for prototyping tools.
- Thermal resistance is a limitation for thermoset tooling, since molds have hot oil or heater cartridges and maintain a temperature of approximately 300 degrees Fahrenheit.
- AM parts with low draft angles require a secondary operation, since the AM finish would be unacceptable.
- Soft tooling isn't viable for complex inserts that include slides or pins needed by molders.
- The surface quality of FDM parts is poor, making aluminum a better and less expensive material option.
- Size constraints are a significant barrier, especially for the thermoset molding of large housings.
- Maintaining a workforce with necessary design skills is a barrier to AM integration.
- AM solutions are considered experimental and therefore not time worthy by some company leaders. Employees who are interested in innovating are pressured to abandon their efforts.
- Many do not understand the value proposition and relevant applications of AM technology.
- Misperceptions exist that production volume is too low and materials are too soft for tooling.

- Cost is a barrier in the minds of many. At least one molder got rid of prototyping printers because they were unreliable and too expensive to maintain. That company now outsources AM to service bureaus as needed.

3. *Parts Manufacturers: Encouraging AM Appeal*

- Maximize machine usage by increasing part production applications, including those that are not "mission critical."
- Educate end-users, such as OEMs, about the potential of AM capabilities.
- Identify opportunities to engage at inception of design, since redesign is not an option for qualified parts.
- Make connections with design and innovation teams at large regional OEMs.
- Encourage management to invest in AM R&D by sharing positive use cases, showing how competitors are cutting costs with AM applications, and by helping companies identify applications relevant to their production.
- Increase competitiveness with the Asian market, since U.S. molders are turning to China for tooling expertise and products, rather than just the lowest price.
- Increase volume production, array of materials and material durability for AM tooling.
- Identify applications that justify the purchase of a machine, such as production of legacy parts for the auto industry or small run applications in volumes of hundreds.
- Demonstrate ROI, as most would be interested in expanding tooling applications that are cost-effective.
- Implement common standards and improved reproducibility required to service Tier 1 and Tier 2 suppliers.

4. *Parts Manufacturers: Timeline of Integration*

- Many companies have no plans to implement AM for parts production, but they would like to learn more and would consider adopting AM processes as appropriate.
- Others have a general interest, but see no short term benefits to drive adoption.
- Many wish to implement AM now for tooling, jigs, and fixtures where production volume and size are feasible.
- Some companies see opportunities for valuable applications now, but they are waiting for evidence of ROI.

- Once they have more R&D time, many companies would like to engage in low volume production and design iterations for mold inserts.
- When production volume increases and materials are hard enough, those companies already using AM for prototyping are willing to consider using AM for tooling purposes.
- Customers are beginning to ask about applications, since they have seen and touched prototypes that enable “as built” visualization.

B. Service Bureaus

1. The Technology House

1. *TTH: Current AM Applications*

- TTH has been using SLA technology since 1996. SLA is used by their customers for fit and function, some testing, marketing models and show models. There are half a dozen applications where thousands of SLA parts are run for production applications for aerospace and commercial products every year. Internally SLA’s are used for master patterns for Silicone molds, foundry patterns, and visual aids for CNC machining and injection molding projects. FDM patterns are run for customers for functional parts out of engineering grade materials as well as parts for testing. They use FDM internally for holding fixtures, QC check fixtures, go/no-go gauges, end effectors and handling fixtures. The volume of customer prototyping has diminished somewhat since more OEMs and processors have purchased AM equipment. Customer use of SLA mold inserts is limited because, while their cost is only half that of AI-produced inserts, SLA-manufactured inserts are more likely to fail after limited use.

2. *TTH: Barriers to AM Production Adoption*

- Production speed and materials availability are key barriers to the broader adoption of AM as production parts. SLA, FDM, SLS and DMLS are currently being used in some production applications and have been for 10+ years.

3. *TTH: Encouraging AM Production Adoption*

- In September of 2015 TTH was selected as one of 4 beta sites in the USA for the new Carbon M1 machine running the CLIP technology. TTH chose the process because of the range of Isotropic production quality materials available as well as the “injection molded quality” surface finished right off the machine. Because of the success of the machine over the past 10 months, TTH has added 2 more Carbon machines for a total of 3.

3. *TTH: Timeline for AM Production Integration*

- TTH believes the timeline for production integration of the Carbon CLIP process along with other newer technologies with improved material capabilities has already started. Materials are the key, as the lack of production quality materials available until now has impeded the growth of additive into the production arena. TTH says the elimination of design restrictions is a key value add for printing of production parts. Designers will no longer have to design for manufacturability, but for weight savings as well as parts consolidation. AM provides the ability to create one part that would have been multiple part assemblies in the past. No tooling costs is another benefit to printing vs injection molding. Currently printing production parts in plastics or metals is a niche, but the continuous advancement of these new technologies is allowing new opportunities to take hold and grow very quickly.

2. rp+m

1. *rp+m: Current AM Applications*

rp+m is a recognized market leader in AM parts production, and they actively advocate an industry focus on high complexity parts, parts integration and the optimization of unique materials to maximize the value of AM. rp+m possesses a broad range of AM machines, making parts from plastic, metal and ceramic. rp+m also possesses strong material development resources and offers this as a service to the AM industry. As a result, their business is split about 50/50 between parts production and R&D efforts in the form of collaborative projects, contract R&D or consulting.

2. rp*+m: Barriers to AM Uses*

- Less than 5% of designs submitted to rp+m are optimized for AM, and this results in unrealistic cost expectations on the part of customers.
- Customers have offered to sell their AM machines to rp+m, complaining of maintenance costs and the need for dedicated labor and material inventory.

- With oversupply in the market, online job shops are priced only to cover costs. A significant number of service bureaus have been squeezed out of the market by integrated machine OEM/service bureaus. Two years ago there were 125 service bureaus in U.S.; that number is now less than 40.
- Closed models on materials are also stifling AM growth. As one example, a 4-pound material canister costs up to $3,000. If a manufacturer chooses to use another material, the machine warranty can be voided, which would result in higher costs for parts and labor.

3. rp+m: *Encouraging the Adoption of AM*

- When existing patents expire or new machine OEMs offer open sourcing, one barrier to growth will be removed and therefore encourage AM adoption.

4. *rp+m: Timeline for AM Integration*

- rp+m has been in part production for a range of uses for many years; the company agrees that tooling is a ready market and would welcome tooling business from molders and fabricators.

C. OEMs/End-Users: Voice-of-the-Customer Interviews

The two lead market verticals for AM, biomedical and aerospace, are core industries for northeast Ohio, employing >11,000 workers here, as shown in figure G. The automotive sector, a major northeast Ohio employer, represents short term AM opportunities in tooling as well as a future market for direct parts production via AM.

Figure G.

End User/Driver Industries: 2014

Industries	Establishments	Jobs	Location Quotient
Aerospace Mfg	43	3,855	.65
Medical/Dental Mfg	217	7,392	1.04
Motor Vehicle Mfg	218	26,842	2.37
Total	**478**	**38,089**	

Source: EMSI, 2015

1. Biomedical

Northeast Ohio is rich in biomedical assets, with world class hospitals that include the Cleveland Clinic, University Hospitals, NEOMED and Akron Children's Hospital. The region also boasts major biomedical device OEMs such as Steris, Invacare, GoJo, GE Healthcare, Siemens, and Philips, as well as major research institutions that include CWRU, the University of Akron and the Lerner Research Institute. Other assets are the vibrant startup communities fostered by Bio-Enterprise in Cleveland and the Austen BioInnovation Institute in Akron.

1. *Biomedical: Current AM Applications*

- Biomedical is a market that fits well with AM, as it primarily involves small volume uses where tooling costs would otherwise be prohibitive.
- To date, biomedical use cases involve prototyping and producing medical devices, models of body parts, pre-surgical imaging, printing of implants and tooling for medical research.
- A biomedical fixture application is the AM production of metal mandrels via DMLS for use in shaping of Nitinol, a shape memory metal.
- Cleveland-based startup Osteo Symbionics manufactures cranio-facial implants using AM to print PEEK and other biologically compatible polymers. These implants are patient-specific, and built to match scans of the patient.
- QED is a northeast Ohio company that uses AM to build medical devices for low volume applications. QED produces CAT (computerized axial tomography)/MRI (magnetic resonance imaging) coils, which are used to image specific body parts. QED uses AM to manufacture plastic device housings; in this case the economics work for these low volume, high margin products.
- Cleveland Clinic's Lerner Research Institute uses AM for a variety of applications. Multi-color Objet printers are used to create models of body parts from patient scans. One application of these models is to inform a surgeon by imaging the plaque buildup in a patient's aorta or to visualize the vascularization in a patient kidney. Another application is the reproduction of a patient's vascular system to help model fluid flow for research purposes. In the future, this work will allow the customization of implants such as hips and knees, replacing the limited sizes available to surgeons today.
- The ability to produce 3DP "cadavers" is the focus of one Cleveland Clinic spinout. The cadavers could be used as teaching aids in medical schools, allowing for disease-specific simulations that could be linked with the ability to use actual patient data for an enhanced learning experience. These AM- produced body

simulations could also be used as teaching aids and as sales tools for surgical products.

2. *Biomedical: Barriers to AM Adoption*

- A limiting factor today in developing more advanced models and implants is the availability of the range of materials needed for accurate simulation of body parts. For example, to accurately model an aorta, the most effective materials would simulate elastin, collagen and musculature.
- Time to market is bound by regulatory considerations, especially in the biomedical market.

3. *Biomedical: Encouraging AM Adoption*

- As advancements in AM continue, future applications will likely include the printing of biological materials, scaffolds for cell growth, and broader use in patient-specific implants.

2. Aerospace

Globally, the aerospace industry has been the lead adopter of AM for finished part production, with hundreds of AM parts incorporated by Boeing and Airbus. This has been a significant growth sector for metal part production, for both mission critical and less critical interior components. Value drivers include weight reduction, parts consolidation and design-driven performance enhancements. However, AM part production applications in aerospace are limited primarily to Tier 1 suppliers such as GE, Alcoa, Pratt and Aerojet.

1. *Aerospace: Current AM Applications*

- Regionally, most of the aerospace industry participants were unwilling to grant interviews, although we are aware of use of AM for tooling such as investment casting.
- Alcoa, a national manufacturer of metal powders and metal parts for aerospace, was generous in sharing use case examples. Nationally, Alcoa uses AM to create value in multiple applications, some of which include:
  - Production of titanium, aluminum and nickel powders at its production facility in the Pittsburgh area.
  - Metal part production via DMLS at its Texas facilities, with these parts being used throughout the aerospace industry. In general, aerospace companies are recognizing the benefits of low volume production,

weight savings and parts consolidation. Alcoa is fully integrated from metal powder production through finished parts.
  - Alcoa also produces finished parts via plastic SLS.
  - Soft tooling is used internally to improve processes; one example is a fixture that is able to marry powder bottles to storage containers
  - Alcoa uses AM to prototype tooling, such as investment casting molds as well as epoxy cores. Alcoa says its Whitehall, Michigan plant saves $1 million in tooling costs while shortening lead times.
  - They also prototype window lineals and complex joints, reducing the customer feedback cycle on new designs.
  - Alcoa has also realized productivity improvements through the use of 3DP steel or Inconel tooling. In one instance, they consolidated a 17-piece fixture into one part. These tooling applications are staged at their technical center in Pittsburgh, PA, and then rolled out to production facilities around the U.S.
  - Alcoa is also investing in hybrid processes such as AmpliForge, which uses AM to create a pre-form which is then finished via forging. This process shortens lead time, increases fatigue strength by 20 percent and lowers die costs.

2. *Aerospace: Barriers to AM Adoption*

- Tier 1 manufacturers cannot afford to risk the use of subcontractors for the production of mission/safety critical parts. Verification and validation standards set by the government or OEMs are appropriately strict on such applications.
- The current state of development of AM has inherent machine-to-machine variance, material batch variations and in-house processing know how. As a result, the Tier 1 manufacturers make their own parts or limit subcontracting only to key trusted suppliers. Thus, there are currently very few opportunities for a service bureau or Tier 2 manufacturer to enter the AM aerospace supply chain.
- Post-processing costs are often as high as the build cost.
- One regional aerospace supplier invested in a DMLS machine, but has been unable to penetrate aerospace applications due to the above supply chain constraints.

3. *Aerospace: Encouraging AM Adoption*

- Open sourcing, faster build times and less post-processing will enhance industry growth.

- Educating end-users regarding finish quality is key to managing expectations for critical components.
- Assistance in identifying use case examples with regional aerospace tiers.

3. Advanced Manufacturing

1. *Advanced Manufacturing: Current AM Applications*

    - OEMs are benefitting greatly from the shortened design cycles associated with 3DP. One OEM in particular shared that they use six Stratasys machines of different sizes, and all are used to run prototypes for their engineering team. They are now ready to upgrade two of their machines to run Ultem, which will allow them to move ahead with small volume production parts.

2. *Advanced Manufacturing: Encouraging AM Adoption*

    - Those OEMs interviewed would like to learn more about AM tooling applications and would specifically like to be introduced to regional supply chain partners.
    - More companies would engage in AM if they could identify a clear ROI.
    - Our work identified key OEMs that have AM design/engineering resources in the region, e.g., Lincoln Electric, Parker Hannifin, Diebold, Swagelok, and Caterpillar. It is clear that these are valuable growth assets for northeast Ohio; attraction of similar resources to northeast Ohio should be a key strategy for regional AM growth.

D. Materials

Limited interviews of this supply chain sector reveal knowledgeable players with good capabilities.

1. *Materials: Current AM Applications*

- 3D Systems purchased Village Plastics in Norton, Ohio in 2013, from which it supplies FDM filaments to the industry. While the acquisition of MakerBot by Stratasys resulted in the loss of its consumer market, 3D Systems still sells to open source systems, including 10 of the largest filament users in the US.
- 3D Systems is also working with regional compounders to co-develop new materials. These compounders run mostly ABS, PLA, HIPS and nylon6. 3D Systems will work directly with open source companies and material

suppliers, keeping the tooling business separate from its proprietary filament grades.

- A few startups in the region are also supplying FDM filament, including one with seven years of filament extrusion experience.
- Lubrizol has developed TPU grades for FDM at its Brecksville development facility and seeks assistance in supply chain collaborations. Their materials run well on open source machines.
- University of Akron has active R&D programs on AM materials.
- In the broader Tech Belt region, Additive Metal Alloys in NW Ohio is manufacturing metal powders for AM. Three major metal powder suppliers are located in the southwest Pennsylvania/West Virginia area - Alcoa, Puris and Carpenter.

2. *Materials: Barriers to AM Adoption*

- Metal printing is too expensive to support in-house prototyping.
- The closed model on materials from the major machine OEMS is a major barrier to new materials development.
- Existing patent portfolios by the major machine OEMs support their closed material model.
- Expensive consumables for industrial systems and limited options for sourcing less expensive materials.
- A small and fragmented market limits interest from major materials companies.
- Machine OEMs do not understand the importance of reproducible materials for a particular process or for the development of new alloys.

3. *Materials: Encouraging AM Adoption*

- Materials suppliers would like to meet a metal printer in the region so they can explore the value for complex parts. They are confident that there is value in this sector and they believe their engineers have sufficient knowledge of the tools and their designs to add value.
- Testing the integrity of materials and understanding ROI on industrial assets would encourage adoption of AM processes.
- Identification of potential users would assist adoption of AM.
- Shared IP, successful case studies, access to material testing and better education among potential end-users would all encourage adoption.
- Confidence in the speed, accessibility and scalability of AM technology would aid adoption.

- Open source machines would eliminate time wasted and significantly impact the potential of AM adoption.
- Better process controls.
- For small businesses, better accessibility to America Makes, the opportunity to leverage YBI's networking capabilities and training programs.
- Relationships with existing machine OEMs would expand opportunities, since OEMs are currently blocking the ability to develop customized products.

E. Design Houses

1. *Design Houses: Current AM Applications*

- The regional custom design studios provide a valued asset, given their 20+ years of experience in AM prototyping.
- One local design house cited an example in which it produces AM parts for a large, low volume housing. The poor quality FDM finish is acceptable since the housing is internal to the final assembly. The AM part has been designed with the intent that it can eventually be replicated in a molded part, once volume grows.
- The AM design assets at CWRU’s [think]box and MAGNET provide additional design resources for prototyping via AM.

2. *Design Houses: Barriers to AM Adoption*

- Aesthetics, structure, surface finish and cost are all barriers to adoption for design houses.
- AM is not always cost-effective. One resource shared an example of a part costing $10 to produce via FDM; the cost to cut a mold in China for the part was $5,000. Thus, for quantities greater than a few hundred, the traditional approach would provide better quality and lower price.
- An alternative route to prototyping is machined plastic models.

3. *Design Houses: Encouraging AM Adoption*

- No design house feedback was gathered in response to this question.

4. *Design Houses: Timeline for Integration*

- Design houses see no need to buy their own AM assets beyond simple desktop units. If they need better capability or extended runs, they use service bureaus like TTH or rp+m to print parts for them.

F. Workforce Training and Education

1. *Industry Training and Hiring Practices*

AM Positions in Corporate Structure

- Most companies continue to employ multi-purpose workers (cross-trained) since their business volume is not yet sufficient to support the hiring of lower-level production workers.
- AM is largely perceived as a free-standing technology rather than a tool to be integrated into the broader manufacturing enterprise.
- A few companies hire students to run production jobs and manage machine maintenance and programming.

Skill Needs

- Interview participants generally agree that design skills are the most critical component of the AM process and, therefore, require the most focused training and hiring processes. As one respondent noted, the key to regional AM success is training a new wave of designers and highly skilled programmers. Design considerations for AM, however, are not yet universally understood and are not yet deeply integrated into curricula.
- Current AM hiring needs are primarily in the area of post-processing and 3D design.
- Design houses are most likely to hire young, talented designers who are trained in AM but who may lack experience and context for integration of these technologies into the broader manufacturing ecosystem.
- Students coming out of current programs exhibit narrow view into the technology, coupled with limited curricular guidance on the appropriate use of this equipment for real-world applications. This leads to students who are excited about the technology but poorly informed about its potential.
- Operator training for AM was not identified as a priority need.

Credential Expectations for New Hires

- Some companies seek individuals with a formal education (i.e. engineering degree) with integrated elements of AM.
- Responders would like to see new accredited programs in Manufacturing Engineering with an emphasis on digital manufacturing.

- Industries would like to be able to rely upon nationally recognized credentials as a way to vet potential employees with AM expertise. However, no suitable credential has yet emerged as a *de facto* standard.

Training for Incumbent Workforce

- The AM process changes the role of machinists to some degree, so they will need to be retrained in AM skills.
- Many companies have more mature lead engineers who are less familiar with 3DP, managing younger engineers who are more familiar with the value proposition of 3DP.
- Most participating companies currently rely on similar and relatively informal training requirements including:
    - Independent programs at companies such as Deloitte and MOOGs
    - Maker Fairs and other industry events and speakers
    - Opportunities offered through America Makes and YBI
    - Personal research
    - Hands-on work experience, including the ability to design and produce prototypes using off-the-shelf parts
- Some note that these limited training options could become an issue should production levels ramp up quickly.

2. *Current AM Educational Curricula*

Content and Delivery

- Some regional curricula are based upon the AM Body of Knowledge or SME curriculum that has been developed by the Milwaukee School of Engineering.
- Educators at all levels exhibit lack of broad familiarity with the basic AM technologies and understanding of the opportunities to incorporate the technologies into current practice. This is a requisite skill to develop appropriate curricula.
- Current education and training programs tend to emphasize prototyping and the use of polymer extrusion equipment exclusively (predominantly MakerBot).

Curricular Integration

- Current AM-specific programs often do not integrate to broader curricula (e.g. mechanical engineering or chemical engineering).

- AM courses at all institutions do not appear to be integrated into the current enterprise framework of skills and disciplines. This limits the accessibility of the technology as an enabling tool with relevance to a broad range of both technical and non-technical disciplines.
- Discipline-specific courses and may limit the reach of the technology into the broader institutional curriculum.
- Faculty who lack adequate familiarity with the breadth of basic AM technologies and sufficient understanding of the opportunities to apply the technology may not appropriately integrate those technologies into existing curricula. Students are not necessarily receiving suitable content and context.
- Many universities now offer graduate level courses on AM. These courses provide broad introductions to the concepts of AM and provide students with context to apply fundamental knowledge from within their discipline to AM applications.

Topic Coverage

- Undergraduate curricula increasingly incorporates AM, but are overwhelmingly based on consumer-focused desktop machines (MakerBots are most prevalent). The narrow view into the technology, coupled with limited curricular guidance on the appropriate use of this equipment for real-world applications leads to students who are excited about the technology but poorly informed about its potential. This is not simply attributable to lack of resources. A $2.5-million investment by the Department of Labor has led to a degree program patterned after the SME / MSOE Body of Knowledge. The program has only polymer extrusion machines and focuses principally on prototyping.
- Curricula tend to emphasize prototyping with little formal incorporation of AM into core manufacturing processes courses or manufacturing enterprises more broadly.
- Design considerations for AM are also not yet formally included in curricula.
- Design strategies are complex and in a state of rapid evolution. Process capabilities and limitations are process specific. Thus, students who have access only to extrusion-based processes may have limited understanding of the broader design capabilities and limitations of AM.

G. Entrepreneurship and Commercialization

1. *Entrepreneurship and Commercialization: Current AM Applications*

- Existing start-ups in hardware production and component parts, education and training, materials and production.
- Strong support through state supported programs like Entrepreneurial Signature Program, PreSeed Fund, etc.

2. *Entrepreneurship and Commercialization: Barriers*

   - Closed relationships between OEMs and materials suppliers limit market opportunities, particularly in polymers.
   - OEMs and/or their employees are risk adverse.
   - The abundance of low quality desktop printers has resulted in a market that is saturated and suspicious of new products.
   - Software limitations reduce the ability of file transfers from companies to customers for downloading and printing because there is no way to control the volume of products that will be printed.
   - An educated and sophisticated investment base is needed, but copyright and patent issues and other uncertainties limit investor interest.
   - Companies do not understand AM technology or its capabilities, and most do not have staff sufficiently trained to implement processes.
   - Concerns exist about the integrity of printed parts and materials.
   - Better design offerings are needed to expand understanding of how to optimize the AM process.
   - More regional support for entrepreneurial, commercialization and investment opportunities is necessary.

3. *Entrepreneurship and Commercialization: Encouraging New Start-Ups*

   - Better and lower cost materials, better machines and better design tools are needed for broader AM adoption.
   - More case studies are needed to make the economic case for direct part production and AM as part of the manufacturing process.
   - More collaboration is needed between large businesses with AM capabilities and smaller businesses without, as well as between universities and businesses.

KEY VOC HIGHLIGHT SUMMARIES

Summary: Current AM Applications among Regional Companies

- Prototyping was clearly the most common AM application**.** Use cases spanned multiple parts of the supply chain. For example, processors who routinely use FDM and SLA said they were able to move more quickly to production because the turnaround time for receiving feedback and gaining customer approval was reduced. Likewise, OEMs and design firms have broadly adopted desktop printers or FDM machines as an engineering prototype tool for internal design development and as a marketing tool to present new product concepts to customers. Larger OEMs sometimes have several FDM machines available for this purpose, while smaller manufacturers rely on lower grade desktop printers. Regardless, all companies that were interviewed and that are engaging in AM were positive about accelerated design cycles, relatively short ROI, and resulting new business wins.

Summary: Barriers to AM Adoption among Regional Companies

- Most regional manufacturers are narrowly focused on production and cost margins. They work within mature industries that have a very low risk threshold for innovation.
- Company leadership does not always support innovation, and they are not motivated to innovate until they know that a competitor has successfully implemented a new technology. In that case, the company leadership is more willing to invest time and effort to remain competitive.
- Another barrier to adoption is process failure. When employees with limited 3DP experience are involved in a project, they often become early detractors if one or more trial processes fail. This hesitancy is typically a result of very limited past experience and unfamiliarity with current best practices.

Summary: Enhancing Appeal of AM Adoption among Regional Companies

- Not surprisingly, the majority of companies could be persuaded to engage in AM innovation if they saw evidence of the effectiveness of AM strategies and if they were confident that these strategies could be successfully and cost-effectively incorporated into their own production processes.

AM BUSINESS USE CASES

VII. BUSINESS USE CASES

Case Study: Extruded Vinyl Welding Fixture

Vinyl windows are typically fabricated from thermally welded sections of vinyl extrusions. The appeal of this process is that the extrusions are very cost effective to produce and can be cut to any length to allow for manufacturing window frames of any size. Different extrusion profiles can accommodate different styles and thicknesses of windows. In a particular application, a manufacturer developed an extrusion profile for a new style of window. Because of a combination of factors, the design has turned out to be difficult to manufacture reliably. Thermal stresses cause the extrusions to warp and they are difficult to align consistently during the welding process.

The current process relies upon poorly fitted wooden fixtures to align frame components during the welding process. Hardware store spring clamps are used to align the profiles in the vicinity of the weld. This process is time-consuming and unreliable. Over the past several years, fallout from the process has been as high as 90 percent (only 10 percent of produced assemblies were acceptable for sale). Through improvements to the extrusion process, the fallout rate has been reduced to around 70 percent. However, with proper tooling, fallout should be less than 10 percent. The cost of welding fixtures for simple extrusions is approximately $5,000. In this case, because of the complexity of the contours, the cost may be expected to be significantly more. Traditional tooling does not include specialized clamping in the vicinity of the weld such as would be required for this application. The necessary tooling for this application could be manufactured from low-cost polymeric printing techniques. The expected savings would be more than $4,000 in capital tooling costs, an expected 60 percent reduction in scrap rate.

Case Study: Blow Molding Tooling

A regional tool and die shop has a contract to produce blow molding tooling for small polypropylene (PP) bottles. The fixed price contract has involved multiple design iterations, each chipping away at the profitability of the job. New designs are manufactured at a cost of approximately $600-$800 each. If adopted, multiple molds can be produced for $200-300 each. Because of the low temperatures and forces involved in the blow molding process for PP, direct-print tooling options may be available. These options would allow for significant design flexibility, faster turnaround, and a new, highly marketable service offering for the tool and die shop.

Case Study: Tool and Die Shop, Part Visualization

Complex mechanical drawings can be challenging to read, even for very experienced machinists. A misinterpretation of a drawing can easily result in hours of valuable embedded work being ruined as a component is incorrectly machined. A regional tool and die shop has mitigated this risk by providing its machinists with physical, 3-dimensional representations of the finished component to aid in correct interpretation of the drawings. While it is difficult to capture the cost of accidents that may have been prevented by this strategy, the few dollars of cost associated with printing these models on a low-cost 3D printer are trivial compared to the potential costs of ruining a job that may be worth tens of thousands of dollars.

Case Study: Assembly and Inspection Fixtures for Hydraulic Pumps

Inspection and servicing of industrial hydraulic pumps requires unit-specific assembly aids and inspection fixtures. These tools can be extremely expensive, sometimes as much as $30,000 per set, and are unique to a specific pump or family of pumps. The tolerances for many of these fixtures are surprisingly generous, often on the order of 0.040”and well within the dimensional tolerances achievable with a wide variety of 3D printing technologies. Using such techniques, it is reasonable to expect that production of these tools may be possible at a fraction of the current cost.

Case Study: Laser Cutting Tooling

Complex metal stamping operations often require subsequent trimming of the excess metal from the edges of the part. In very high volume production, this trimming operation is often performed by expensive trimming dies. In lower volume production, the capital equipment costs may be reduced by using multi-axis cutting lasers. In a similar operation, lasers may also be used to weld two or more components together. In such setups, the complex contours of the components are precisely located by fixturing tooling. A northeast Ohio stamping company currently buys such fixtures machined from a combination of wood and metal. A typical cost for these fixtures was estimated at $6,000. 3D printed tooling to achieve this function could be manufactured at an estimated cost of $1,000, an 80 percent cost savings.

Case Study: Out of Production Parts

A regional hydraulic pump manufacturer receives frequent requests for repair parts for historical hydraulic pumps. These components have often been out of production for decades with no documentation available. The customers are not interested in replacing the pump with one of similar performance. The value of the application lies in the historical accuracy, something for which the customer is willing to pay a considerable premium. The manufacturer does not presently have a good way to serve this market. However, through the use of 3D scanning and several very cost effective techniques for creating castings from 3D printed tooling, this is an unserved market that the manufacturer may be able to capture.

Case Study: Low Volume Compression Molding

Compression molded thermoset polymers are used in a variety of high-strength polymer applications. A regional manufacturer of these products is frequently approached to quote components in low production volumes. Parts are ordinarily made in steel or aluminum molds. To reduce capital costs, prototype and low production volume parts may be made in single-cavity molds. Multi-cavity molds are typically used for higher production volumes. The cost of such a tool is typically $50k-$100k, which is prohibitive for small volume applications. For example, in one case the cost of tooling and production was quoted at $180k for a 400 part run. The process involves relatively high temperatures on the order of 250-300 degrees Fahrenheit. However, this temperature range is in the approximate range of some commercially available 3D printed materials and some that are currently under development. Foreseeable applications of 3D printed tools have the potential to reduce tooling costs in this case by 90 percent or more, thereby increasing the potential customer base and increasing the competitiveness of domestic tooling suppliers as compared to offshore tool production.

Case Study: Mold Redesign Assisted by 3D Printing

The thermoforming manufacturer made an innovative effort to use 3D printing to solve a manufacturing defect. Flow paths around a protruding insert within an existing tool were leading to a cosmetic “knit line” defect on the surface of an aesthetically critical component. The metallic inserts cost $5k-$10k to manufacture and had significant lead times. Engineers attempted to explore a variety of innovative solutions to the problem using $500 FDM printed inserts that were infiltrated with a polymer resin. This effort was assisted by an employee on staff who has specialized knowledge of 3D printing.

Had the effort been successful, it would have allowed the manufacturer to demonstrate the ability to use printed tooling for both cost savings and innovative process design. Unfortunately, the tooling stuck to the resin and broke during de-molding. While this manufacturer was on-track to making a significant leap forward in manufacturing processes, the failure of the process revealed several challenges to adopting these new methodologies. First, most manufacturers are narrowly focused on production and cost margins. They work in mature industries and have a very low risk threshold for innovation. The engineers who attempted this innovation were chastised for the time they spent on this idea and were told that they should not invest further effort in this approach. However, they admitted that if they knew that the approach was being successfully implemented by a competitor, they would invest significant effort and time to ensure that they remained competitive. The second challenge was that the staff engineer who came from a 3D printing background was one of the principal detractors of the effort. Within the company, he is the resident expert on 3D printing. Because his scope of expertise is limited, the perspectives he presented to management are not reflective of current and emerging best practices for 3D printing.

This case serves as an example of both the tremendous potential for 3D printed tooling applications and some of the unexpected sources of resistance to exploration of the technology. The most impactful motivator for companies to innovate will be a combination of demonstrating the effectiveness of these strategies and assisting companies to incorporate the strategies into their own production processes.

Case Study: 3D Printed Centerless Turning Tooling

A regional manufacturer of high-precision power-transmission components uses a centerless grinding technique to manufacture the "shoes" used to support the surface that is being ground. Ordinarily, these shoes are manufactured from high strength ceramic or metal that is precisely ground to match the contour of the production part. As part of an internal R&D effort, the manufacturer has explored the use of 3D printing as an alternative process for manufacturing these components. Preliminary results have shown that they are able to produce these components at a fraction of the price of the traditional process while achieving better performance in the application. As a result, the consumable shoes that had previously been imported from China are now being exported from the United States to production locations around the world including China.

Case Study: FDM Printed Mold Insert

As part of a small project that was funded through the University of Dayton, a regional injection molding company explored the use of FDM printed inserts for low volume production. The mold inserts were printed in ABS and were used to mold a clip to hold a metal cage on a Hobart mixer. Several hundred parts were successfully molded in polypropylene. The molding material was then switched to a glass-filled PP. The highly abrasive filled polymer destroyed the tooling, but only after 17-18 parts were successfully molded. The cost of the tooling was insignificant at a few hundred dollars compared to the $20k-$50k that might be expected for a comparable tool in aluminum.

Case Study: Prototyping/Design Enhancement and Validation

A plastic injection molding company is following the development of the technology, but currently, their production volume is too high for successful integration into their tooling development. However, the leadership recognizes the long term value of the technology and has personally learned how to design and print in order to better understand the future applications and opportunities. Currently, the company prints scale models of products for customers to validate before beginning the tooling process. By using an iterative process with the customer, they have been able to get better designs for products and more accurate tooling for production.

Case Study: Tire Mold Inserts

A metal fabrication company had traditionally made aluminum tooling for tire production. As tread designs became more complex, they were made aware that a German company had invested in metal AM to make "sipes", small complex steel inserts pinned into the aluminum tool. The local manufacturer invested in a metal machine a few years ago and now has two AM machines, supplying these inserts to tire manufacturers around the globe.

Case Study: Medical Implants

A Cleveland-based start-up manufactures cranio-facial implants from Polyetherketoneketone (PEKK), high-density polyethylene (HDPE) and other powdered plastics using SLS. This is a good example of patient-specific implants, where the printed part is built to match scans of the patient. The proximity to Cleveland Clinic made development of this business easier due to local opportunities to support such surgeries at CCF.

Case Study: Medical Device Manufacture

In a similar instance as above, a local manufacturer uses FDM to build medical device housings for low volume applications. The economics work for these low volume (less than a few hundred parts), high margin products. Costs include not only AM but many finishing steps including painting, but still is lower cost than building a production tool.

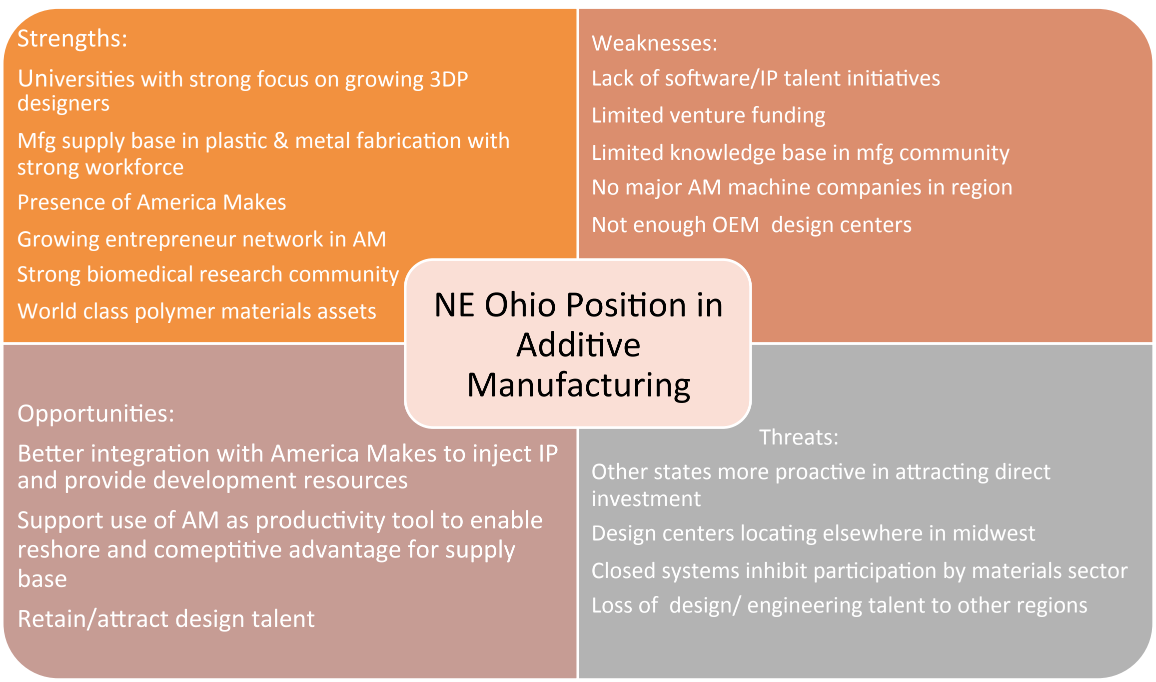
Case Study: Prototyping

Use cases for prototyping span multiple parts of the supply chain and were the most common applications identified. Processors use FDM or SLA routinely as a tool to demonstrate prototype designs to customers. This enables easier feedback and earlier acceptance of design concepts, allowing the processor to move forward with tool approval and production. Similarly, OEMs and design firms have broadly adopted desktop printers or FDM machines as an engineering prototype tool for internal design development and as a marketing tool to present new product concepts to customers. Larger OEMs sometimes have several FDM machines for this use. Smaller manufacturers may have a single low level engineering grade desktop printer. All seemed very satisfied with the return on this investment both as it accelerates the design cycle and increases new business wins.

Outcomes and Recommendations

VII. OUTCOMES AND RECOMMENDATIONS

The northeast Ohio region is ideally suited to become a national leader in additive manufacturing. There is an unusually high concentration of universities training design talent, a historically strong manufacturing base of industry and workforce, world-class materials and biomedical assets, and a growing presence of innovators and innovation service providers. The respective strengths and weaknesses of the northeast Ohio AM cluster are analyzed in the graphic below:



Drawing on the strengths identified in the assets inventory and building upon existing regional programs, the Asset Map team articulated a vision for proliferation of AM in northeast Ohio.

A. Vision

By 2023, Northeast Ohio will be recognized as a leader in:

- **design and engineering for additive manufacturing**
- **the use of additive manufacturing for productivity enhancements**
- **AM entrepreneurial investment and growth**
- **AM materials innovation**

- **the attraction of direct investment related to the core activities of America Makes**

B. Goals

To realize this vision, the team has defined five key goals for the region.

1. The formation of a regional innovation cluster that relies heavily on focused engagement with America Makes and that establishes northeast Ohio as the nexus of AM in the Midwest.
2. Drive expanded applications of AM for tooling, fixtures, and enhanced manufacturing productivity by making investments in technical support, capital equipment, workforce development, and industry-based educational programs.
3. Use formal education and workforce training initiatives to boost the adoption of AM, and place a strong emphasis on the development and retention of design and engineering talent.
4. Build out supply chain strength in the key market verticals of the automotive, biomedical and aerospace industries, including an attraction strategy for key gaps in the existing supply chains.
5. Establish a framework that will foster entrepreneurship and commercialization of AM supply chain technologies, as well as the northeast Ohio "maker" community.

C. Implementation Strategies

Goal #1: The formation of a regional innovation cluster that relies heavily on focused engagement with America Makes and that establishes northeast Ohio as the nexus of AM in the Midwest.

<u>**ACTION #1:** Engage with state, federal and local resources to support a northeast Ohio-based AM cluster:</u>

(Initiating Within Years 1-2: Short-Term Start)

- **1.1.A)** Establish a northeast Ohio- based AM innovation cluster, building from assets identified in this study
- **1.1.B)** Increase regional participation in America Makes through programs that will offset costs for Ohio-based businesses or provide other means of direct support for Ohio-based operations.

- **1.1.C)** Develop a state-sponsored collaboration with America Makes that targets retention and attraction of AM design centers for industrial leaders like Caterpillar, Parker and Eaton.
- **1.1.D)** Increase opportunities within the OTF for equipment funding, training, technology transition, commercialization, entrepreneurship and other needs.
- **1.1.E)** Expand the Federal Research Network of the Ohio Federal and Military Jobs Commission to include a focus on AM and America Makes.

(Initiating Within Years 3-4: Mid-Term Start)

- **1.1.F)** Establish an Ohio- based cluster for AM activities with regional nodes.
- **1.1.G)** Establish cluster membership model to supplement grant-based cluster financing.
- **1.1.H)** Initiate activities that will increase business visibility and expand opportunities for AM OEMs, materials companies, and software companies within the JobsOhio network and its partner organizations.
- **1.1.I)** Provide matching funds for various federal programs to support cluster development, including: U.S. Department of Commerce's pilot program entitled "One Commerce," which is intended to establish economic development support for institutes that are part of the National Network for Manufacturing Innovation (NNMI).
    - SBIR and STTR programs used to support R&D and advance the industry's technical capabilities
    - America Makes project opportunities to advance technology, conduct workforce development activities, promote commercialization and more

ACTION #2: Leverage America Makes' technical expertise, network, professional relationships, supply chain access, branding and other assets in order to optimize their economic impact on the region.

(Effort is currently happening "Year 0": Immediate Start)

- **1.2.A)** Create a commercialization model for startups and "scale-ups".
- **1.2.B)** Establish new working relationships and partnerships with economic development organizations, universities and other regional AM resources.
- **1.2.C)** Serve as a convener of TBEDs and other state and regional assets to create a steering committee for shaping future cluster development.
- **1.2.D)** Establish a low cost affiliate with America Makes (comparable to MEP models) that would support cluster activities, provide information and

assistance to companies regarding technology transition opportunities in Technology Readiness Levels (TRL) 7-10, and serve as a conduit to full membership in America Makes.

- **1.2.E)** Support the development of AM-focused industry groups.

(Initiating in Year 1-2: Short-Term Start)

- **1.2.F)** Act as an influencer by serving as a connector, networking organization and general resource to help develop markets, refine technology, secure business and provide technical advice.
- **1.2.G)** Build technology transfer programs relative to AM that will extend beyond America Makes' IP to include other research institutions.
- **1.2.H)** Create mechanisms to build AM capacity within OEMs supply chain.
- **1.2.I)** Lead prioritization efforts of common technical and workforce needs to ensure that public and private investments are directed to appropriate cluster activities.
- **1.2.J)** Establish programs that will generate increased utilization of the Innovation Factory for industry-related education and training.

(Initiating in Year 3-4: Mid-Term Start)

- **1.2.K)** Establish protocols to engage subject matter experts to review America Makes' IP for commercial readiness and then identify commercial partners to take the products to market.
- **1.2.L)** Participate in the America Makes' roadmapping and other processes that determine funding priorities, as well as those of other organizations, (e.g. Air Force Research Lab) to influence topic selections included in SBIR/STTR Broad Area Announcements).
- **1.2.M)** Aggregate content and facilitate sharing of data from partners to foster better decision-making and business use case models for AM.

(Initiating Within Years 5-7: Longer-Term Start)

- **1.2.N)** Create mechanisms to share foundational IP that will broadly advance technology without impinging upon the individual commercial opportunities.

ACTION #3: Leverage the relationships and infrastructure of the Tech Belt region to more effectively compete with other regions in terms of talent, company attraction and commercialization efforts.

(Effort is currently happening "Year 0": Immediate Start)

- **1.3.A)** Maintain ongoing dialogue with the Southwest Pennsylvania AM cluster regarding best practices, benchmarking and other shared resources.
- **1.3.B)** Maximize resources and value of the MEP network in AM activities throughout the region.

(Initiating in Year 1-2: Short-Term Start)

- **1.3.C)** Establish a regional marketing presence at the 2017 RAPID Conference.

(Initiating in Year 3-4: Mid-Term Start)

- **1.3.D)** Open a dialogue with key Technology Based Economic Development Organizations in Michigan to gain access to European AM machine transplants and the automotive market.
- **1.3.E)** Identify project opportunities for regional supply chain collaborations with Tech Belt OEMs & Tier 1 suppliers.

(Initiating Within Years 5-7: Longer-Term Start)

- **1.3.F)** Develop multi-state proposals to garner federal support for AM cluster building activities

Goal #2: Drive expanded applications of AM for tooling, fixtures and enhanced manufacturing productivity by making investments in technical support, capital equipment, workforce development and industry-based educational programs.

ACTION #1: Establish and scale programs to support the integration of additive manufacturing technologies into the existing manufacturing base in order to increase their global competitiveness.

(Effort is currently happening “Year 0”: Immediate Start)

- **2.1.A.)** Fully scale the Advanced Tooling Acceleration Program (ATAP), a partnership between YBI, YSU, and Magnet, to promote the integration of AM for tooling in northeast Ohio small and medium enterprises (SMEs).
- **2.1.B.)** Secure funding to deploy AM and enabling technologies on a broad scale within the northeast Ohio manufacturing base.
- **2.1.C)** Establish a database of AM service providers, processes and equipment in the region.

(Initiating in Year 1-2: Short-Term Start)

- **2.1.D)** Build upon hybrid manufacturing expertise that is currently being developed within YBI's Precision Printed Parts Network in order to further integrate AM and traditional manufacturing processes.
- **2.1.E)** Develop outreach campaign to regional manufacturers to encourage cluster participation.
- **2.1.F)** Host events and meetings to encourage deeper understanding of the technology.
- **2.1.G)** Leverage work statewide through MEPs, JobsOhio, and Entrepreneurial Signature Program (ESP) programs as a means of expanding the economic use cases and disseminating information on current industrial AM applications.
- **2.1.H)** Create marketing campaigns through Cleveland+ to position the region as a leader in use of AM to enhance productivity.
- **2.1.I)** Establish formal linkages between existing regional assets including universities, incubators and service providers with the goal of creating a shared resource and encouraging the formation of an ecosystem that includes mechanical testing, materials formulation, mechanical design, prototyping, fabrication, and post-processing.
- **2.1.J)** Create professional development and marketing materials to position economic development professionals to conduct outreach within the industry regarding the competitive advantages associated with AM.

(Initiating in Year 3-4: Mid-Term Start)

- **2.1.K)** Develop core competency in reverse engineering techniques and legal issues related to the subject.
- **2.1.L)** Market regional AM leadership at national and international manufacturing events such as IMTS and Hannover Messe.

(Initiating Within Years 5-7: Longer-Term Start)

- **2.1.M)** Create technical resources within universities, chambers of commerce and tech based economic development organizations to help companies successfully apply AM in their production processes.
- **2.1.N)** Establish a facility and/or technical resource to provide independent third party evaluation of printers and materials to reduce the risk associated with capital investments.

Goal #3: Use formal education and workforce training initiatives to boost the adoption of AM and place a strong emphasis on the development and retention of design and engineering talent.

ACTION #1: Support the growth of AM workforce training and the development and dissemination of nationally recognized credentials for AM professionals.

(Initiating in Year 1-2: Short-Term Start)

- **3.1.A)** Train incumbent manufacturing professionals at all levels to understand AM processes and the ways in which this technology will change current technologies and business models.
- **3.1.B)** Participate in the efforts of standards development bodies and educational institutions to advance the development of standardized AM credentials and robust training opportunities that address industry needs and opportunities.

(Initiating Within Years 3-4: Mid-Term Start)

- **3.1.C)** Identify available curricula that will best support workforce development, including technician training, certification programs, degree programs, and C-level training.
- **3.1.D)** Encourage public awareness and positive media support to advance the development and implementation of workforce training and educational programs.
- **3.1.E)** Work with State of Ohio Workforce Policy Board to establish common curricula and learning goals for AM-related training activities.

ACTION #2: Expand inclusion of relevant AM content within K-12 and post-secondary degree program curricula.

(Effort is currently happening "Year 0": Immediate Start)

- **3.2.A)** Foster the development of college curricula that integrate AM into both undergraduate and graduate programs across a range of disciplines that extends beyond engineering and the sciences.

(Initiating in Year 1-2: Short-Term Start)

- **3.2.B)** Provide training opportunities for educators to become familiar with the current state of AM, fundamentals of AM design for AM, and best practices of AM in relation to traditional manufacturing processes.
- **3.2.C)** Establish a formal relationship between America Makes, YSU, YBI and other regional training institutes to create seamless delivery systems and avoid duplication of services.
- **3.2.D)** Develop and proliferate undergraduate curricula that emphasize practical, real-world applications of AM, potentially covering the spectrum

from the maker view of desktop 3DP through commercial applications of industrial grade printing.

(Initiating in Year 3-4: Mid-Term Start)

- **3.2.E)** Provide industry engagement opportunities for students and faculty to encourage awareness of industry needs and culture to ensure that AM classroom activities align with real world applications.

Goal #4: Build out supply chain strength in the key market verticals of the automotive, biomedical and aerospace industries, including an attraction strategy for key gaps in the existing supply chains.

Materials

<u>**ACTION #1:** Establish programs that will drive materials R&D and advance industrial applications and lower cost structures for AM.</u>

(Initiating in Year 1-2: Short-Term Start)

- **4.1.A)** Link materials companies to emerging open source printer manufacturers, such as HP and Carbon.
- **4.1.B)** Work with America Makes to leverage its relationships with OEMs to support the integration of new materials into the supply chain.

(Initiating in Year 3-4: Mid-Term Start)

- **4.1.C)** Conduct additional VOC calls and customer surveys to determine the most critical materials needs for industrial applications.
- **4.1.D)** Provide market development support to link regional filament manufacturers to open source printers and captive users.
- **4.1.E)** Build ties to the metal powder manufacturing base in the Tech Belt region.

(Initiating Within Years 5-7: Longer-Term Start)

- **4.1.F)** Create a marketing campaign to raise awareness of regional suppliers.
- **4.1.G)** Provide support for the submission of SBIR and STTR proposals on topics that would result in commercially viable materials projects. Leverage the relationships that America Makes and its members have on a federal level to have related topics included in SBIR/STTR Broad Area Announcements.

Biomedical

<u>**ACTION #2:** Work with the existing cluster organization, BioEnterprise, to strengthen their knowledge of AM and support collaborations where appropriate:</u>

(Initiating in Year 1-2: Short-Term Start)

- **4.2.A)** Initiate a series of communication forums to inform Bio-E team of AM opportunities in biomedical.
- **4.2.B)** Host informational and networking meetings, publish articles and conduct other outreach to raise awareness of the opportunities for AM within biomedical.

(Initiating in Year 3-4: Mid-Term Start)

- **4.2.C)** Link large regional biomedical companies to regional supply chain assets.
- **4.2.D)** Link the existing regional supply chain in parts production to research assets at CCF, UH and the VA hospitals to help create a broader materials palette that is needed for medical implants and pre-surgical models.
- **4.2.E)** Work with regional researchers at UA, CWRU and CCI to identify funding sources to establish startups or create spin-outs for their work, and provide a mechanism for incubating these innovations through cluster resources.

(Initiating Within Years 5-7: Longer-Term Start)

- **4.2.F)** Conduct attraction programs for companies and research assets relating to tissue engineering.
- **4.2.G)** Support startups and spin outs from CCI relating to tissue engineering

Aerospace and Defense

<u>**ACTION #3:** Leverage statewide resources in aerospace and defense to create AM focused attraction and expansion mechanisms.</u>

(Effort is currently happening "Year 0": Immediate Start)

- **4.3.A)** Support the rollout of YSU/YBI's Maturation of Additive for Low Cost Sustainment (MAMLCS) to engage of Ohio manufacturers in the OEM supply chain through the strategic use of AM.

(Initiating in Year 1-2: Short-Term Start)

- **4.3.B)** Establish programs to leverage America Makes' relationships with OEMs to facilitate supply chain development.

- **4.3.C)** Use America Makes relationships to facilitate more effective VOC with existing regional Tier 1s.
- **4.3.D)** Partner with JobsOhio and Team NEO to create a focus on the attraction of development and production centers for OEMs or Tier 1 suppliers.

(Initiating in Year 3-4: Mid-Term Start)

- **4.3.E)** Partner with Ohio Aerospace Institute (OIA), University of Dayton Research Institute (UDRI) and the Air Force Research Labs (AFRL), to probe for tooling and other applications specific to aerospace supply chain participants.
- **4.3.F)** Identify and support the use of AM by regional Tier 1s.
- **4.3.G)** Link regional supply chain to aerospace OEMs.

Automotive

ACTION #4: Identify AM needs and drivers in the automotive industry and link them to a core manufacturing productivity strategy.

(Initiating in Year 1-2: Short-Term Start)

- **4.4.A)** Pursue further VOC activities with automotive OEMs and Tier 1 suppliers, with a short--term focus on the identification of tooling and fixture opportunities.

(Initiating in Year 3-4: Mid-Term Start)

- **4.4.B)** Establish broader cluster linkages to automotive OEMs and Tier 1s and link them to northeast Ohio service bureaus and processors.
- Survey needs of regional OEMs and Tier 1s and link to supply chain assets.
- **4.4.C)** As new, faster AM technologies become available, encourage adoption for direct parts production. For example, Carbon who is already in beta test at The Technology House, indicates that they are already in development of direct parts production at automotive Tier 1, Delphi.
- **4.4.D)** Link to market survey efforts by other NNMIIs; for example, NextFlex is identifying needs among automotive and appliance manufacturers.

Goal #5: Establish a framework that will foster entrepreneurship and commercialization of AM supply chain technologies, as well as the northeast Ohio "maker" community.

ACTION #1: Establish a culture to support technology commercialization and entrepreneurship in AM technologies.

(Effort is currently happening "Year 0": Immediate Start)

- **5.1.A)** Conduct startup challenges or business attraction activities to identify new software, hardware, and materials solutions for the AM industry. Leverage America Makes, JobsOhio, ESP and other assets to bring visibility and significant prize packages to the effort.
- **5.1.B)** Work with state agencies and the U.S. Department of Commerce to align resources and programs to support entrepreneurship and technology commercialization in AM, without regard to the business stage.

(Initiating in Year 1-2: Short-Term Start)

- **5.1.C)** Leverage the relationships of America Makes, the Jumpstart Entrepreneurial Network, YBI, and other resources to establish a network of angel investors and venture capital organizations willing to support startups in the field.
- **5.1.D)** Establish programs to promote successful state and federal research grants to develop new intellectual property.

(Initiating Within Years 3-4: Mid-Term Start)

- **5.1.E)** Support "Maker Spaces" and other resources throughout the region to encourage the development and commercialization of both high-tech and low-tech products.
- **5.1.F)** Establish protocols to engage SMEs to review America Makes' IP for commercial readiness and then identify commercial partners to take the products to market.

BIBLIOGRAPHY

IX. BIBLIOGRAPHY

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REFERENCE PAGE

INDUSTRY TERMS AND ACRONYMS

X. INDUSTRY TERMS AND ACRONYMS

- 3DP: Three-Dimensional Printing
- AFRL: Air Force Research Laboratory
- AM: Advanced Manufacturing
- AM4MC: Advanced Manufacturing For Metal Casting
- CAGR: Compounded Annual Growth Rate
- CAT: Computerized Axial Tomography
- DMLS: Direct Metal Laser Sintering
- FDM: Fused Deposition Modeling
- IDC: International Data Corporation
- IP: Intellectual Property
- MAMLCS: Maturation of Advanced Manufacturing for Low Cost Sustainment
- MRI: Magnetic Resonance Imaging
- OAI: Ohio Aerospace Institute
- OEM: Original Equipment Manufacturer
- OTF: Ohio Third Frontier
- P3N: Precision Printed Parts Network
- PEKK: Polyetheretherketone
- PP: Polypropylene
- ROI: Return on Investment
- SLA: Stereolithography
- SME: Small to Medium Enterprise(s)
- TPU: Thermoplastic Polyurethane
- TTH: The Technology House
- Tiers: Tier 1 companies are those supplier companies most critical to an OEM. Tier 2 companies are those supplier companies which service Tier 1 companies.
- UDRI: University of Dayton Research Institute
- UT ORNL: University of Tennessee Oak Ridge National Laboratory

XI. APPENDIX: LIST OF AM ASSETS IN THE NORTHEAST OHIO REGION

Value Chain Participants Identified in NE Ohio

OEMs	Biomedical	Automotive	Aerospace	Advanced Mfg	Other
	GE Healthcare, Cleve Clinic, OrthoHelix, QED, GoJo			Diebold, Nanotronics, Swagelok, Timken, EGC	American Greetings, Riddell, Turning Technology

Post Production Processing	Akron Metal Etching, AZZ Galvanizing, Bodycote, Clever AM, HI TecMetal Group, Pressure Technology of Ohio, Team Industrial
Part Production	3D Bakery, Acro Tool & Die, AkroMils, Akron Polymer Products, Alios 3D American Engineering Group, Apto-Orthopaedics, Astro Mfg & Design, Automation Plastics, Cam-Lem, Clever AM Co., Flambeau, HotEnd Works, Humtown, Intellirod, Kovatch Castings, Laszeray, MDF Tool, Midwest Valve, Molded Extruded Specialties, Molding Dynamics, New image, OsteoSymbionics, Parallel Designs, Parker Hannifin, PCC Airfoils, Robin Ind., RP+M, S&B Metal, Tek USA Composites, Technology House, XL Pattern Shop, Zimmer Biomet, Zin Tech. Colonial Pattern, Venture Plastics, Alcoa Tempcraft, Prospect Mold, Sajar Plastics
System Mfrs and system parts	3D PrinterWorks, AMI, AST2, B3 Innovations, Cam-Lem Inc, Hapco, Hotend Works, Eagle Engring Sol'ns., Helix Linear Tech., JuggerBot 3D, Lincoln Electric, MakerGear, Saint Gobain, Strangpresse, Stratasys
Product Design	AMI, Alios 3D, AST2, Cardboard Helicopter, C2P, Dillen Greenhouse, Freshmade 3D, IAMT, Interdesign Inc, Jergens, Kovatch Castings, MAGNET, Monoco Design, Nottingham Spirk, Parabolic Designs, Sare Plastics, SmartShape
Materials	Alcoa Titanium, Atotech, BASF, Curbell Plastics, Eagle Elastomer, Freeman Manufacturing & Supply Co., Fila-mint, Graf Tech Global Ent., Hapco, HC Starck, Lubrizol, Materion, PolyOne, Powdermet, Praxair, Pyrotek, Saint Gobain, Smart 3D Solutions, Village Plastics, TripTech Plastics, Zircoa
Workforce	Advanced Employment Connection, AST2, ASM International, Case Western Reserve University, Cleveland Engineering Society, Cleveland State University, College of Wooster, Cuyahoga County Community College, Lorain County Community College, NCATC, North Central State College, Stark State College, Tooling U-SME, University of Akron, Wire-Net, Youngstown State University
Research Institutes	Case Western Reserve University, Cleveland State University, University of Akron, Youngstown State University