Ohio Jobs Project

A Guide to Creating Advanced Energy Jobs

MARCH 2016

AMERICAN JOBS PROJECT

A Letter from the American Jobs Project

It's no secret that America's middle class is in crisis; indeed, "the hollowing out of the middle class" has become a well-worn phrase, causing politicians to rail, bloggers to rage, and citizens to reel. Polls consistently reveal that jobs and the economy are at or near the top of citizen concerns.[1] Over the last few decades, the loss of middle-income jobs in America has been due largely to the global shift in manufacturing ("tradable jobs") to emerging economies.[2] Of the millions of jobs lost during the recession, most were good-paying, middle-class jobs.[3] Unfortunately, many of the jobs created during the recovery have been in low-skill, low-paying occupations.[4] These trends are not going to reverse themselves. Leadership is needed, but the gridlocked U.S. Congress has failed in recent years to adopt robust policies to stoke middle-class jobs in America.

In President George W. Bush's autobiography, *Decision Points,* the former president recounts a conversation he had with the then-President of China, Hu Jintao. "What keeps you up at night?" President Bush asked President Hu as an icebreaker. As we can easily guess, what kept President Bush up at night was worry about terrorism. Hu Jintao's response was telling: what kept him up at night was "creating 25 million new jobs a year" for his people.[5]

Is it possible to create good-paying American jobs in today's global economy? And what if the solutions did not involve Congress at all? What if there were creative middle-class job creation strategies being developed and tested in the laboratories of democracy—the states and cities? The American Jobs Project seeks to answer these questions and provide a research-based roadmap for action for state and local leaders who are kept up at night trying to figure out how to create jobs for the people they serve.

Our quest starts with identifying the biggest market opportunity of our era: the global demand for advanced energy solutions. That demand—whether borne out of a need for diverse, reliable, and clean power or to achieve energy independence from unstable regimes—creates "the mother of all markets" for local U.S. businesses to build and sell those solutions.[6] Strategically minded businesspeople looking at global growth projections in advanced energy demand are making major investments and

reaping large revenues. In 2014, the private sector reported $1.3 trillion in global advanced energy revenues, the fastest growing year on record.[7] Advanced energy investments are now bigger than the global apparel sector and almost four times the size of the global semiconductor industry.[8] And jobs? Up to 16.7 million jobs are projected to be in the global advanced energy sector by 2030, almost tripling the 5.7 million people employed in the sector in 2012.[9] The question for the United States is: where will those new jobs be created?

The American Jobs Project is about finding ways to make our states the answer to this question. If countries across the globe, including the United States, are seeking technical products and solutions for our growing energy needs, how can U.S. businesses take advantage of this demand and build products locally that can be exported to the world? And how can we equip U.S. residents with the skills those businesses need to build their advanced energy products?

It is true that the United States will not likely be able to attract back the traditional manufacturing jobs of the past; those jobs are gone—either to low-wage countries or to automation—and we have to accept the fact that they are not coming back.[10] But our research shows that with innovative policies and a smart focus on industrial clusters, states can become hubs of innovation and job creation in specific advanced industries that soar with a state's strengths.

The American Jobs Project gives policymakers the tools to create good-paying jobs in their states. We propose innovative solutions built upon extensive research and tailored to each state. Many are best practices, some are new, and all are centered upon a state's business ecosystem. These solutions are written with an eye towards streamlining bureaucracy and are seasoned with the principles of competition, local control, and fewer regulations.

If these recommendations are adopted, the beneficiaries will be those hard-working Americans looking for the dignity of a good-paying job.

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About Us

American Jobs Project

The American Jobs Project is a national, interdisciplinary, research-based initiative. Our team includes nearly 100 student researchers with a broad range of expertise, including law, business, engineering, and public policy. We have ongoing relationships with hundreds of on-the-ground stakeholders and are actively collaborating with university partners and industry allies.

Academic Partner: The Great Lakes Energy Institute at Case Western Reserve University

The Great Lakes Energy Institute (GLEI) at Case Western Reserve University (CWRU) empowers faculty, students, and partners to catalyze breakthroughs in energy sustainability that address the most pressing problems facing our world. GLEI directly supports faculty in energy research by promoting collaborations—including industry and university partnerships—for the pursuit of winning major energy funding and educating students. Since the Institute's inception, CWRU has quadrupled its level of energy-related research. CWRU has more than ninety faculty focused on energy and sustainability research across all disciplines. GLEI's focus research platforms include energy storage, future power, solar energy, wind energy, and sustainable natural gas exploration. In addition to research, GLEI plays an integral role in connecting faculty and assets at CWRU with the wider world, including hosting an energy Speaker Series, which brings together industry, academia, and government energy leaders.

Acknowledgments

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We extend sincere gratitude to the hundreds of individuals from businesses, government, nonprofits, utilities, and universities for meeting with us, exploring ideas, participating in working groups, collaborating on the report, and sharing their vision for the future. Many thanks to Trish Demeter and Brennan Howell from the Ohio Environmental Council for their thorough and thoughtful review of our report.

Dozens of hands were involved in the process of researching, writing, and designing the report. The lead researcher and author was Mary Collins, the lead editors were Stephanie Smith and Kate Ringness, the lead analyst was Henry Love, and the graphic designer was Amariah Baker. Other authors and researchers include Rachel Young, AJ Hermann, Tiffany Wong, Peter Florin, Rob Moore, Nimit Dhir, and Amanda Brief.

Executive Summary

The American Jobs Project was borne of two tough problems: loss of middle-class jobs in America and congressional paralysis. It seeks to address these problems by taking advantage of one of the biggest market opportunities of our era—the advanced energy sector—and to do so at the state, not the federal, level. Policymakers who leverage the unique strategic advantages of their state to grow localized clusters of interconnected companies and institutions are poised to create quality jobs.

Ohio is well-positioned to benefit from the growing demand for advanced energy given the state's strengths in advanced manufacturing and engineering, leading universities and research facilities, and skilled labor force. Opportunities to leverage this momentum to further serve growing regional, national, and global markets offer real benefits for Ohio's economy and good-paying jobs for the state's residents.

Extensive research and more than 100 interviews with local stakeholders and experts in Ohio have resulted in identifying two economic sectors that show particular promise: wind and additive manufacturing.

There are several barriers hindering Ohio's advanced energy industries and preventing supply chains from reaching their full potential. Ohio must address these roadblocks to grow the state's advanced energy sectors and realize economic gains. To take full advantage of these opportunities, Ohio's policymakers can enact policies to increase demand for wind power and additive manufacturing technology and to help the state's businesses grow, innovate, and outcompete regional, national, and global competitors. Indeed, with the right policies, Ohio can support as many as 26,000 total jobs annually between 2016 and 2030 in these two clusters.

This project serves as a research-based roadmap for state and local leaders who seek to develop smart policies focused on leveraging the state's resources to create skilled, good-paying jobs. Concerted effort at the state and local levels can create an environment that attracts advanced energy businesses to take root in Ohio. Employees in the advanced energy sector will spend their earnings in the local economy at grocery stores and restaurants, and those local establishments will need to hire more employees to satisfy demand. This creates a multiplier effect throughout Ohio's economy, where a single dollar spent in a community circulates through local businesses and their employees numerous times.

Summary of Policy Recommendations

The analysis presented in this report culminates in four thematic sets of recommendations for Ohio's leaders. Each set of recommendations identifies opportunities for barrier removal and future growth in the wind and additive manufacturing clusters. While the recommendations are intended to be complementary and would be powerful if adopted as a package, each can also be viewed as a stand-alone option.

Wind Energy

Encourage Foreign Direct Investment: Recruit foreign companies to Ohio in order to boost wind investments and fill gaps in the supply chain.

Amend Setback Requirements to Allow Flexibility for Turbine Size: Modify current setback requirements to meet the needs of rapidly growing turbines and small-sized distributed turbines.

Create an Ohio Wind Credit: Stimulate wind investment by establishing a wind production credit.

Create an Anchor Company Tax Credit: Offer a tax credit to companies that successfully recruit other wind-related businesses and suppliers to Ohio.

Establish a Port Retooling Strategy and Infrastructure Funds: Upgrade the Port of Cleveland for offshore wind activity through a public-private funding mechanism or a revolving loan program.

Additive Manufacturing

Encourage Foreign Direct Investment: Recruit foreign additive manufacturers to Ohio in order to boost investment and fill gaps in the supply chain.

Capitalize on Digital Manufacturing Innovation to Drive Job Creation: Promote advances in manufacturing technology by assisting companies with corresponding workforce training and technical support.

Connect Small Businesses to Research Institutions Through an Innovation Voucher Program: Encourage 3D printing adoption by allowing small businesses to use a voucher program to pay for equipment and consulting services from industry experts and local research institutions.

Establish an Additive Manufacturing Factory Retooling Program: Encourage in-state manufacturing of 3D printing machines, materials, and services by providing capital for retooling factories, purchasing equipment, and building facilities.

Minimize Manufacturing Waste: Reduce manufacturing waste in Ohio by providing incentives for waste-minimizing technologies or mandating a waste reduction target for the manufacturing sector.

Create a Manufacturing Technology Council: Form a council that unites Ohio's additive manufacturers, advises state leaders on polices, and helps the state remain competitive in national and global markets.

Innovation Ecosystem and Access to Capital

Create an Intrastate Securities Exemption for Equity Crowdfunding: Spur innovation, economic activity, and small business growth by creating an intrastate securities exemption for equity crowdfunding. The exemption will expand the pool of investors that could finance Ohio startups.

Establish an Early-Stage Capital Gains Tax Exemption: Increase the flow of venture capital and incentivize investors by establishing a capital gains tax exemption for investments in early-stage Ohio companies.

Workforce Development

Develop Regional Strategies for Allocating Training Programs and Ensure Community College Participation in Southeastern Ohio: Work with business, industry, and research institutions to align training strategies with employer needs and geographic conditions. Encourage Ohio community colleges to contribute by tailoring relevant degree programs to provide students with the necessary skills to support local manufacturers.

Expand Apprenticeship Programs to Support and Foster Career Pathways: Provide tax incentives and additional support to companies that hire and train apprentices. Further expand apprenticeship opportunities by linking work hours to school credits and certifications. Enhancing apprenticeship opportunities will help meet employer demand for trained workers and prepare Ohioans for jobs in advanced energy sectors.

Enable Dislocated Veterans to Return to Work: Leverage Ohio's well-trained veteran workforce by designing a program that allows them to continue their education and connects them with employers in need of their technical expertise.

Drawing a wind turbine up for placement
Photo Credit. Dennis Schroeder / NREL

3D printer
Photo Credit. Creative Tools / Foter / CC BY

Chapter 1: Introduction

The American Jobs Project aims to spur job creation in the advanced energy sector by identifying innovative and state-specific policy and technology roadmaps. This national initiative takes advantage of the emerging global demand for advanced energy products and services. The American Jobs Project team analyzed the advanced energy economy in Ohio and designed recommendations specifically tailored to the state's strengths. These recommendations are informed by extensive research and more than 100 interviews with local stakeholders and experts.

This report identifies opportunities to stimulate growth in two economic clusters in the advanced energy sector that leverage the state's legacy industries, current investments, and entrepreneurial business development activities. State and local leaders who seek to capitalize on the state's existing resources to create skilled, good-paying jobs can use this report as a foundation for action.

Market Opportunity

Demand for advanced energy has soared in recent years and is poised for continued growth. Between 2004 and 2014, new investment in the advanced energy sector totaled over $2.3 trillion worldwide.[11] In the United States alone, more than $386 billion was invested in advanced energy between 2007 and 2014; 2014 investments alone totaled $51.8 billion.[12] In nationwide polls, Americans increasingly support renewables over other forms of energy[13] and demand for renewable energy is likely to continue to grow. States will need to significantly reduce pollution from power plants, which will make an even stronger case for advanced energy technology, renewable energy resources, and increased energy efficiency.[14] Projections show that renewable energy will be the vast majority of new generation (69 percent to 74 percent) between now and 2030.[15] These trends point to a clear market signal: demand for advanced energy will continue to grow over the next fifteen years.[16] Ohio's rich history of energy innovation prepares the state to take advantage of increased global demand in advanced energy.

Ohio's Energy Profile

Ohio Energy Production Estimates, 2013

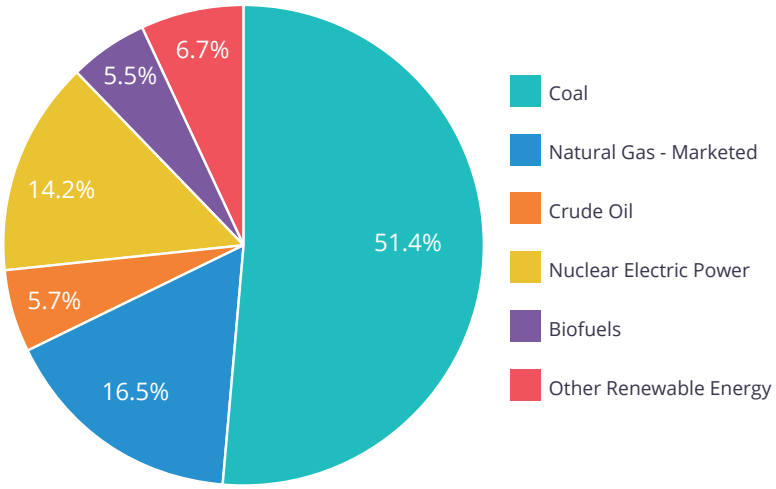


Figure 1. Coal and natural gas make up two-thirds of Ohio's energy production (Data Source: U.S. Energy Information Administration)

Ohio's energy sector is heavily reliant on coal and natural gas.[17] The state ranks sixteenth nationwide in total energy production[18] and ninth in electricity generation,[19] due in part to the energy intensity of the state's manufacturing-based economy.[20] Coal is currently responsible for over 67 percent of Ohio's electricity production, while natural gas (18 percent) and nuclear energy (12 percent) make up the remainder.[21] Due to new natural gas resources and fluctuations in coal prices, Ohio is increasing natural gas-fired electricity.[22]

Despite being one of the top electricity generators in the country, Ohio's local production does not meet statewide demand.[23] As a result, Ohio imports electricity from other states.[24] Ohio also relies on imports for other energy resources. For example, two-thirds of the state's coal supply is imported—largely from West Virginia, Wyoming, Kentucky, and Pennsylvania.[25]

Renewable Energy Development

Since 2010, Ohio has seen a dramatic increase in its renewable energy installations, especially wind turbines. Ohio's first wind farm was built in 2004 with four turbines generating about 7.2 MW of power.[26] Since that first farm in Bowling Green, thirty-two projects were brought online by 2014—three of which were utility-scale projects. Ohio has also expanded in-state solar and biomass energy production.[27] Many of these renewable energy expansions have been driven by effective state policy.

In May 2008, the Ohio General Assembly unanimously passed S.B. 221 to restructure the electric industry. The law created the state's Alternative Energy Portfolio Standard, which mandates utilities to procure 12.5 percent renewables by 2025, of which 0.5 percent must be from solar energy and at least half must be generated in-state.[28] S.B. 221 also established a state Energy Efficiency Resource Standard (EERS), which requires a "gradual ramp up to a cumulative 22 percent reduction in electricity use by 2025."[29] Other provisions in the bill included a "solar ready schools" program, which ensures new construction would be able to accommodate future solar installations.[30]

The Governor's 21st Century Energy and Economic Summit held in September 2011 resulted in an inclusive state energy policy resting on ten broad goals, including energy efficiency, alternative fuels, and renewables.[31] Drawing from this statewide energy policy, the Ohio General Assembly passed S.B. 315, emphasizing the importance of supplying reliable, cost-effective energy in order to meet job growth demands.

In 2014, despite historical support from manufacturers for the renewable energy industry, Ohio was the first state to halt its planned ramp-up of renewable power deployment and energy efficiency requirements with the passage of S.B. 310. As mandated by S.B. 310, a twelve-person Energy Mandate Study Committee researched the impacts of this freeze on Ohio's economy, later recommending an indefinite freeze.[32] The Ohio Manufacturers Association and several large companies, including Honda, came out against S.B. 310 on the grounds that indefinitely postponing increases in required renewable power use hurts its bottom line, damages its image, and is bad for business overall.[33]

S.B. 310 stifles an opportunity to fortify Ohio's energy assets and bring revenue to the state. Over 14,000 Ohioans are employed in the renewable energy sector, but industry job growth has slowed to a below-average rate of 1.5 percent and shifted out-of-state in 2014.[34] Firms involved in in-state sales and installation grew by 1 percent, compared to the 8 percent growth seen at firms shifting to out-of-state markets.[35] For example, Dovetail Solar and Wind, a renewable energy company that previously had more than 95 percent of its work in Ohio, now has less than 60 percent of its projects in-state.[36] Moreover, S.B. 310 limits the energy efficiency measures that minimize price surges in the wholesale electricity market, and creates a disadvantage for manufacturers working in fields such as energy efficiency.[37]

In order to support the industry, create jobs, and avoid losing out on major foreign and domestic investment, Ohio should consider allowing the Alternative Energy Portfolio Standard freeze to expire at the end of 2016.

Evolving Energy Needs

Although Ohio is among the top five consumers of coal in the United States, oil and natural gas production are becoming more prominent as a result of resources now available from the Marcellus and Utica shale beds.[38] Additionally, the retirement of older coal generation plants provides Ohio with an opportunity to invest in energy-saving technologies and renewable energy. Many plants have been shut down to avoid high renovation costs; these closures have also resulted in fewer coal-fired power plant operating jobs and contributed to Ohio's energy deficits.[39] Ohio could replace coal with renewable sources that will yield in-state investment and support jobs for Ohioans. Meeting a portion of Ohio's energy needs with wind technologies produced in-state and integrated additive manufacturing practices offers distinct economic benefits for the state and will create good-paying, skilled jobs for residents.

Economic Clusters

"Clusters are geographic concentrations of interconnected companies and institutions in a particular field."

– Michael Porter, *Clusters and the New Economics of Competition*[40]

Economic clusters encompass a variety of linked industries and institutions—including suppliers of specialized services, machinery, and infrastructure—which form a supply chain.[41] Clusters also extend to manufacturers of complementary products and to industries related in skills and technologies. By placing themselves in close proximity to industry allies, companies benefit from each other's unique expertise and skilled workers.[42] Companies in a cluster enjoy closer access to specialized skills and information, which helps increase productivity and efficiency.[43]

Geographic proximity and repeated exchanges of information help foster an environment of coordination and cooperation among companies and institutions. Business clusters are shown to improve the productivity of participating companies; drive innovation in the field; and facilitate the commercialization of this innovation by increasing communication, logistical support, and overall interaction between cluster entities.[44] Clusters also build a strong foundation for creating and retaining employment opportunities. Ohio has had several successful economic clusters, including the nanomanufacturing cluster in Northeast Ohio. The state is poised for cluster development in other industries, such as additive manufacturing.

Jobs Potential

Maximizing job creation within Ohio depends largely on local action. An original equipment manufacturer (OEM) and its local suppliers employ workers from their community. Those employees spend their earnings at businesses within the local economy, such as grocery stores and restaurants. Local businesses also hire employees from within the community, who spend their earnings at other local establishments. This results in a multiplier effect, where a single dollar of spending in a community circulates through local businesses and their employees numerous times. Recruiting advanced energy OEMs and their suppliers to a community can result in increases in local spending many times greater than the actual expenses of those companies.

Economic Cluster

Economic Clusters are created when industries and institutions become linked with suppliers of specialized services, machinery, and infrastructure that are within close proximity, forming a supply chain. Key elements to a successful cluster include Policy Certainty, Workforce Development, Innovation Ecosystem, and Access to Capital.

Policy Certainty

- Provides a clear market signal
- Reduces business risk
- Allows for long-term planning

Workforce Development

- Invests resources in people
- Bridges skills gap
- Develops training programs and industry partnerships

Innovation Ecosystem

- Promotes research and development
- Facilitates new technology to market
- Incubates early-stage businesses

Access to Capital

- Provides funding for new and growing businesses
- Connects investors with market opportunities
- Attracts entrepreneurs

By implementing strategic and well-researched policies, Ohio's wind and additive manufacturing industries can support up to 26,000 total jobs annually through 2030.

Report Structure

The analysis presented in this report is divided into four complementary chapters, each covering key elements of building advanced energy economic clusters in wind power and additive manufacturing. Chapters 2 and 3 present a supply chain analysis for Ohio's established wind energy and 3D printing clusters, respectively. This analysis culminates in an assessment of the state's job growth potential within each cluster and policy recommendations tailored to Ohio's needs. Chapter 4 offers an analysis of Ohio's innovation ecosystem and access to capital programs—both crucial elements of sector development—and provides recommendations for further developing the state's innovation pipeline. Chapter 5 provides recommendations for workforce development programs and policies to prepare Ohioans for advanced energy jobs. The conclusion of the report summarizes key themes and the appendix explains the jobs modeling methodology.

Chapter 2: Wind Energy

Identifying Ohio's Strengths, Weaknesses, Opportunities, and Threats in the Wind Sector

STRENGTHS	WEAKNESSES
• Ohio is a U.S. leader in wind-related manufacturing with more manufacturing facilities than any other state[1] • Blue Creek Wind Farm in northwest Ohio is a successful model of wind power feasibility and potential • Over 2,500 Ohioans work in the wind industry giving the state a strong foundation for advancement[2] • Strong wind manufacturing and maintenance training programs offer sector-specific workforce development • Local support for wind farms as a job creator in northwest Ohio • Farmers with wind turbines on their properties have higher income streams from lease payments	• Recent divestment in the wind industry due to the current freeze on Ohio's renewable portfolio standard • Restrictive regulations on siting large-scale onshore wind farms • No national best practices for offshore wind • Utilities are unwilling to participate in long-term power purchase agreements with wind farms • Average cost of onshore wind power is comparable with coal[3]
OPPORTUNITIES	**THREATS**
• Ohio has the potential to develop the first freshwater off-shore wind project in the United States • With currently available technologies, onshore and offshore wind power has a total potential of 156 GW, especially in northwest Ohio and on Lake Erie[4,5] • Lake Erie is primed for offshore wind development • Community choice aggregation programs can build local demand for wind power	• Wind developers could establish long-term investments and relationships in other states • Policymakers have shifted attention from wind power to natural gas because of Ohio's shale oil boom • The public has misconceptions about the safety, reliability, and environmental impacts of wind energy

Wind-Generated Energy in Ohio

There are three major categories of wind power generation methods: onshore, offshore, and small-scale distributed. Onshore and offshore wind turbines are very similar, with turbines around 100 meters tall and built for utility-scale distribution. Distributed wind systems include power-generating technologies that are smaller-scale (between 1 kW and 10 kW) and produce electric power close to the site of consumption. These technologies can be either off-grid—meaning they only serve the facility they are located on—or connected to the grid, where the majority of consumption still occurs on-site.[6]

The most common form of wind power generation in Ohio is utility-scale onshore, followed by small-scale distributed. There have been no offshore wind projects developed in the state. There are eight onshore wind power plants and several smaller-scale installations.[7] Ohio is a leader in distributed wind and was identified by the Pacific Northwest National Laboratory as one of the top states in cumulative wind power capacity from 2003 to 2014.[8] The state has 435 MW of installed capacity in onshore wind,[9] forming a strong base for further development in the wind sector.

With total wind energy potential exceeding 156 GW[10,11] (enough to power 33 million homes),[i] Ohio's wind market would likely take the form of onshore wind in northwest Ohio and offshore wind in the Great Lakes. In December 2015, foreign investors announced plans to develop offshore wind in Lake Erie, signaling global interest in the development of Ohio's offshore wind resources. As a leader in wind-related manufacturing, Ohio can also take advantage of growing regional demand for offshore wind[12] through large-scale export of Ohio-built components to other U.S. regions via waterways connected to the Great Lakes.

Rising Demand for Wind Energy

Increased innovation and global investment in wind-generated energy technology will continue to result in decreased costs and increased efficiency. Between 2004 to 2013, global investment in wind power grew from $14 billion to $80 billion.[13] Total global installed wind capacity currently stands at 370 GW, which covers nearly 5 percent of electricity demand worldwide.[14] Additionally, 2014 brought a record growth rate in global installations: 50 GW of added capacity surpassed both 35.6 GW installed in 2013 and 45 GW installed in 2012.[15] Popular demand for offshore wind

i 156 GW of potential powers about 35 million homes given that 1 GW powers between 225,000 and 300,000 U.S. homes annually. (Source: "Offshore Wind Energy," Bureau of Ocean Energy Management, accessed December 21, 2015, http://www.boem.gov/renewable-energy-program/renewable-energy-guide/offshore-wind-energy.aspx)

power abroad is a significant part of the current strength and future growth of the wind industry. Worldwide, almost 4.5 GW of offshore wind have been installed with another 4.7 GW under construction and 30 GW already approved.[16]

National demand for wind power tripled from 2008 to 2013[17] and large-scale wind installations increased 300 percent from 2013 to 2014.[18] Strong growth in the domestic wind sector is projected to continue: forecasts show that installed wind capacity in the United States will likely triple between now and 2030 (see Figure 2).[19]

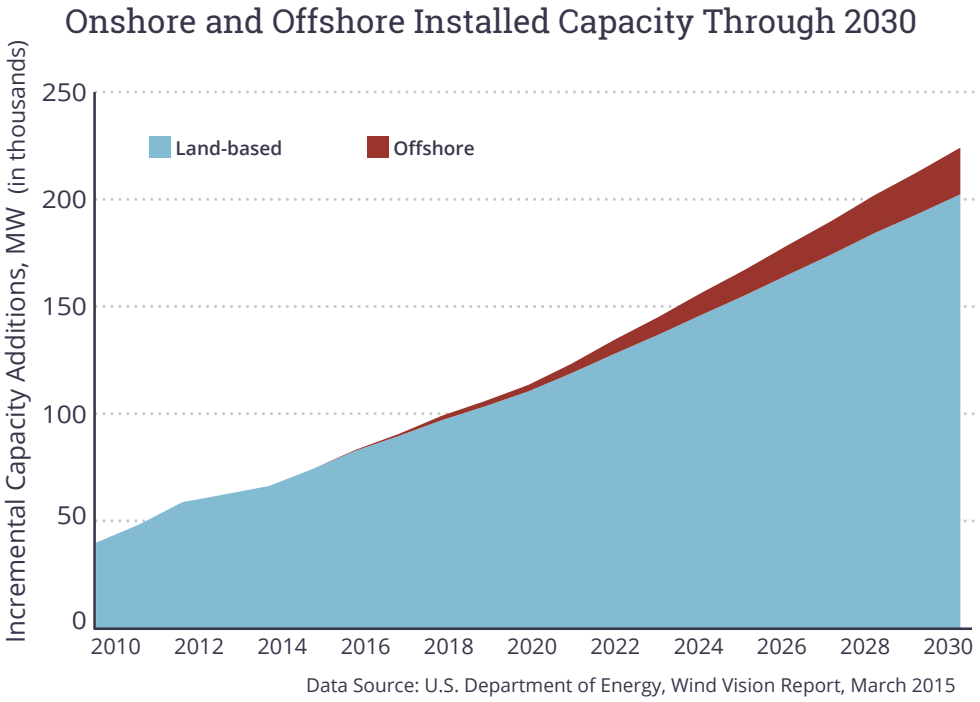


Figure 2. Total installed wind capacity will triple by 2030 with offshore wind reaching 20 GW

Onshore distributed wind in the United States reached a cumulative capacity of nearly 906 MW in 2014, reflecting the 74,000 wind turbines installed across the country.[20] While this is a promising start, the distributed wind market has substantial room for growth: installed capacity of distributed wind could reach 1,000 GW by 2030.[21]

Offshore development in the United States has been slow to catch hold. Common reasons are complicated permitting, challenging logistics, high capital costs, and lack of consistent price support policies. However, the success of offshore wind in many other developed nations, such as Denmark and the United Kingdom, demonstrates that these barriers can be overcome with careful infrastructure planning and consistent price support policies. Offshore wind is no longer a new technology and states can incorporate best practices from other nations.

Photo Credit. (Left) janie.hernandez55 / Foter / CC BY
(Right) Ad Meskens / Wikimedia Commons

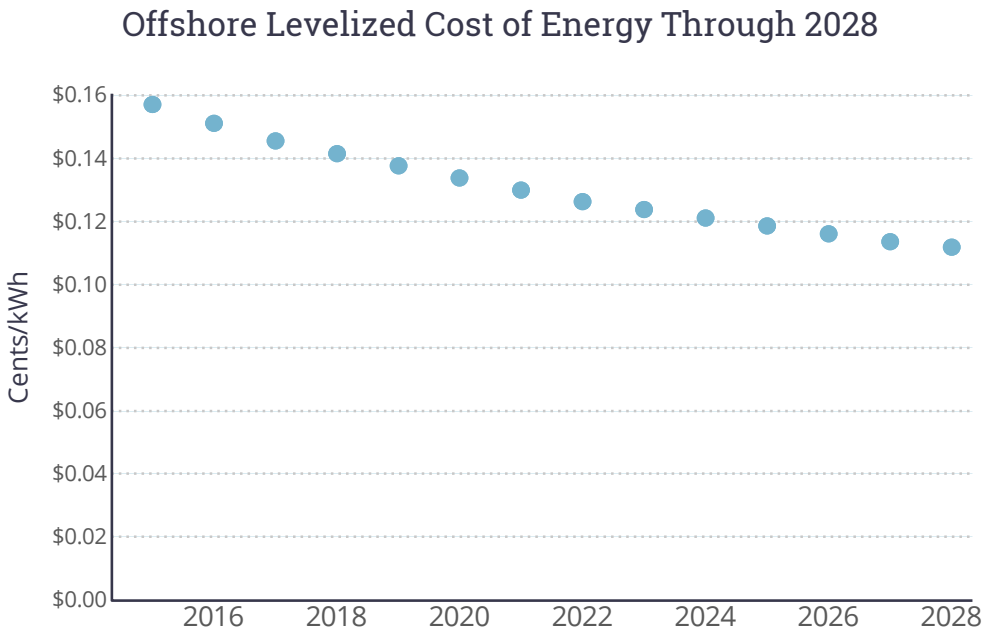
Falling Cost of Wind Energy

What is Levelized Cost of Electricity?

The levelized cost of electricity (LCOE) represents the cost per kilowatt-hour of building and operating a particular power plant. To calculate the total cost of the plant or technology, the LCOE assumes a lifespan and capacity level and adds up capital costs, fuel costs, operation and maintenance costs, and financing costs.[22] LCOE is often reported in dollars per kilowatt-hour, which allows utilities or policymakers to compare costs of installing wind power system to other generation sources such as a coal-fired power plant. LCOE for wind technology is mostly capital and financing costs because there is no fuel required for generation and variable operations and maintenance costs are low.[23]

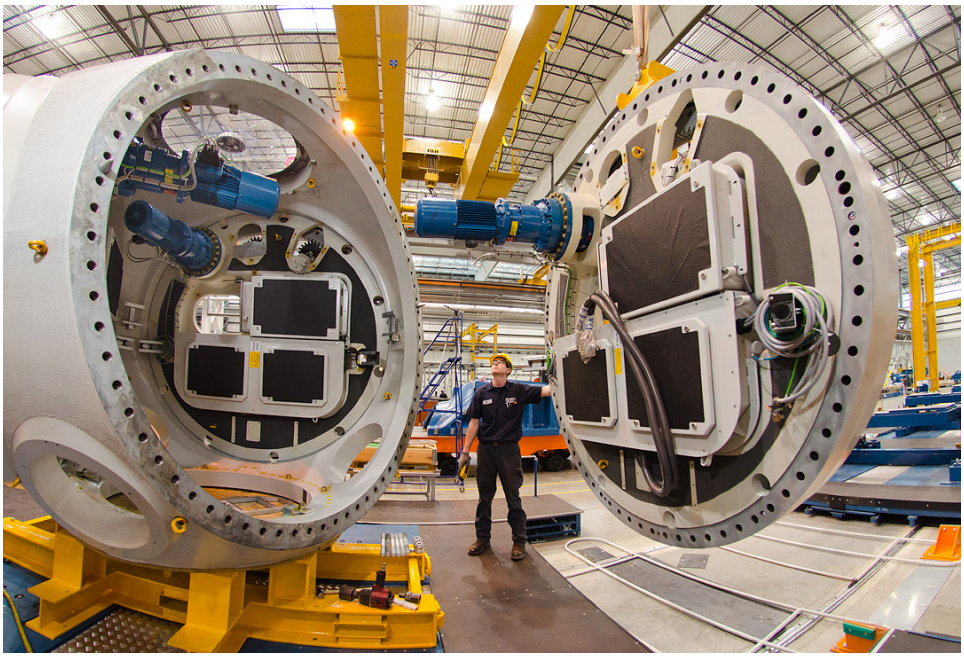
Costs for wind-generated energy will continue to fall as the technology develops and global investments increase. Most studies estimate a 20 percent to 30 percent fall in LCOE of onshore wind by 2030 compared to 2010 costs,[24] and from 2008 to 2015, wind power costs fell by more than one-third.[25] The cost of onshore wind power has significantly declined in the past decades to about 5 cents per kilowatt-hour due to increased design and production scale, improved operation practices,[26] and increased global investment in wind power. While LCOE for distributed wind turbines vary greatly,[27] industry experts identified target LCOEs at 32 percent to 46 percent of 2014 LCOEs, depending on turbine size and end-user markets.[28]

As more offshore wind projects are developed in the United States, the LCOE of offshore energy is projected to fall below 12 cents per kilowatt-hour by 2030 (see Figure 3).[29] Cost reductions will largely come from similar trends in advanced technology, built capacity, and improved operation and maintenance of offshore turbines.



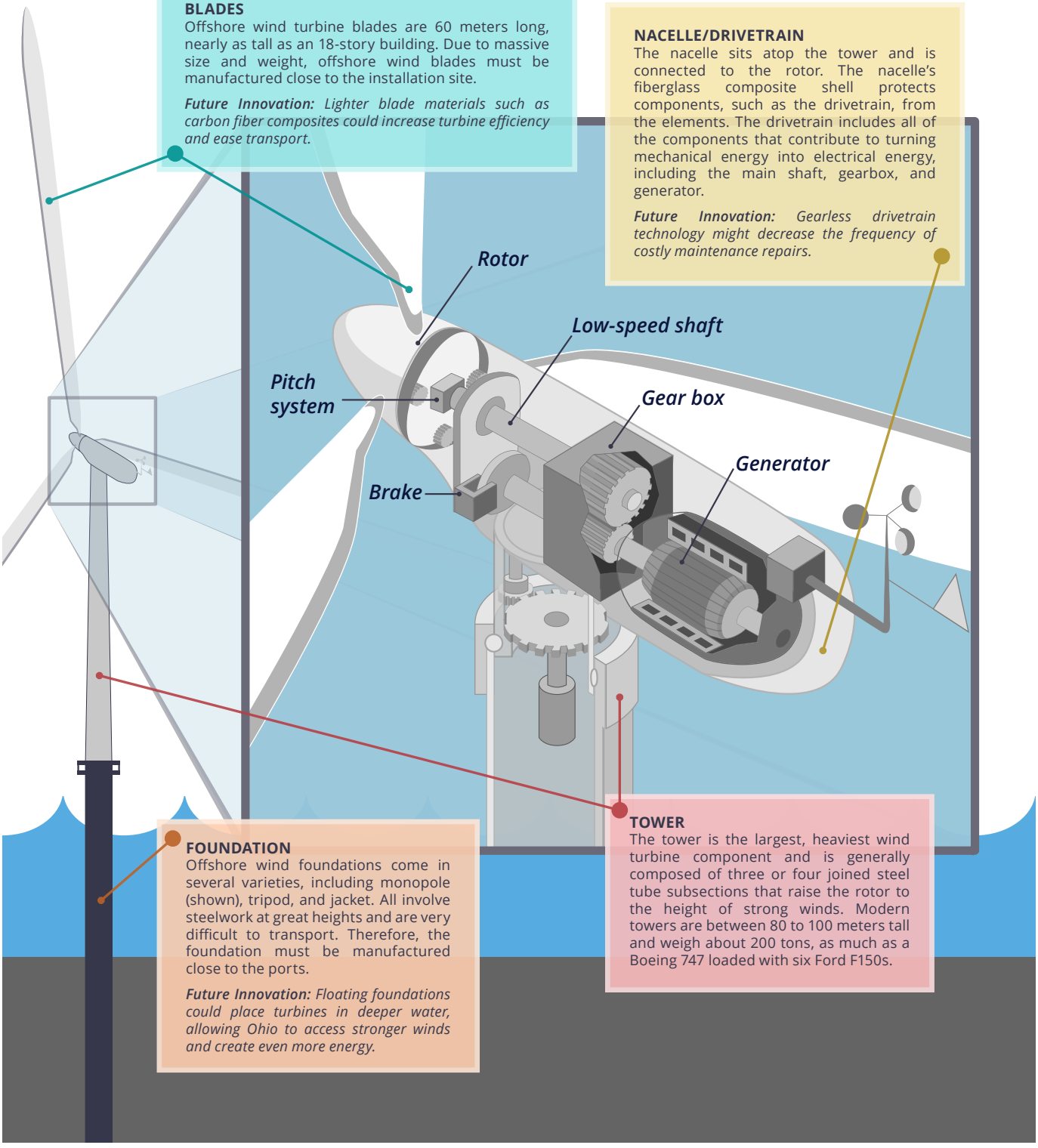
Data Source: Navigant, Offshore Wind and Market Analysis, February 2013; Open EI Cost Database, http://en.openei.org/apps/TCDB

Figure 3. LCOE for offshore wind will decrease by 30 percent by 2030



Manufacturing of a wind turbine
Photo Credit. U.S. Department of Energy

Anatomy of an Offshore Wind Turbine



BLADES
Offshore wind turbine blades are 60 meters long, nearly as tall as an 18-story building. Due to massive size and weight, offshore wind blades must be manufactured close to the installation site.

Future Innovation: *Lighter blade materials such as carbon fiber composites could increase turbine efficiency and ease transport.*

NACELLE/DRIVETRAIN
The nacelle sits atop the tower and is connected to the rotor. The nacelle's fiberglass composite shell protects components, such as the drivetrain, from the elements. The drivetrain includes all of the components that contribute to turning mechanical energy into electrical energy, including the main shaft, gearbox, and generator.

Future Innovation: *Gearless drivetrain technology might decrease the frequency of costly maintenance repairs.*

FOUNDATION
Offshore wind foundations come in several varieties, including monopole (shown), tripod, and jacket. All involve steelwork at great heights and are very difficult to transport. Therefore, the foundation must be manufactured close to the ports.

Future Innovation: *Floating foundations could place turbines in deeper water, allowing Ohio to access stronger winds and create even more energy.*

TOWER
The tower is the largest, heaviest wind turbine component and is generally composed of three or four joined steel tube subsections that raise the rotor to the height of strong winds. Modern towers are between 80 to 100 meters tall and weigh about 200 tons, as much as a Boeing 747 loaded with six Ford F150s.

Ohio's Wind Industry: A Strong Foundation for Growth

Blue Creek Wind Farm: Generating Energy and Revenue for Northwest Ohio.

The Blue Creek Wind Farm has served communities in northwest Ohio for over three years. The project grew from a $600 million private investment in 2011, when economic development in the state stalled due to the recession.[30] Even before going online in 2012, it provided many local benefits, putting over 500 construction workers and more than 30 Ohio companies to work and garnering about $25 million in local spending.[31]

As the largest wind farm in the state, the 304 MW project powers an average of 76,000 Ohio homes each year[32] and annual tax revenue further powers these communities. Recently, the Van Wert and Paulding counties received over $2 million and $666,000, respectively,[33] making the project one of the largest single taxpayers in each county.[34] Because the turbines are mostly on farmland, farmers also receive about $2 million annually in royalties,[35] even though Blue Creek covers less than 1 percent of the area of crop fields.[36] The financial benefits are especially significant for smaller farmers that support local communities. Thus, wind energy bolsters Ohio's top industry on both the state and local level.[37]

Furthermore, rural school districts greatly benefit from this economic boost. In the Lincolnview school district, wind farm funds helped provide every student with a computer, when previously there were only two computer labs in the whole district.[38] There is immense local support for wind farm development and Blue Creek is a great state model for expanding wind power.

(Left) Transporting a wind turbine blade, Photo Credit. Evert Kuiken / Foter / CC BY-ND
(Right) Tripile offshore wind turbine foundations, Photo Credit. U.S. Department of Energy

Table 1. Wind Manufacturing Supply Chain (American Wind Energy Association, Great Lakes Wind Network)

TYPE OF FACILITY	NUMBER OF COMPANIES	DETAILS
Manufacturing	73	
Drivetrain	14	main shaft, gearbox, generator
Rotor	6	blades, pitch system, spinner
Tower	5	tower and supporting components
Structural	4	main structural frames, fasteners
Electrical	16	power inverter, logic boards, control systems
Materials	9	composite material, steel foundries
Power Transmission	19	equipment to connect wind farm to grid
Foundation	0	steel foundation for offshore applications
Service	10	
Logistics	4	supply chain management, shipping, trucking
Operation and Maintenance	2	repair services
Nonprofits	2	advocacy and supply chain development support
Distributed Wind Turbines	2	small wind turbines
Total Companies	**83**	

Strengths

Ohio leads the nation in wind-related manufacturing with more than seventy facilities currently producing components, as well as ten companies providing service-level support to the industry (see Table 1). The majority of Ohio's manufacturing facilities produce components used for drivetrains or power transmission. Most drivetrain manufacturers have the ability to construct the main shaft and produce gearboxes, while three established companies also produce generators. Several companies provide mechanical components for power conversion, such as gears, bearings, and housing. Since the components for onshore and offshore turbines are similar, firms in onshore wind turbine manufacturing will be able to transition to the burgeoning offshore industry.

Ohio is home to companies like Argosy and SUREnergy, which give the state a competitive edge in the distributed wind market. Furthermore, established nonprofits such as the Lake Erie Energy Development Corporation (LEEDCo), the Great Lakes Wind Network (GLWN), and WIRE-Net help propel economic development and support the wind industry.

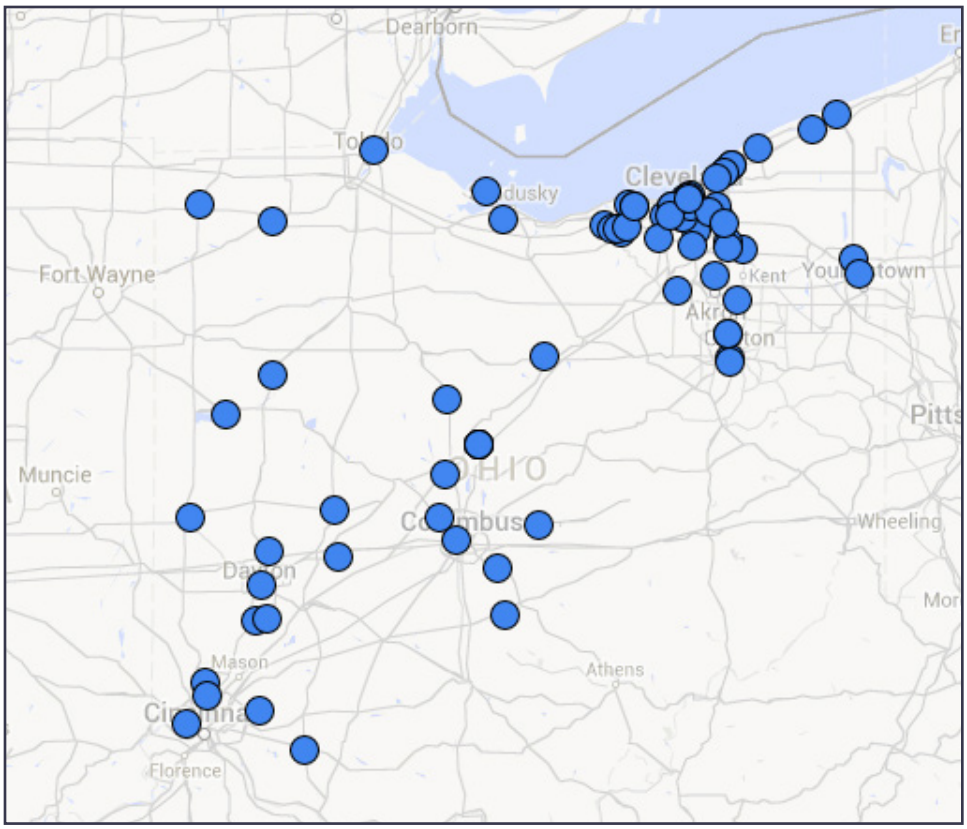


Figure 4. Map of Ohio's wind component manufacturers (Source: Great Lakes Wind Network)

Opportunities for Growth

Ohio's many facilities dedicated to wind component manufacturing will allow the state to remain competitive in the wind industry if it diversifies its production. Ohio facilities produce most of the internal components of a nacelle, but nacelle assembly is a logical addition to the industry. Furthermore, foundation and rotor manufacturing also have room for growth.

Ohio also lacks expertise in the offshore wind industry. The Port of Cleveland will need a geotechnical survey performed to ensure it can handle the weight of large, heavy offshore turbine components such as towers and blades, which will need to be manufactured close to the installation site. Moreover, specialized installation vessels must be constructed for the Lake Erie project. Ohio could create jobs through ship construction, and in turn, power the offshore wind industry in the Great Lakes.

With demand for wind power projected to rise over the coming decades and energy costs securing its cost-effectiveness, Ohio's wind component manufacturing base is poised to take off. Overall, these supply chain gaps are significant opportunities to engage international companies and draw foreign investment to the state.

Offshore and Land-Based Wind Employment Potential

As demand for wind energy skyrockets, Ohio has the opportunity to expand the wind economy, increase in-state spending, and employ an average of over 22,000 more Ohioans annually over the next fifteen years. If optimistic projections prove to be correct and Ohio's wind companies are able to fill a larger share of their supply chain needs with in-state purchases, up to 335,500 direct, indirect, and induced job-years would be supported. While up to 46,700 of those would be direct job-years in the state's wind industry, over 288,800 indirect and induced job-years could be supported if wind companies were able to procure more of their supplies from in-state companies.

These projections for job-years potential in Ohio's wind industry are based on tools and analysis by the National Renewable Energy Laboratory (NREL), the Department of Energy's Office of Energy Efficiency and Renewable Energy, the Great Lakes Wind Collaborative (GLWC), and Bloomberg New Energy Finance. Additionally, the Jobs and Economic Development Impacts (JEDI) tool was utilized to estimate job-years at different levels of local supply chain concentration for wind.

To highlight why clustering supply chain businesses in Ohio is so important, we have estimated the number of direct, indirect, and induced jobs based on future demand and the percentage of supply chain purchases made within the state. Figures 5 and 6 show how the number of onshore and offshore job-years vary as the local share changes. The figures show the number of direct, indirect, and induced jobs based on local share percentages of 25 percent, 50 percent, and 75 percent.

Since projections often vary, we analyzed how those supply chain differences affect three reputable estimates of future demand for offshore wind energy: GLWC's High Forecast as a high-demand scenario, NREL's Renewable Electricity Future 80 Percent High Constraint forecast as a medium-demand scenario, the Office of Energy Efficiency & Renewable Energy's (EERE) Wind Vision as a low-demand scenario. We also analyzed how supply chain differences affect three reputable estimates of demand for onshore wind energy: NREL's Renewable Electricity Future 80 Percent Advanced Technology Improvement as a high-demand scenario, EERE's Wind Vision as a medium-demand scenario, and Bloomberg New Energy Finance's forecast as a low-demand scenario. Figure 5 presents estimates for onshore wind construction, operations, and maintenance jobs. For offshore wind, estimates of construction, operations, and maintenance jobs are in Figure 6.

What is a Job-Year?

A job-year is one full-time equivalent job for one year (i.e., forty hours per week for fifty-two weeks, which is 2,080 hours per year). If two people each work a part-time job for twenty hours per week for fifty-two weeks, this is counted as one full-time equivalent job for one year, i.e., one job-year. If one person works forty hours per week for ten years, this it is counted as ten job-years.

Why Use Job-Years?

By using job-years, our analysis can take into account the length of a job. In energy projects, many construction and installation jobs are short-term, while manufacturing and maintenance jobs may be long-term. Using job-years allows us to accurately count both types of jobs. For example, if ten full-time wind turbine installation workers are expected to each spend 208 hours on a wind project, this is measured as one job-year. Alternatively, if one full-time engineer is expected to spend fifteen years operating that same wind farm, this is measured as fifteen job-years. In our analysis of Ohio's wind supply chain, total job-years are aggregated over the 2016 to 2030 period.

Direct, Indirect, and Induced Job-Years

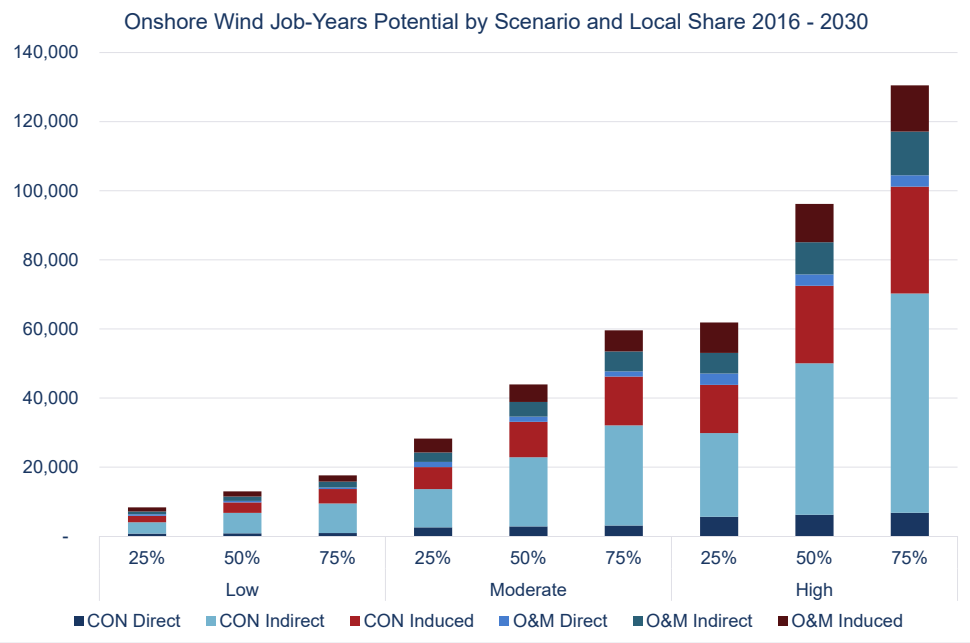
In order to estimate the potential economic impact of Ohio's wind supply chain, direct, indirect, and induced job-years are measured:

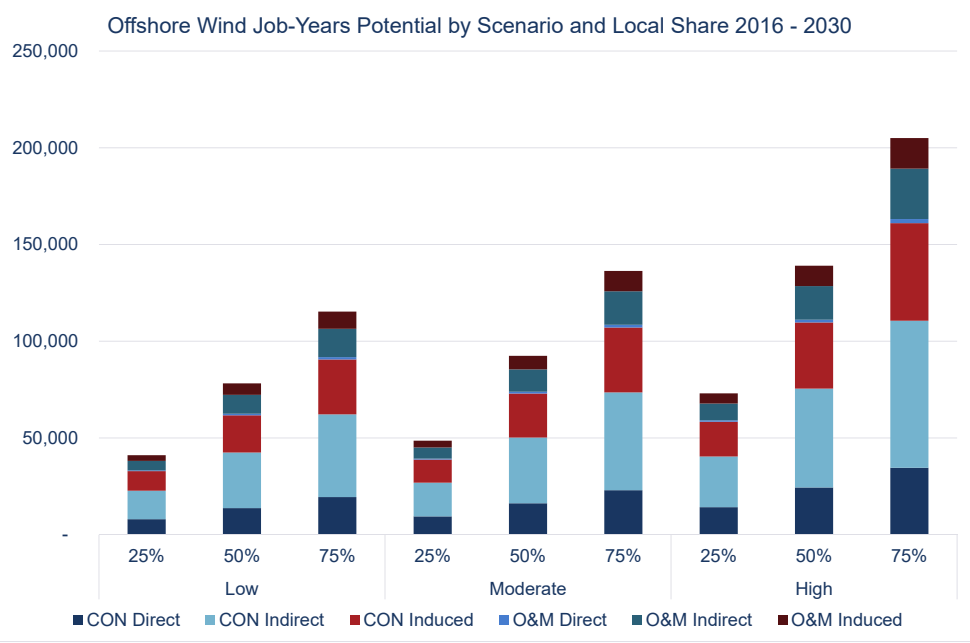
- Direct job-years: reflect jobs resulting from initial changes in demand in Ohio's onshore and offshore wind industry
- Indirect job-years: reflect jobs resulting from changes in transactions between industries as supplying industries respond to increased demand from Ohio's onshore and offshore wind industry
- Induced job-years: reflect jobs resulting from changes in local spending as a result of increased demand in Ohio's wind and indirect industries

Local Share

Local share is the percentage of expenditures that are spent in Ohio. For example, if a wind installation company plans to spend $3 million on imported wind turbines and $1 million on additional supplies from companies in Ohio, the local share is 25%. In the JEDI model, local share is an independent variable.

In all of the demand scenarios, increasing the percentage of local spending by Ohio's wind companies creates thousands of job-years. For example, in the offshore high-demand scenario, increasing in-state supply chain purchases from 25 percent to 75 percent would support over 130,000 direct, indirect, and induced job-years. In the onshore high-demand scenario, increasing in-state supply chain purchases from 25 percent to 75 percent would support over 68,000 direct, indirect, and induced job-years.





Figures 5,6. An increase in Ohio's local share will increase job-years potential for both onshore and offshore wind.

Even in the low-demand scenarios, increasing the percentage of in-state supply chain purchases creates tens of thousands of jobs. An increase of in-state supply chain purchases for offshore wind companies from 25 percent to 75 percent would support over 74,000 job-years. For onshore wind in the low-demand scenario, that same percentage increase of in-state purchases supports over 9,000 direct, indirect, and induced job-years.

If a concerted effort were made by the state to fill in the supply chain and strengthen the wind cluster, Ohio companies could meet the expected demand for onshore and offshore wind, supporting up to 335,500 job-years. Increasing the number of supply chain businesses can create thousands of good-paying, skilled jobs and make Ohio a leader in the wind industry.

Policy Recommendations

Ohio can jumpstart the state's wind cluster by focusing on innovative policies that remove obstacles and boost demand within the state. Creating a robust in-state market will attract private investment, strengthen the economy, and create new value chains, which will subsequently stimulate and accelerate new export markets.

Policy 1: Encourage Foreign Direct Investment to Fill Supply Chain Gaps

Ohio leads the nation in wind manufacturing and is strategically located along major Midwest waterways. With growing demand for wind power across the Midwest, Ohio is primed to export wind turbine components to the rest of the nation. Ohio can recruit both onshore and offshore turbine component manufacturers to locate in Ohio. An influx of foreign wind manufacturers would not only encourage wind energy development, but also increase the state's capacity to export necessary components—ultimately creating new jobs for Ohioans.

Transporting a blade to wind turbine site
Photo Credit. "Caveman Chuck" Coker / Foter / CC BY-ND

Lake Erie Offshore Wind Pilot Project

Ohio could be the first state in the nation to successfully construct freshwater offshore wind turbines. Fred.Olsen Renewables, a Norwegian wind developer with projects located in Sweden, Scotland, Norway, and the United Kingdom, purchased the right to develop a $120 million pilot project in Lake Erie off the shores of Cleveland.[39] Construction for the 18 MW pilot—a collaborative effort with the Lake Erie Energy Development Corporation—is scheduled to begin in 2018.[40] Named "The Icebreaker," the pilot project will use Siemens 3.0 MW turbines[41] and cost-effective mono bucket foundations.[42] Cleveland Public Power will purchase a quarter of the Icebreaker's output and provide interconnection access to the grid.[43] Given its progress, the Icebreaker could potentially receive more Department of Energy funds to offset development costs, in addition to the combined $7 million granted in 2012 and 2014.[44]

Many governors attract international companies to their states to create jobs for their citizens. Ohio is no exception. In 2013, over 881 international firms did business in the state, employing more than 181,000 Ohioans.[45] Industry clusters include automotive, advanced manufacturing, and polymers and chemicals. These investors are the result of a coordinated effort from Ohio's Department of Development and the Governor's Office.

The Governor can turn gaps in both the onshore and offshore wind supply chains into international investment missions to attract component manufacturers to locate in Ohio. Table 2 shows a list of potential investors based on turbine component.

Table 2. Potential Foreign Direct Investors in Turbine Components

Turbine Component	FDI Target
Large-Scale Turbine Blades	DeWind (Germany) and LM Wind Power (Denmark)
Nacelle Assembly	Romax (UK), Eickhoff (Germany) and Enercon (Germany), onshore only
Towers and Foundations	AMBAU (Germany), Bladt Industries A/S (Denmark), and Sif Group (Netherlands)
Foundry	Global Castings (Germany)
Underwater Cables	JDR Cables (England) and Sudkabel GmbH (Germany)

By recruiting these foreign companies to either locate in the state or partner with Ohio's wind businesses, the state stands to bring foreign capital into the state, strengthen its wind cluster, and create jobs for a dedicated Ohio workforce.

Policy 2: Amend Setback Requirements to Allow Flexibility for Turbine Size

Due to legislation passed in 2014, wind turbines must be sited at least 1,125 feet away from the property line of the nearest adjacent property.[46] This setback is nearly twice as deep as was previously required[47] and seven times the setback requirement for oil and gas drilling.[48] The current setback requirement would apply to any group of turbines whose total capacity reaches 5 MW.[49] For example, a group of ten 500 kW turbines standing 200 feet tall[50] are restricted to the same setback requirements as a 3 MW turbine, which is more than twice as tall at 488 feet.[51] Since turbine heights vary so greatly,[52] Ohio needs a setback requirement that recognizes the reduced impacts related to small turbines. The current setback limit not only adversely affects small turbines, but also could become outdated for large turbines—as wind turbines continue to grow in size, a setback limit measured in feet may quickly become obsolete.

In order to adapt to the diversity of turbines and their expected increase in size, Ohio lawmakers should consider modifying the setback requirement to a more adaptable limit that meets the needs of both rapidly growing turbines and small-sized distributed turbines. Instead of a setback distance measured in feet, the setback limit could be measured by the ratio of the turbine height plus blade tip measured at 90 degrees to the property in question. States such as Pennsylvania have similar requirements.[54] This will ensure the setback protects neighboring property as turbines grow larger,[55] and prevent excessive regulation for small turbines.

Moreover, Ohio lawmakers should consider measuring the setback distance from the nearest residential structure instead of the property line. Many rural residents live acres from their property line and those residents would not be at risk for turbine malfunction.[ii] In the unlikely case that property values decline due to proximity to a wind turbine,[56] the developer could be required to compensate the homeowner for the home's depreciation. The current setback limit will be an economic disadvantage to all Ohioans touched by the wind industry: rural homeowners risk losing the opportunity to receive monthly income from leasing their property to wind developers, while wind developers will not be able to develop wind projects.[57] Thus, measuring the setback limit from the nearest structure instead of the property line will allow for continued economic growth in Ohio.

What is a Setback Requirement?

A setback is the distance a building or structure, such as a wind turbine, must be built from a building, property line, street, body of water, or other place that needs safeguarding. In general, the level of government that owns the land determines setback requirements. Municipalities may control local setbacks (known as "home rule") while the federal government may control federal highway setbacks. Wind turbine setbacks vary greatly across the nation, and are set by states or municipalities.[53]

ii In 2014, only one-tenth of 1 percent of U.S. wind turbines experienced catastrophic failures. (Source: U.S. Department of Energy, "Wind Vision: A New Era for Wind Power in the United States," April 2015, pg. 105, http://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf)

Wind Development: A Benefit to Rural Economies

Each year, Ohio landowners receive $3 million from land lease payments for renewable energy facilities, and Ohio communities receive $3.7 million through taxes from these facilities.[58] Rural communities likewise benefit from wind development around the nation. In Texas, the state with the most installed wind capacity, an analysis of rural western counties showed the economic activity to be $520,000[iii] per MW of installed wind capacity.[59] On a national level, local landowners receive about $180 million in lease payments from wind producers,[60] and over an eight-year period county-level income increased by $11,000 per MW of installed capacity.[61] Farm families and rural school districts can continue to receive the benefits of this significant source of revenue if setback requirements are suitably determined.

Modifying the setback requirements of wind turbines can continue to protect the health and safety of Ohio residents, grow rural economies, and ease burdensome permitting for wind developers in Ohio—ultimately helping to create more wind jobs in Ohio.

Policy 3: Create an Ohio Wind Credit

Ohio leads the nation in wind manufacturing facilities[62] and more than 2,500 Ohioans are employed in the wind industry.[63] The state boasts 435 MW of onshore installed wind capacity,[64] demonstrating the state's commitment to wind-generated power. Additionally, Fred.Olsen Renewables' recent purchase of an 18 MW, $120 million offshore wind pilot project in Lake Erie represents a significant opportunity for Cleveland's manufacturing industry.[65] If the project proves successful, more foreign and domestic wind developers could make Ohio their home base.

To signal that Ohio is committed to wind development, the state could pass its own Ohio Wind Credit (OWC) instead of relying solely on federal funds. The cost of the OWC can be offset by income from the leasing of state lands for renewable energy development, as New Mexico has successfully done with its economy-boosting Renewable Energy Production Tax Credit. The OWC can be modeled after similar credits in New Mexico and Kentucky, or the federal investment or production tax credits.

iii Measured in 2011 U.S. dollars.

New Mexico's Renewable Energy Production Tax Credit

In 2003, New Mexico instituted a state Renewable Energy Production Tax Credit (REPTC) to stimulate clean energy investment. The program was so successful that all available production tax credits for solar have been claimed until 2022.[66] The tax liability is capped at a maximum of $33.5 million per year for 10 years, a fraction of the money the state will earn by leasing land for renewable energy uses.[67] Those land leases are expected to bring in $574 million to the state, far exceeding the cost of the tax credits.[68] Neighboring states, including Arizona, followed New Mexico's lead and instituted similar policies.

Ohio could follow New Mexico's example and lease some of its state lands, such as land under control of the Department of Transportation, to pay for the OWC. Ohio owns a total of 422,000 acres,[69] and would only need to lease a small fraction of that to generators of onshore wind and solar. Leasing state lands and rooftops could be a significant source of revenue that could be used to pay for a wind tax credit. Offering an Ohio Wind Credit would send a clear signal to investors that Ohio is serious about offshore wind development and attracting middle-class jobs to the state.

Policy 4: Create an Anchor Company Tax Credit

Fred.Olsen Renewables, the largest independent power producer in the United Kingdom, recently announced its new U.S. headquarters in Cleveland.[70] This signifies a major opportunity for wind-related manufacturing in Ohio. With wind turbines requiring up to 8,000 components,[71] supply chain management represents a significant hurdle. The state could support development of a robust supply chain by partnering with Fred.Olsen Renewables and other anchor companies with incentives such as the Anchor Company Tax Credit.

Anchor Company Tax Credit

As the first state to develop an offshore wind pilot project in the United States, Rhode Island created an Anchor Institution Tax Credit to bolster the offshore wind industry. If a Rhode Island anchor company is responsible for a job-creating supplier locating in Rhode Island, the anchor company receives a tax credit.[72] For instance, if a wind developer lures a manufacturer of subsea cables, the wind developer will receive a tax credit.

Ohio could implement a policy similar to Rhode Island's Anchor Institution Tax Credit to create a robust supply chain and wind manufacturing center. The credit could be extended to other industries in the state with complex supply chains, contingent on number of jobs created for Ohioans. With its complex supply chain needs, incentives like the Anchor Company Tax Credit could boost the wind manufacturing industry, resulting in good-paying jobs for Ohioans.

Photo Credit. U.S. Department of Energy

Policy 5: Establish a Port Retooling Strategy and Infrastructure Funds

Offshore wind farms require significant investment and planning of waterside ports.[73] Before development of offshore wind turbine farms can begin, Ohio will need to build specialty ships to facilitate the installation process and begin manufacturing wind turbines near the coast. Cleveland's ports are not currently prepared to handle this increase in manufacturing activity and shipbuilding infrastructure. Port planning and upgrades should begin as soon as possible to prevent a delay of wind energy implementation.

In the United Kingdom, the Port of Grimsby has been dedicated to wind activities. Through coordination with local officials and business leaders, it acts strategically with other nearby ports to coordinate supply chain activities, including establishing operation and maintenance hubs, allocating terminal space for offshore wind installation vessels, and allotting space for manufacturing wind turbine components.[74] Phase three of offshore wind turbine installation will bring an additional 1,500 jobs to the Port of Grimsby alone,[75] not counting the United Kingdom's 6,800 full-time offshore wind jobs.[76] Denmark's Port of Esbjerg is an example of a successful port that was strategically planned: more than 270 companies and organizations make up the Offshore Center Danmark, an innovation complex for offshore wind.[77] The Port's Board of Directors invested $183 million in facilities over a ten-year period to create space for wind turbines.[78] The Port of Esbjerg has witnessed continued economic growth: for three consecutive years from 2012 to 2014, the port had its highest profits on record. From 2013 to 2014, wind turbine transport increased by 44 percent and ship calls increased by 21 percent.[79]

The state of Ohio could help the Port of Cleveland prepare for the offshore wind industry via strategic planning and investments like those in Grimsby and Esbjerg. If just one port was upgraded to facilitate the U.S. offshore wind industry,[iv] 6,000 full-time employment jobs could be created and $449 million added to the state's gross domestic product.[80] The Port of Cleveland, Ohio Public Works Commission, Ohio Department of Transportation, and stakeholders involved in the Icebreaker project should consider a commission to assess the needs of the port. The State of Ohio could consider using funds from the State Infrastructure Bank,[81] creating a public-private funding mechanism specifically for port upgrades, or providing low-interest loans through a revolving loan program. To create an industrial cluster that leverages the Port of Cleveland and the facilities needed to

iv "Port upgrades" in this scenario include moderate port upgrades and the addition of a component manufacturing facility.

manufacture and install wind turbines, the state of Ohio and Port of Cleveland could work strategically to invest in port planning and infrastructure, ultimately resulting in good jobs for Ohioans.

Chapter Summary

With Ohio's strength in the wind turbine manufacturing industry and prime location for export, the state is poised to lead the nation in wind turbine manufacturing. Demand for wind energy is projected to triple by 2030 and Ohio must act quickly to capitalize on this demand. State lawmakers have several opportunities to improve the manufacturing landscape, strengthen supply chains, and create in-state demand for wind-generated energy. Implementing these recommendations will help Ohio create a strong economy while providing more diverse and reliable energy for ratepayers.

Chapter 3: Additive Manufacturing

Introduction to Additive Manufacturing

What is Additive Manufacturing?

Additive manufacturing, commonly known as 3D printing, is the process of connecting ("adding") successive layers of various substances—such as plastic polymer or metal—closely over one another, which creates a usable 3D version of whatever is being modeled. Using computer-aided design (CAD) software, products ranging from ear buds to jet engine fuel nozzles to medical implants can be modeled and printed, transforming them from virtual to material with the click of a button.[1]

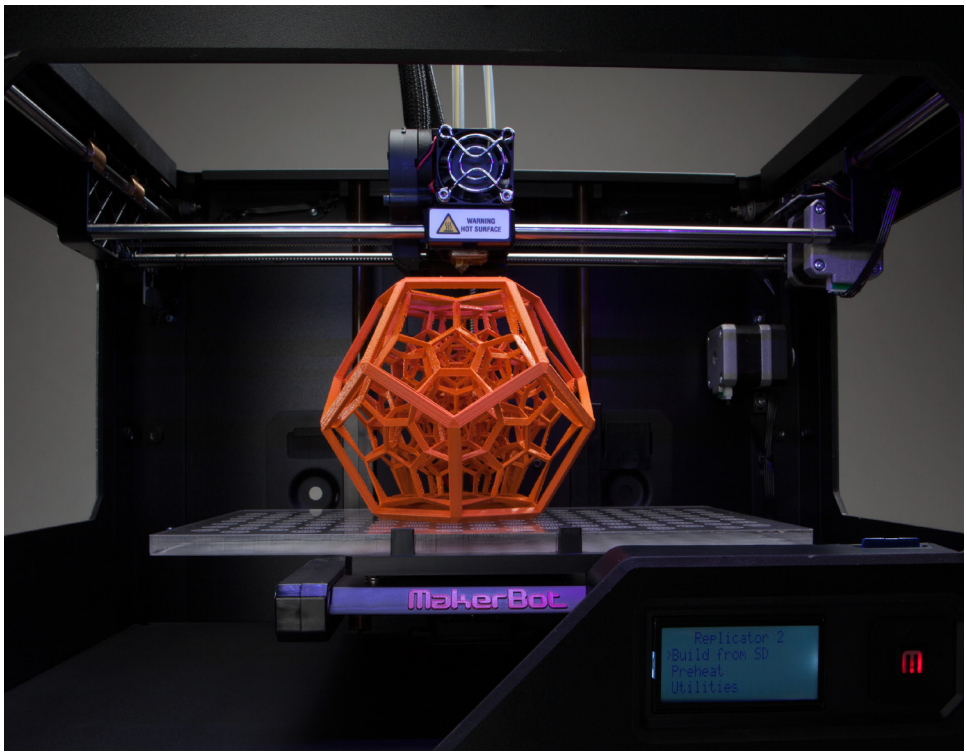
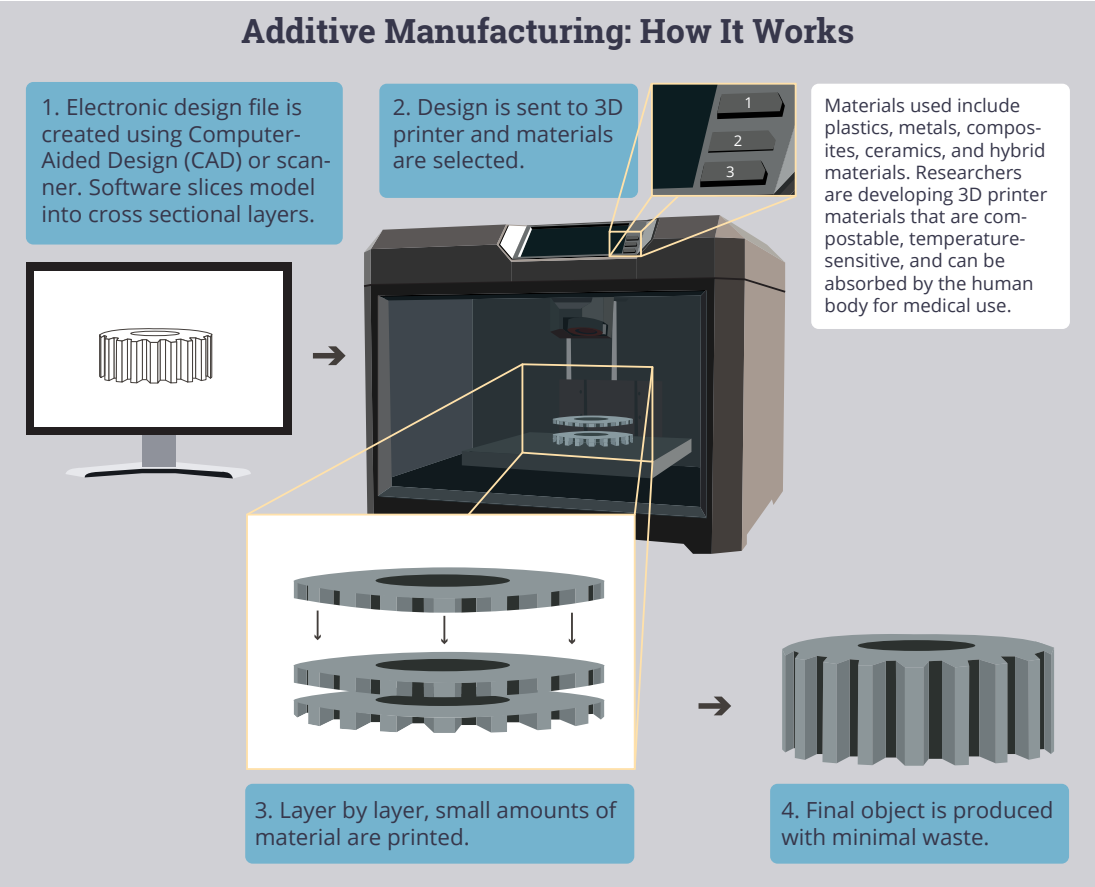


Photo Credit. Creative Tools / Foter / CC BY

How Do 3D Printers Work?

Traditional manufacturing methods use a subtractive process, which removes unnecessary material by cutting raw material away from the object. 3D printers can eliminate this waste.[2] The main components of a 3D printer are the circuitry, software, nozzle, LCD display, and metal/plastic structure. Production of a 3D-printed object is comprised of three main steps: design, manufacturing, and assembly. A model of the object is designed using a CAD file with a digital representation.[3] The model contains object dimensions, material properties, and the machine steps for printing. The main types of 3D printing are selective binding, selective solidification, and selective deposition.[4] The selective binding technique creates a 3D-printed object by binding chemical agents and a powdered metal or gypsum. Selective solidification creates an object by solidifying a liquid into layers. The final method, selective deposition, creates objects by positioning or placing the material at a specified location without chemical binders.

Plastics remain the most prevalent 3D printing filament, some of which—including polylactic acid—are compostable.[5] Other materials include metals, hybrid metals, composites, and ceramics.[6]



Advantages of Additive Manufacturing

The adoption of 3D printing has begun to shift the way society designs, manufactures, engineers, and customizes products. Additive manufacturing is the key to reducing waste and increasing energy efficiency in the production process, which ultimately lowers costs and accelerates innovation. Currently, common 3D printing uses include rapid prototyping and casting of dental, medical, and production parts.[7] Some of the many benefits of additive manufacturing include the following:

1. Waste Reduction: Traditional manufacturing is subtractive, meaning a block of material is whittled down to a targeted shape, which can waste anywhere from 90 percent to 97 percent of the original material.[8,9] Alternatively, additive manufacturing not only reduces the amount of raw material needed, but also utilizes about 98 percent of input material for a product.[10] The aerospace industry, for example, has benefited from a 50 percent cut to its "buy-to-fly" ratio (a measure of the amount of material needed to produce one pound of product).[11]

Additive manufacturing can reduce all seven categories of waste, which include:

1. "Overproduction: occurs when more is produced than is currently required by customers
2. Transportation: transportation does not make any change to the product and is a source of risk to the product
3. Rework/Defects: discarded defects result in wasted resources or extra costs correcting the defect
4. Over-processing: occurs when more work is done than is necessary
5. Motion: unnecessary motion results in unnecessary expenditure of time and resources
6. Inventory: is similar to that of overproduction and results in the need for additional handling, space, people, and paperwork to manage extra product
7. Waiting: when workers and equipment are waiting for material and parts, these resources are being wasted"[12]

2. Energy Efficiency: Because fewer production steps and less material are required, 3D-printed products require up to 50 percent less energy than if they were produced with conventional processes.[13,14] This significant difference in energy consumption is a result of the heating each method uses: traditional manufacturing requires intense heating of large areas, whereas additive processes heat elements at a smaller scale.[15] Many 3D-printed goods are more energy-efficient. For example, 3D-printed components in General Electric's airplane helped

increase efficiency by almost 7 percent.[16,i]

3. Faster Prototyping: Prototyping a new product is faster and less expensive than ever before. Some business owners opt to purchase a 3D printer to produce their own prototypes, while others seek prototyping services from a third party. From 2010 to 2015, prototyping service revenues grew at an annualized rate of 22.6 percent.[17] 3D-printed prototypes were made for several industries, including construction and architecture, aerospace, automotive, medical and dental, toys, jewelry, and home goods.[18]

4. Design Flexibility: Layer-by-layer production allows for design of more complex shapes and enables the incorporation of varying printed materials with different design characteristics, such as stiffness and conductivity.[19] Manufacturers have taken advantage of these design benefits. For example, Boeing and Lockheed Martin use 3D printing for aerospace components, LUXeXcel uses it to manufacture LEDs,[20] and auto manufacturers such as Bentley use it for production of intermittent or intricate parts.[21] Consequently, design and manufacturing sales for 3D printer manufacturers have increased. 3D Systems, for example, saw a 27 percent increase in their design and manufacturing revenues from 2013 to 2014.[22]

5. Increased Customization: 3D printing enables mass customization, meaning that one product, such as a shoe, can be molded to fit the individual. 3D printing also enables individual customization of goods tailored to the consumer's preferences.[23] Companies like NRML customize ear buds for the perfect fit for their customer.[24] New Balance 3D released its first 3D-printed midsole and was the first company to utilize 3D printing to customize track spikes for competitive athletes.[25] Other companies like Twikit enable customers to personalize items ranging from trophies to jewelry.[26]

6. Space Efficiency: Being able to create components on demand minimizes the number of molds and dies that need to be created and stored, especially if only a small volume of the product is required.[27] The Naval Undersea Warfare Center-Keyport uses additive manufacturing to manufacture a supply of replacement parts for submarines or ships without requiring a great deal of space or complicated logistics.[28]

7. Reduced Costs to Manufacturers and Customers: Because 3D printing requires less input material, it can reduce material costs by up to 90 percent.[29] It can also cut the cost of transporting components by housing the manufacturing process at assembly sites. These cost savings trickle downstream to customers.

i See example of General Electric's efficient 3D-printed fuel nozzle on page 46.

Identifying Ohio's Strengths, Weaknesses, Opportunities, and Threats in the Additive Manufacturing Industry

STRENGTHS	WEAKNESSES
• Ohio is home to America Makes, the national accelerator for additive manufacturing[30] • Ohio has 13,000 manufacturing firms,[31] placing the state fourth in the nation in manufacturing gross domestic product[32] • Ohio's Third Frontier program and state universities are national models for driving local innovation[33] • The additive manufacturing industry has multilateral codes and standards[34] • Most manufacturers (67 percent) currently use 3D printing[35] • The number of additive manufacturing employees grew an average of 6.6 percent from 2010 to 2014[36]	• High costs of industrial 3D printers restrict widespread adoption and experimentation by small companies • Newer printing technologies lack consistent quality[37] • Design changes needed to shift some manufacturing processes are a barrier to adoption
OPPORTUNITIES	**THREATS**
• The 3D printing industry is projected to grow up to 300 percent in the next ten years[38] • Additive manufacturing is used by diverse sectors including medical and dental, aerospace, energy, and automotive industries for specialty tools, customized goods, rapid prototyping, and rapid product development[39] • Foreign companies desire U.S. manufacturing facilities • Ohio can export 3D printers to other states and countries	• Some states, including New York, are investing millions of dollars in advanced manufacturing, potentially edging out Ohio as a leader in the field[40] • Ohio could lose its leadership role in additive manufacturing research and development (R&D) if the state does not maintain current investment levels

America Makes: A Leader in Additive Manufacturing Innovation

In August 2012, the U.S. federal government asserted its leadership in additive manufacturing by establishing a national accelerator in Youngstown, Ohio. The National Additive Manufacturing Innovation Institute, currently known as America Makes, was funded by a joint federal grant provided by NASA, the National Science Foundation, and the Departments of Defense, Energy, and Commerce. It was the first institute developed for the National Network of Manufacturing Innovation, a federal initiative announced earlier that year.[41] America Makes serves as a public-private commitment to additive manufacturing research, aiming to increase both technological competitiveness and the number of jobs in the manufacturing sector.[42] The institute attracts and supports businesses and initiatives nationwide, and its Youngstown base gives Ohio unique access to this national resource.

Rising Demand for 3D Printers

In 2014, the additive manufacturing industry saw a 35 percent growth rate, its largest increase in history, and amounted to a $4 billion global industry.[43] Due to increased financial support and growing innovation, the global 3D printing industry has quadrupled in size in the past five years.[44]

Bullish market projections indicate that the global additive manufacturing industry will grow by approximately 49 percent each year until 2019,[45] or up to 300 percent within ten years.[46] More conservative estimates predict that the industry will grow an average of 18 percent per year, reaching up to $7 billion by 2020.[47]

Domestically, the $1.5 billion U.S. industry is expected to grow 16.2 percent in 2016.[48] In 2011, approximately 63 percent of commercial and industrial 3D printers were sold by three U.S.-based companies: Stratasys, Z Corporation, and 3D Systems.[49] Almost 65 percent of all 3D printers sold worldwide were manufactured in the United States.[50]

3D printers have transitioned from industrial workshops to home offices and surgery wards. In 2014, desktop printer revenues increased 98 percent, amounting to $173 million.[51] Worldwide, sales of desktop printers under $5,000 jumped from 355 in 2008 to 72,503 in 2014.[52] Leading desktop 3D printer manufacturers include RepRap (Denmark), Makerbot Industries (United States), and Beijing Tiertime (China).[53] Demand for 3D printing in the

medical field has burgeoned over the past few years, with 3D Systems' healthcare sales increasing by 80 percent from $71 million in 2013 to $129 million in 2014.[54]

Both government aid and key research investments have played a major role in jumpstarting the global additive manufacturing industry.[55] In 2013, the United Kingdom committed over $16 million in R&D funding to help expand 3D printing technology across industries.[56] The United States also established the National Additive Manufacturing Innovation Institute, now called America Makes, to create a strong foundation for public-private partnerships and to attract manufacturing companies and investors.[57] The private sector also continues to invest in 3D printing R&D. For example, General Electric invests $6 billion annually in R&D and plans to incorporate 3D printing in the production of airplanes.[58]

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Innovations in 3D Printing Will Create New Markets

3D-Printed Fuel Nozzle Increases Fuel Efficiency in Airplanes

General Electric now uses several 3D-printed parts, including sensor housings and fuel injection systems in commercial jets. Additionally, the Federal Aviation Administration has approved the use of 3D-printed fuel nozzles in General Electric's LEAP commercial jet engines.[59] The 3D-printed fuel nozzles are five times stronger and two-thirds lighter than previous models.[60] Furthermore, the old nozzles contained twenty-one parts, whereas the new 3D-printed models consist of only one part.[61] The resulting 3D-printed system is 15 percent more efficient than the previous engine models manufactured with subtractive methods.[62] This increase in efficiency can save airlines $1.6 million per airplane in annual fuel costs.[63] Companies around the world have already ordered more than 6,000 LEAP engines worth a combined $78 billion.[64]

Department of Defense Decreases Maintenance, Removes Obsolescence, and Encourages Creativity Through 3D Printing

Each year, the Department of Defense spends almost $75 billion on maintenance costs.[65] Moreover, the military often demands that parts are delivered quickly to remote locations and in small quantities.[66] 3D printing enables the military to redesign components in a manner that will ultimately decrease maintenance needs. For example, the Navy's Fleet Readiness Center used 3D printing to redesign its V-22 Osprey aircraft with enhanced hydraulic manifolds that are 70 percent lighter and have fewer leak points (thus requiring less maintenance) than the traditionally manufactured manifolds.[67] Reverse engineering can help overcome obsolescence of specific parts. For example, the B-52 aircraft was introduced in 1952 and many of the parts are no longer routinely manufactured. With 3D printing, parts can be reverse-engineered and produced on-site when needed, extending the B-52 aircraft's lifespan until 2044.[68]

3D Printing Increases Efficiency in the Surgery Ward

3D Systems' sales of medical devices increased by 80 percent from 2013 to 2014,[69] which suggests that additive manufacturing has a significant impact on the healthcare industry. Companies such as Therics, a medical device manufacturer, already hold a number of patents in the medical field[70] that could transform the way doctors are trained and treat patients. For example, at teaching hospitals such as University of Florida, doctors practice surgery techniques on 3D-printed models of real patients' skulls and brains.[71] Realistic, hands-on practice can help save lives and reduce healthcare costs through reduced surgery time. Some procedures can cost as much as $300 per minute, so any reduction in surgery time results in significant savings.[72] 3D

printing can also increase efficiency of medical implants through design of various porosity and density to match human tissue.[73] Research at America Makes focuses on products for surgery that can be reabsorbed by the body,[74] and some experts predict that in the future 3D bioprinters will print body parts.[75] Researchers have already printed human blood vessels and a small heart that successfully beat moments after printing.[76]

Other Medical Applications of 3D Printing

More than 500,000 patients worldwide have 3D-printed dental implants and 30,000 patients have 3D-printed orthopedic implants.[77] Some niche medical sectors solely rely on 3D printing for their products. For example, the U.S. hearing aid industry completely shifted to 3D printing in less than 500 days, reflecting the ability for entire industries to quickly shift manufacturing processes.[78]

Falling Cost of 3D Printers

As a result of R&D investments and rising demand for 3D printers, the cost of 3D printers has fallen significantly in recent years. Between 2001 and 2011, 3D printer costs decreased 51 percent.[79] A 3D printer cost at least $45,000 in 2001, and the same model is predicted to cost less than $2,000 in 2016.[80] Siemens predicts the cost of 3D printing will drop by 50 percent from 2013 to 2018,[81] while other industry experts predict the cost will drop 60 percent in the same time period and another 30 percent from 2018 to 2028.[82]

Although some types of 3D printers are still too expensive for widespread adoption—some 3D metal printers cost upwards of $200,000[83]—the majority of industrial manufacturers (67 percent) currently use 3D printers.[84] However, manufacturers are not the only end users. Many small home printers are priced less than $500, making them affordable for the average consumer.[85]

As America Makes and other national public-private institutions research new 3D printing methods and applications, the cost could continue to fall.[86]

Ohio's Additive Manufacturing Industry

Ohio leads the nation in manufacturing: the state houses the third largest industry workforce in the country and, as of 2013, produces almost $100 billion in manufacturing output.[87] Additionally, almost 60 percent of Ohio's counties depend heavily on manufacturing for their economic wellbeing.[88] Keeping the industry healthy in the coming decades will require the implementation of economic policies that support 3D printing and other emerging technologies.

The 3D Printing Supply Chain

The 3D printing supply chain breaks into seven subgroups: design, manufacturing, software, hardware, services, business development, and research. Design includes direct and indirect prototypes, while manufacturing consists of direct, indirect, or specialty parts like those produced for the medical industry. Cloud platforms and digital threading make up the software for additive manufacturing.[89] The hardware supply chain includes consumer and industrial printers and materials such as metal, plastic, ceramics, composites, and glass.[90] Business development and research are critical to maintaining competitiveness in this rapidly changing industry.

Ohio's 3D printing industry has several strengths including R&D, business development, and hardware manufacturing. 3D printing R&D occurs at universities, public-private institutions, and private companies. Universities such as Case Western Reserve University, Youngstown State University, University of Akron, University of Dayton, and Ohio State University are currently researching additive manufacturing technologies and materials.[91,92,93] Public-private partnerships include Case Western and rp+m, an Avon-based manufacturing and material R&D company,[94] as well as a partnership between Cincinnati Incorporated and Oak Ridge National Lab that develops large-scale polymer additive manufacturing systems.[95] Meanwhile, General Electric and other private firms are researching new methods of printing complex aircraft components.[96]

Business development is another strength of Ohio's additive manufacturing industry. America Makes (see page 44) closely collaborates with the Youngstown Business Incubator, the top university-affiliated incubator in the world,[97] to support new additive manufacturing companies.[98] JuggerBot 3D, a software and hardware developer and consulting services group, is one example of a successful firm that has come out of Youngstown.[99] Older companies exist in the supply chain such as MakerGear in Beachwood, which has been manufacturing 3D printers for home use since 2009.[100]

Growth and expansion in the global 3D printing industry continues to impact Ohio. 3D Systems, an international additive manufacturing firm, recently acquired an advanced manufacturing engineering services company in Columbus known as Laser Reproductions.[101] 3D Systems also acquired Village Plastics, a filament producer based in Norton.[102]

3D printing materials research and production is a burgeoning industry in Ohio with room for growth. For example, 3D Systems opened a 30,500-square-foot facility in Barberton in 2014 to produce 3D printer filament materials and research new thermoplastic materials for 3D printing.[103] In Miamisburg, Mound Laser and Photonics Center researches metal powder technologies for 3D printers.[104] To capitalize on these existing assets and keep up with rapidly evolving industry technology, Ohio has the opportunity to strengthen its materials supply chain, with an emphasis on emerging trends such as thermoplastics, ceramics, and biomaterials.

Table 3. Companies in Ohio's Additive Manufacturing Supply Chain

Business Sector	**Ohio Companies**
Printing Machinery and Equipment Manufacturing	22
Software Publishing	646
Semiconductor and Related Device Manufacturing	55
Plastics Product Manufacturing (including nozzles)	723
Machine Tool Manufacturing (including metal cutting)	102
Electronic Component Manufacturing (including LCD)	132
Total	1,680

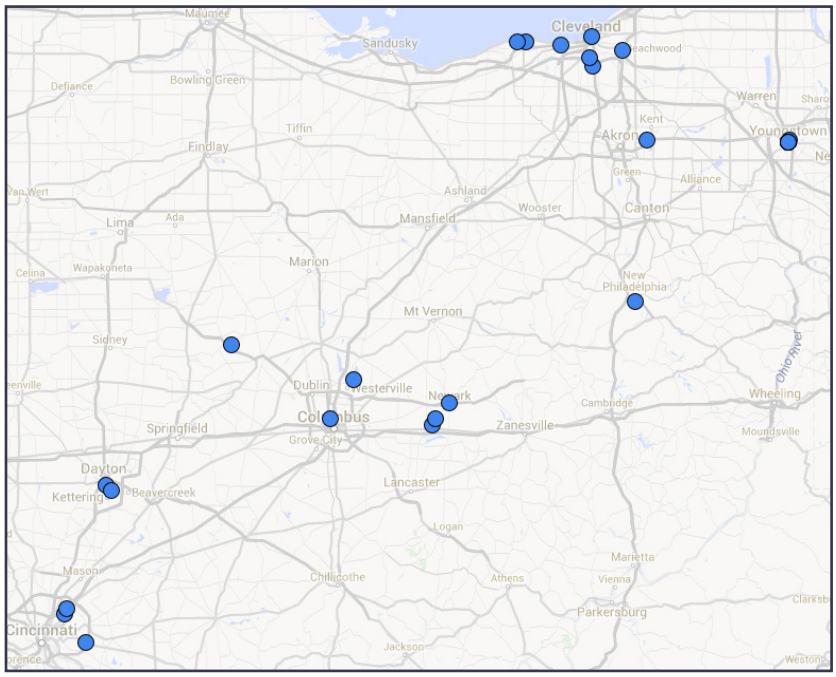


Figure 7. Map of companies in Ohio's additive manufacturing supply chain

3D Printer Manufacturing and 3D Printing Services Employment Potential

As demand for 3D printers skyrockets, Ohio has the opportunity to expand the 3D printing economy, increase in-state spending, and employ an average of over 4,400 more Ohioans annually over the next fifteen years. If optimistic projections prove to be correct and Ohio's 3D printing companies are able to increase their national market share to 10 percent, over 65,000 direct and induced job-years would be generated. While nearly 49,000 of those would be direct job-years in the state's 3D printing industry, over 16,000 induced job-years would also be supported.

These projections for job-years potential in Ohio's 3D printing industry utilized IMPLAN and industry growth estimates and benchmarks from IBIS World. Based on these national projections, we estimated the direct and induced jobs created. Due to the variability and proprietary nature of 3D printing technologies, we were unable to estimate the number of indirect jobs.

To highlight why growing the 3D printing industry in Ohio is so important, we have estimated the number of direct and induced jobs based on Ohio's share of firms in the national 3D printing industry. Figures 8 and 9 show how the number of 3D printing manufacturing and service jobs vary as Ohio's market share increases from 4 percent to 10 percent. Ohio's current market share of the 3D printer manufacturing and 3D printing services industries is approximately 4 percent.[105]

Increasing Ohio's share of the national 3D printing market would create thousands of jobs for Ohioans. Over the next fifteen years, doubling Ohio's market share of 3D manufacturing jobs would create over 12,000 direct job-years and over 4,500 induced job-years. Doubling the state's market share of 3D service jobs would create nearly 7,000 direct job-years and over 2,000 induced job-years between 2016 and 2030. Thus, if a concerted effort were made by the state to expand the 3D printing cluster, Ohio companies could double their market share, creating over 26,000 job-years.

By increasing the number of 3D printing manufacturers, service companies, and supply chain businesses to capture 10 percent of the national market, the state can support over 65,000 job-years and make Ohio a leader in the 3D printing industry.

What is a Job-Year?

A job-year is one full-time equivalent job for one year (i.e., forty hours per week for fifty-two weeks, which is 2,080 hours per year). If two people each work a part-time job for twenty hours per week for fifty-two weeks, this is counted as one full-time equivalent job for one year, i.e., one job-year. If one person works forty hours per week for ten years, this it is counted as ten job-years.

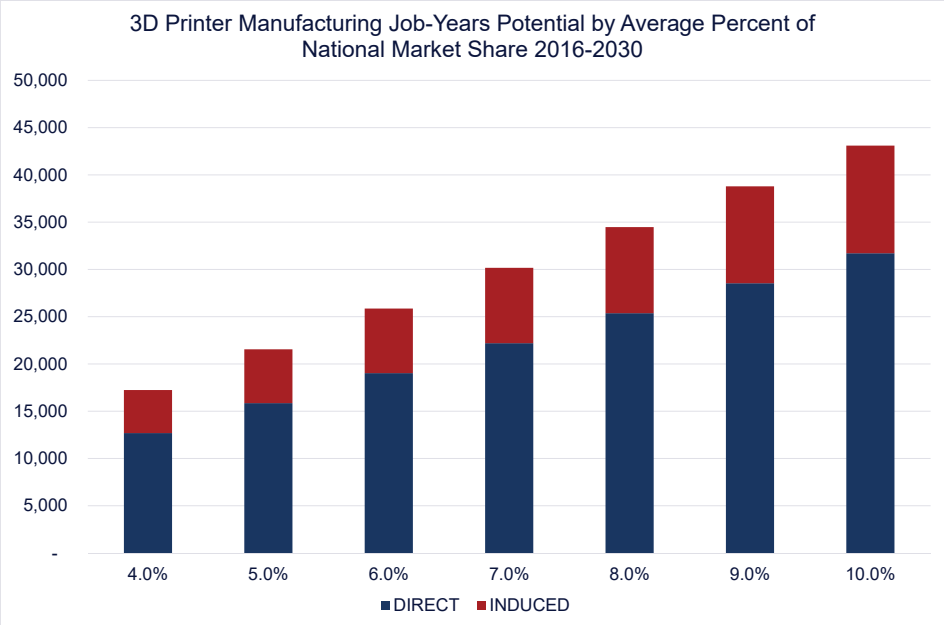
Why Use Job-Years?

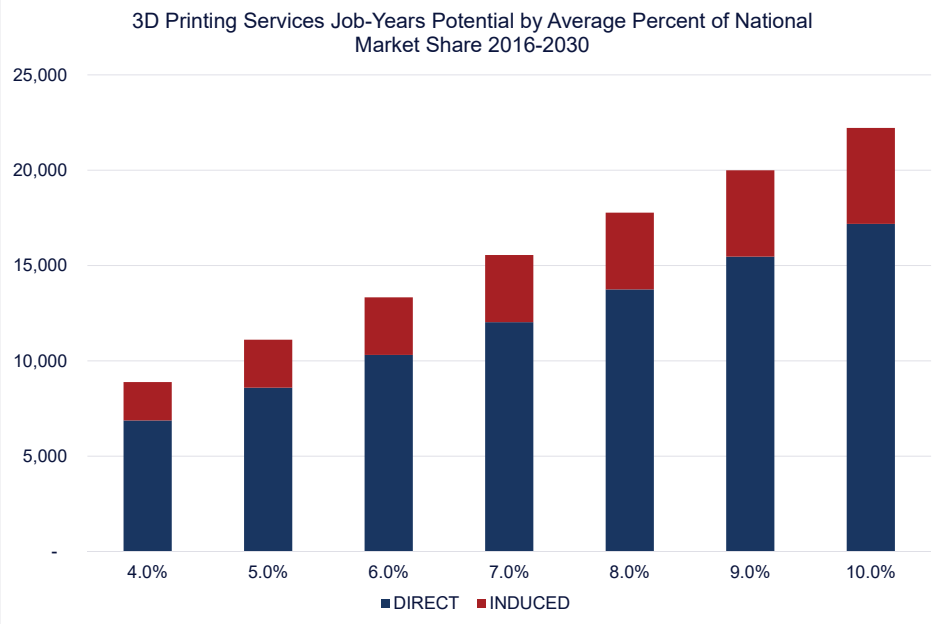
By using job-years, our analysis can take into account the length of a job. In energy projects, many construction and installation jobs are short-term, while manufacturing and maintenance jobs may be long-term. Using job-years allows us to accurately count both types of jobs. For example, if ten full-time manufacturing workers are expected to each spend 208 hours building 3D printers, this is measured as one job-year. Alternatively, if one full-time technician is expected to spend five years operating a 3D printer, this is measured as five job-years. In our analysis of Ohio's 3D printing supply chain, total job-years are aggregated over the 2016 to 2030 period.

Direct, Indirect, and Induced Job-Years

In order to estimate the potential economic impact of Ohio's 3D printing supply chain, direct, indirect, and induced job-years are measured:

- Direct job-years: reflect jobs created in the 3D printing industry to meet demand
- Indirect job-years: reflect jobs created at supply chain companies resulting from increased transactions as supplying industries respond to increased demand from Ohio's 3D printing industry. We do not provide indirect job-years in this analysis because we do not have accurate industry data on their expected supply chain expenditures
- Induced job-years: reflect jobs created throughout the local economy as a result of increased spending by workers and firms in Ohio's 3D printing and indirect industries





Figures 8,9. Increasing Ohio's market share for both additive manufacturing industries secures more jobs for Ohioans

Policy Recommendations

By focusing on innovative policies to remove obstacles and boost demand within the state, Ohio can become a national leader in additive manufacturing. Ohio can lead not only in the manufacturing of 3D printers, but also in R&D and 3D printing services. A robust additive manufacturing market will attract private investment and strengthen the economy. Additionally, Ohio can create thousands of skilled, good-paying jobs for local residents by stoking competition, encouraging demand, and incentivizing innovation. Below are key policies that the state could implement to maintain its competitive edge as a national leader in additive manufacturing, research, and services.

Policy 1: Encourage Foreign Direct Investment to Fill Supply Chain Gaps

A welcoming environment for manufacturers, a strategic location in the Midwest, and a stronghold on additive manufacturing innovation make Ohio an attractive locale for 3D printing manufacturing facilities. Ohio could strengthen its additive manufacturing supply chain with targeted foreign direct investment (FDI) missions.

Table 4. Potential Foreign Direct Investors in 3D Printing Components

Supply Chain Component	FDI Target
Printer manufacturing, software, and materials	Ultimaker (Netherlands)[106]
Printer manufacturing and materials	Dynamo 3D (Italy)[107]
Materials	Hoganas (Sweden)[108]
Printer manufacturing and materials	Arcam (Sweden)[109]
Software and prototyping services	Materialise (Belgium)[110]
Printer manufacturing, materials, and prototyping services	Farsoon / Varia 3D (China)[111]
Printer manufacturing	Zortax (Poland) [112]
Printer manufacturing	Norwegian Titanium (Norway)[113]

Ohio is a major destination for FDI, and about 14 percent of the FDI projects since 2003 are related to industrial machinery and equipment.[114] By leveraging its strong manufacturing base, Ohio can take advantage of foreign supply chain resources—from software to hardware—to boost economic development and generate stable, good-paying jobs. Overall, the state can assert its leadership in additive manufacturing by attracting financial support and expertise from large-scale international companies.

Policy 2: Capitalize on Digital Manufacturing Innovation to Drive Future Job Creation

Ohio boasts a strong base of additive manufacturing firms, and its research institutions give the state a competitive edge. To enhance the growth of additive manufacturing within Ohio, state leaders could continue to support and facilitate public-private partnerships that expand competition and the innovation capacity of small- and medium-sized manufacturers. As seen with America Makes, these exchanges have fostered about 200 new 3D printing jobs in the state, and more jobs could be created as the institute continues its focus on commercialization.[115] Ohio can continue this success by promoting advances in manufacturing technology and the corresponding workforce training to ensure that workers can keep up with skill demand. High-performance computing technology and new modeling simulation and analysis can build "competitive advantage through innovative product design, production techniques, cost savings, improved time-to-market cycles, and overall quality," according to the senior vice president of the Council on Competitiveness.[116] However, without assistance, many companies cannot afford to invest in this type of technology, putting them at risk of missing significant business opportunities.[117]

Trends and Best Practices in Digital Manufacturing Training

To address rapidly evolving technologies, the Economic Development Corporation allocated money to the National Center for Manufacturing Sciences in November 2012. The purpose of this funding was to help establish the Grid Cell (formerly named the Predictive Innovation Center), a facility that provides companies with equipment and workforce training to aid in virtual design and prototyping.[118] Ohio Northern University has a digital manufacturing and simulation lab that teaches students digital manufacturing software and connects them to local companies.[119]

In Michigan, North Central College has partnered with the Northern Lakes Economic Alliance, Charlevoix-Emmet Intermediate School District, Ferris State University, Little Traverse Band of Odawa Indians, Precision Edge, and numerous manufacturers to create a "self-contained mobile digital manufacturing lab," otherwise known as the "Fab Lab." The mobile lab can be set up near the workforce to improve the efficiency and accessibility of training programs. Students who complete the program receive a nationally recognized certificate in Computer Numerical Control.[120]

In-state digital manufacturing, which refers to computer-based systems that use 3D analytics to create manufacturing processes and design products, could be expanded to drive job creation in Ohio. State policymakers could look to the success of the National Digital Engineering and Manufacturing Consortium's (NDEMC) public-private partnerships. NDEMC's Midwest pilot program matched $2 million in private sector investment with $2 million in federal grants, $900,000 in Ohio state funds, and technical assistance from local universities.[121] The funding was used to increase the accessibility of high-performance computing and training resources for small- and medium-sized firms. The twenty manufacturers that received NDEMC funding saw a combined $20 million increase in sales revenue each year, with exports accounting for half of total sales. These manufacturers also created 160 new jobs in 2012 and developed three new products.[122] Ohio could expand on the successful pilot program by reinstating the public-private partnership using state funding and leveraging the resources of the state's public university network. Additionally, Ohio's Manufacturing Extension Partnership site could provide these digital tools and training to small manufacturers. Bolstering the state's workforce and innovation capacity within the digital manufacturing sector will set the stage for future growth and allow Ohio to effectively compete in the advanced energy global economy.

Policy 3: Connect Small Businesses to Research Institutions Through an Innovation Voucher Program

Small businesses often lack the tools and resources needed to commercialize innovative products in early stages of development. For small Ohio business owners, the inability to access new technologies could prevent them from advancing their business. Moreover, while some small businesses have considered 3D printing, the majority of small- and medium-sized business owners have yet to fully incorporate 3D printing into their supply chain.[123] Some states have encouraged 3D printing adoption by creating an innovation voucher program or establishing grant funds that small businesses can use to pay for equipment and consulting services from technological experts.

The New Mexico Small Business Assistance Program is a successful model that has helped 2,341 businesses gain access to technology at the Sandia or Los Alamos National Labs through a competitive application process that matches qualified businesses to scientists at the national labs.[124] The state government provides funding for the program, enabling the national labs to connect to local businesses and bolster the state's economy.[125] In Tennessee, the state created a $2.5 million innovation voucher

program whereby manufacturers of varying sizes can "purchase" services from the national lab.[126,127] Local businesses consult Oak Ridge scientists to test and develop new materials and improve manufacturing processes.[128]

While both of these examples focus on connecting small businesses to national labs, Ohio can modify the programs so that vouchers could be used at places like Battelle laboratories, Youngstown State University's Center for Innovation in Additive Manufacturing, or America Makes. Ohio can connect small businesses to all types of innovative local institutions, giving them the diverse tools and resources needed to incorporate 3D printing in their supply chain.

Policy 4: Establish an Additive Manufacturing Factory Retooling Program

Ohio is tied for the fifth largest market share for the U.S. additive manufacturing industry.[129] With 4 percent of all U.S. industry establishments and a strong research base, Ohio is poised for continued growth in the 3D printing industry. However, potential 3D printing manufacturers face several barriers to entry in the market, including the high costs of machines and materials.[130] State policymakers could remove obstacles and make Ohio a leader in additive manufacturing by initiating a Factory Retooling for Additive Manufacturing program. This program would encourage in-state manufacturing of 3D printing machines, materials, and services through a revolving loan fund for factory retooling. Ohio could model its factory retooling initiative after successful programs in Wisconsin.

Manufacturers in Ohio could use loans to purchase machinery and equipment, upgrade or build facilities, or use as initial operating capital. To receive a loan, firms could also be required to meet metrics such as energy efficiency benchmarks or a minimum number of jobs created. Implementing a Factory Retooling for Additive Manufacturing program will send a signal that Ohio is serious about cultivating its additive manufacturing industry and creating good-paying jobs for state residents.

Policy 5: Minimize Manufacturing Waste

U.S. firms generate 7.6 billion tons of non-hazardous solid waste each year.[134] The traditional subtractive manufacturing process can waste up to 90 percent of the original material.[135] Solid waste is costly to dispose of and recycle; in 2014, the Ohio Environmental Protection Agency spent at least $2 million on compliance assistance and pollution prevention for Ohio businesses[136] and $20 million on combined solid waste and recycling in the state.[137] To decrease costly waste, the state could provide incentives for

Wisconsin's Clean Energy Manufacturing Revolving Loan Fund

Wisconsin established the Clean Energy Manufacturing Revolving Loan Fund (CERLF) in 2009 to provide up to $1 million of low-interest financing to private companies investing in clean energy-related projects.[131] The Wisconsin Economic Development Corporation and the Wisconsin Public Service Commission jointly manage CERLF. The revolving loan fund received funding through the American Recovery Act and now boasts $38 million of working capital and equipment.[132] Gearbox, a Wisconsin-based wind turbine component manufacturer, utilized CERLF funding to expand and grow its advanced energy operations.[133]

the use of waste-minimizing technologies or mandate a waste reduction target for the manufacturing sector.

Ohio could create a tax incentive for waste-reducing machinery modeled on Ohio's Air Quality Improvement Tax Incentives, which exempt qualified technologies and businesses from the property tax, corporate franchise tax, and sales and use tax.[138,139] These incentives arguably encourage the use of technologies to reduce harmful pollutants before they are emitted into the atmosphere. Similarly designed incentives could focus on reducing material waste before the manufacturing process begins. Per Ohio's State Solid Waste Management Plan,[140] the executive branch could also consider a mandate to reduce industrial waste related to state-procured goods by a set percentage of 2015 levels within an achievable timeline. A broader waste reduction mandate would require legislation. Given that Ohio already documents waste reduction,[141] measurement and evaluation of waste reduction targets may be a low-cost mandate for the state. Upstream approaches to reduce waste would lower waste disposal and recycling costs for the state, while also stimulating advanced technologies such as additive manufacturing.

Waste Reduction Impacts

Some industries already benefit from the waste-reducing benefits of additive manufacturing. For instance, the aerospace industry cut the amount of material needed to render one pound of aerospace-quality material by 50 percent. In addition to reducing material requirements, engineers can also design more complex structures with 3D printing.[142]

Policy 6: Create a Manufacturing Technology Council

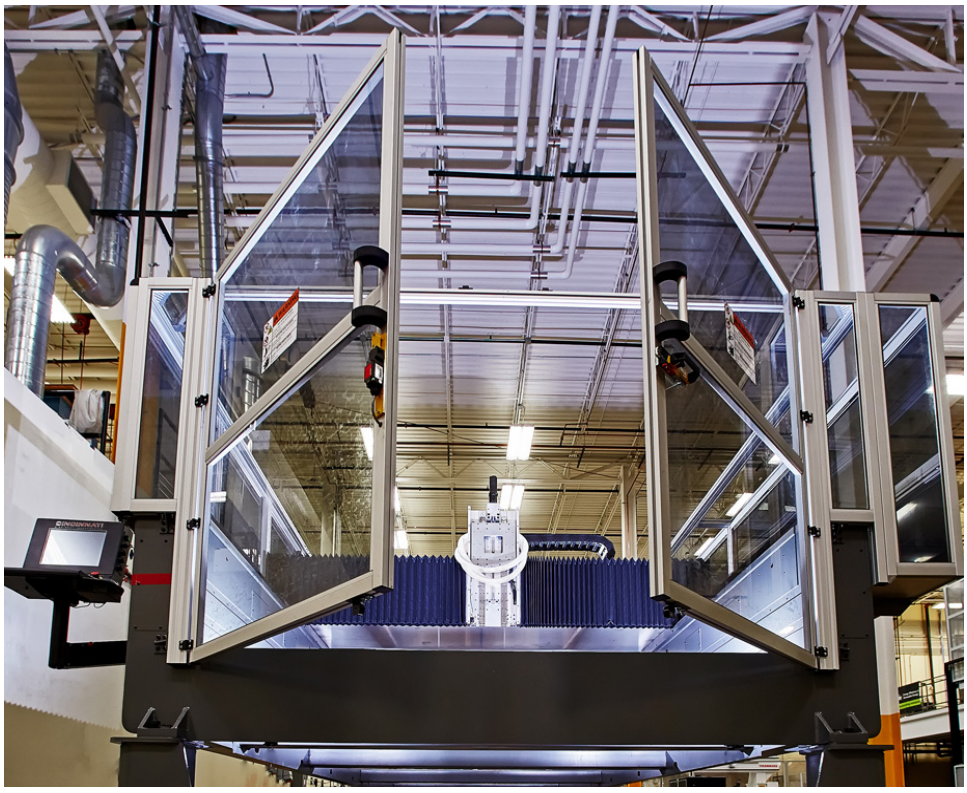
Maintaining Ohio's manufacturing industry into the coming decades will require adapting economic policy to support emerging technologies such as 3D printing. In order to adapt to new manufacturing technologies, Ohio will need a state body or council to advise on rapidly changing policy needs. Ohio currently houses several additive manufacturing organizations, including America Makes and the Additive Manufacturing Consortium.[143] However, these organizations have a national, not a state, focus. Ohio lacks a central body that can unite statewide additive manufacturers, recommend business-friendly policies on behalf of the changing manufacturing landscape, and help the state remain competitive in national and global additive manufacturing markets.

Ohio could create a Manufacturing Technology Council to unite statewide manufacturers and advise the state on policies that will keep Ohio competitive in the next generation of manufacturing. The council could include leaders from advanced manufacturing businesses, research universities and community colleges, and government entities. Regional efforts could be supported by engaging the Ohio Manufacturing Extension Partnership centers and JobsOhio network, a regional alliance of economic development organizations. Ohio also houses three institutes of the National Network for Manufacturing Innovation—America Makes, American Lightweight Metals, and Advanced Composites

Manufacturing—which the council could tap into as a resource.[144] This is a low-cost, straightforward way for Ohio to keep up with current manufacturing trends, develop strategies to bolster demand, fill supply chain gaps, and engage with companies that are seeking to set up new U.S. operations.

Chapter Summary

Ohio has the potential to be a national leader in 3D printer manufacturing, research, and printing services. Smart, strategic policy choices can help leverage the state's unique strengths in additive manufacturing research and business development in order to create a thriving 3D printing sector. As clusters coalesce around a nucleus of activity and relationships, Ohio's policy-makers could remove obstacles and stoke in-state demand. Expanding the additive manufacturing supply chain by seeking foreign direct investment, capitalizing on digital manufacturing job growth, establishing innovation voucher and factory retooling programs, and creating a formalized manufacturing technology council are potential opportunities for Ohio policymakers to facilitate growth in the additive manufacturing sector. Passing policies that spur demand and innovation and remove barriers to entry will reduce overall manufacturing waste, increase consumer choice, and make Ohio a more competitive state in the advanced energy economy.



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Chapter 4: Innovation Ecosystem and Access to Capital

In today's competitive, globalized economy, businesses are more likely to thrive in cities and states that offer a rich innovation ecosystem and break down barriers to capital. A successful innovation ecosystem bridges the gap between the knowledge economy and the commercial economy, while access to capital programs provide the necessary funds to facilitate commercialization and expansion of businesses. State and local government institutions, as well as private entities, can take action and collaborate to maximize the impact of innovation, support new and expanding businesses, and create good-paying jobs in Ohio.

Innovation ecosystems promote research and development (R&D), bring new technologies to market, and incubate early-stage businesses. Allowing ideas to be easily transferred from the lab to the marketplace accelerates further entrepreneurship and job creation. Robust innovation ecosystems include efficient intellectual property protection mechanisms, mentoring for entrepreneurs, and engagement of business and venture capital.

Access to capital is critical for the success of advanced energy technologies. New and growing businesses will face severe financial hurdles during technology development, commercialization, and expansion. Having access to investors and non-dilutive capital can be the difference between success and failure. In order to maximize the success of advanced energy businesses that create good-paying jobs, states should consider actively facilitating access to capital.

Seamless connections between researchers, entrepreneurs, investors, and non-dilutive capital are vital for advanced energy technology businesses to thrive. The new energy economy is a race, and only businesses capable of bringing innovative ideas to the marketplace quickly and efficiently will be in a position to win.

Innovation Ecosystem

- Promotes research and development
- Facilitates new technology to market
- Incubates early-stage businesses

Access to Capital

- Provides funding for new and growing businesses
- Connects investors with market opportunities
- Attracts entrepreneurs

Non-Dilutive Capital

Non-dilutive capital, such as grants and loans, does not affect ownership of a company. These funding sources may carry interest rates or have restrictions on how they are used, but will not impact the shares of the company.

Ohio's Innovation Ecosystem

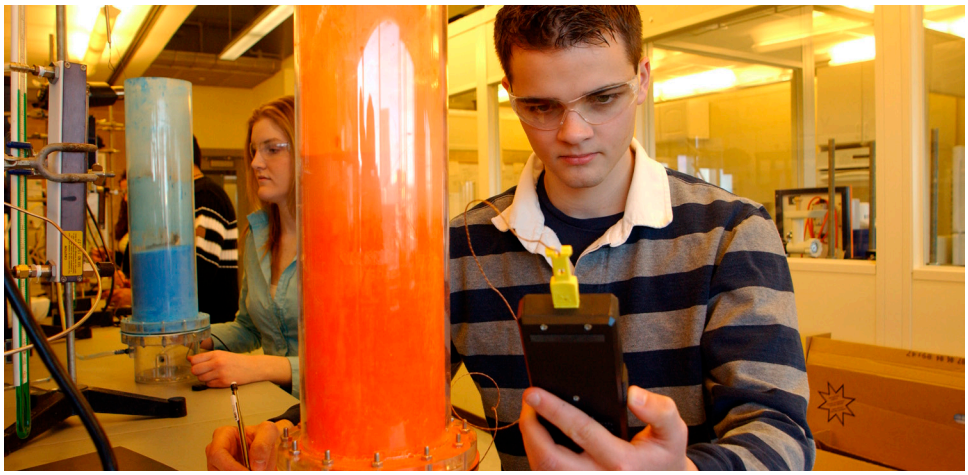
Since the 1980s, Ohio has made innovation a top priority. Under the Third Frontier Program, the state has created thousands of jobs and leveraged public money to create billions of dollars in

local economic activity. Ohio's state government encourages the growth of small- and medium-sized businesses, as well as cross-university research, collaboration, and commercialization efforts. Policymakers have used every economic development tool available, from direct appropriations to tax credits and public-private partnerships. This chapter explores ways to improve upon Ohio's existing institutions and initiatives to maintain the state's competitive edge and foster growth and innovation in the advanced energy economy.

Research Institutions and Initiatives

Headquartered in Columbus, Battelle is the largest non-governmental, nonprofit R&D organization in the world.[1] In addition to a $5 billion annual budget for research and development, the organization manages several national laboratories and employs 21,000 people.[2] Battelle's laboratories manage multiple projects focusing on advanced energy integration.

Ohio is home to a robust academic network that leads advanced energy research and includes strong models for bringing innovations to market. Eight higher education Centers for Excellence in Advanced Energy—located at Bowling Green State University, Case Western Reserve University, Central State University, University of Cincinnati, University of Dayton, The Ohio State University, Ohio University, and University of Toledo—lead the state in advanced energy innovation.[3] Ohio universities also serve as an important industry resource. For example, Bowling Green State University, University of Toledo, and Case Western Reserve University have led extensive Department of Energy-funded research in offshore wind power.[4] Case Western has particularly strong ties with the private sector as Lake Erie Energy Development Corporation's research partner and the manager of rp+m's R&D arm.[5]



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Resources for Startups

SciTech is developing a large-scale research park at Ohio State University to promote technological innovation.[6] The campus also houses Rev1 Ventures, a national award-winning incubator. Thus, the necessary resources to support innovation and commercialization are centralized at SciTech.[7]

Furthermore, the additive manufacturing sector gets a boost from America Makes, which awards R&D funding to institutions nationwide. Ohio can also bring innovations to market through the world-renowned Youngstown Business Incubator. Additionally, Youngstown State University operates the Center for Innovation in Additive Manufacturing within the regional 3D printing hub.

Government Programs

Entrepreneurial Signature Program Regional Offices

- Northeast: Jumpstart, Inc.
- Southeast: Techgrowth Ohio
- Southwest: Cincytech
- Western: Accelerant Dayton
- Northwestern: Rocket Ventures
- Central: Rev1 Ventures

The Ohio Third Frontier program is housed within the state's Development Services Agency. It supports activities in innovation and commercialization, as well as capital and talent acquisition. The Ohio Third Frontier Technology Validation and Startup Fund (TVSF) provided $4.5 million ($1.5 million for three cycles) in 2015 for startup companies that commercialize technologies developed at Ohio-based universities.[8] The program aims to benefit from innovations in the state by encouraging startups and young companies from Ohio research institutions and federal labs to establish their business in the state. The program awards funding in two phases: (1) $50,000 to move technology from the R&D phase to the prototyping stage and past the initial "valley of death," and (2) $100,000 per project to support startup companies that are commercializing technology developed in Ohio.[9] The Third Frontier also created the Entrepreneurial Signature Program, which established regional offices to support entrepreneurs throughout the state.[10]

Recognizing the importance of coordination within and across sectors, the state funded the Ohio Federal Research Network in July 2015.[11] Wright State Applied Research Corp. will receive $20 million over the course of two years and Ohio State University will receive an additional $5 million to establish collaboration between the state's research universities, Wright-Patterson Air Force Base, NASA Glenn Research Center, and the private sector.[12] Approximately half of this funding will be used to create a model of how the research network will run.[13]

The goal of the Ohio Federal Research Network is to bring in $300 million in new federal research contracts to Ohio-based companies in the next five years. It is estimated that this funding will result in 2,500 new jobs, $250 million in private-sector investment, and the creation or expansion of 100 companies.[14]

Access to Capital

Access to capital is essential for businesses to grow and bring new products to market. Many entrepreneurs are unable to find the necessary capital to sustain their companies long enough to reach the commercialization phase. As shown in Figure 10, companies nationwide face funding shortages during the prototyping and commercialization phases. Seventy-five percent of all venture capital funding goes to companies in California, New York, and Massachusetts.[15] Businesses in the other forty-seven states compete over the remaining 25 percent, making state-based policies for venture capital investments incredibly important.

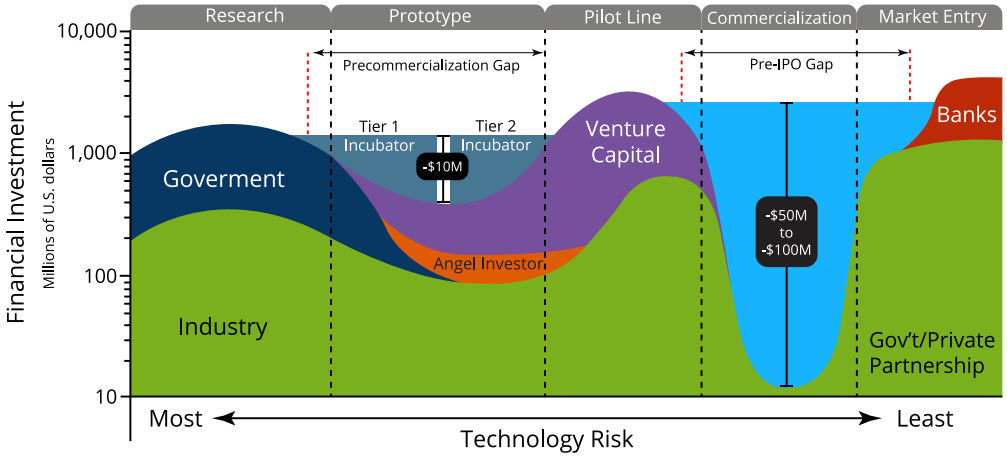

Figure 10. New technologies need help crossing the second "valley of death" during the commercialization process (Source: U.S. Department of Energy)

Venture Capital

The Ohio Capital Fund (OCF) provides early capital support to state tech firms. Created in 2003, the OCF is a bonding program that can raise up to $380 million, capped at $20 million per year. It has generated hundreds of millions of dollars in state economic activity at no cost to taxpayers. All OCF investments are overseen and approved by the Ohio Venture Capital Authority. OCF capital can be distributed to state venture capital firms that invest in seed or early-stage companies or established businesses developing new technologies in any field.[16] In the event that the OCF loses money on its investments, the venture capital firm's losses are offset by tax credits.[17] However, the program has experienced an 8 percent return and no losses to date, meaning no tax credits have been claimed and taxpayers have not incurred any cost.[18]

To date, the OCF has had a significant impact on the state economy by providing a source of early investment money for new Ohio-based companies. A detailed report conducted by SRI

International in 2009—a mere six years after the inception of the OCF—concluded that the program had delivered a return of $2.19 in economic impact for every $1 invested.[19] Additionally, the OCF's 2014 annual report stated that the program has distributed $245 million of its $380 million maximum and created an estimated 2,595 jobs in seventy-six Ohio companies.[20] Companies with OCF investments have experienced an average 33 percent increase in revenue growth over the last four years.[21] As a result of the program's success, the Ohio Legislature has recently considered proposals to increase the maximum amount of capital the OCF can issue.

Ohio attracted $321 million of venture investment in 210 companies in 2014.[22] However, there has been a slowdown of private venture capital from Ohio-based firms, which is an emerging issue.[23] In 2016, the state expects to see a $392 million gap between the needs of Ohio seed and early-stage companies and available venture capital.[24] To overcome this challenge, Ohio policymakers should consider new options to attract early-stage investment capital and foster growth.

Non-Dilutive Capital

Ohio's state government oversees grant and low-cost/low-interest loan programs to help businesses succeed. The Advanced Manufacturing Program (AMP) and the State Energy Program (SEP), both of which are administered through the Ohio Development Services Agency, provide grants to businesses. The AMP strives to encourage advanced manufacturing activity by providing funding to Edison Technology Centers and also nonprofits that show value-added advanced manufacturing assistance.[25] The Ohio Development Services Agency receives funding from the U.S. Department of Energy through the SEP and provides competitive grants for renewable energy and energy efficiency technology.[26] The SEP aims to support new jobs, reduce emissions, and increase energy efficiency and renewable energy in the state.[27]

Ohio also has programs that provide low-cost loans to businesses. Ohio's GrowNOW, ReEnergize Ohio, and Minority Direct Loan programs provide capital for businesses at below-market interest rates. The GrowNOW program stems from the partnership between the Ohio Treasury and eligible banks. It provides qualifying small business owners with loans at a 3 percent interest rate for two years with the chance to renew for another two-year period.[28] With a $400,000 cap, the loans go to both new and existing small businesses that commit to creating or retaining a minimum of one full-time job for every $50,000 borrowed.[29] ReEnergize Ohio helps new or existing small businesses by providing a four-year interest rate reduction of up

to 3 percent on up to $550,000 of new or existing loans.[30] At least 50 percent of the loan proceeds must be used for energy-efficient building upgrades.[31] For businesses to qualify, they must be headquartered and operate exclusively in Ohio, and the majority of their employees must live in the state.[32]

Through the Minority Direct Loan Program, minority-owned businesses located or expanding in Ohio are able to obtain fixed, low-interest rate loans with the condition of new job creation.[33] Fifteen-year loans are available for building acquisition, renovation, or new construction, and ten-year loans can be used for purchasing machinery and equipment.[34] Qualifying businesses must be certified as a Minority Business Enterprise by the State Equal Opportunity Coordinator.[35]

Tax Incentives

Established in 1996, the Technology Investment Tax Credit (TITC), gave investors an income tax credit from the state equal to 25 percent of up to a $250,000 investment.[36] Alternatively, investors could collect 30 percent of up to a $300,000 investment if they committed funding to businesses in distressed counties.[37] The conditions also encourage long-term investments (more than three years) and rewarded commitments to Ohio companies of all sizes. When the program was initially created, it was designed to terminate after providing $45 million in tax relief.[38] A report by SRI International estimated that the TITC program had a $109.8 million overall economic impact through 2009, which equated to almost a $4 return for every $1 invested.[39] The program reached its cap in 2012 and has since been discontinued.[40]

InvestOhio is another program focused on spurring economic growth through private-sector investments. Like the TITC, InvestOhio grants personal non-refundable income tax credits to investors, but it focuses strictly on investments in small businesses.[41] Under InvestOhio, a small business must not have assets exceeding $50 million, and must have either fifty or more full-time employees total or stationed in Ohio.[42] Distributed funds must be spent in specific categories: tangible property or real estate within Ohio used to operate the business; intangible property, such as patents and copyrights; vehicles used primarily for business purposes and purchased in-state; or compensation for new employees.[43] Both the investor and investee are required to prove that this condition is met, and investors are required to maintain their position in their investee's company for at least two years.[44] Although initially a small program with a $10 million cap—of which only $4.1 million was ever claimed—investments claiming InvestOhio tax credits during the 2011–2013 biennium created more than 700 state jobs.[45]

Facility at Oak Ridge National Laboratory
Photo Credit. U.S. Department of Energy

Policy Recommendations

Policy 1: Create an Intrastate Securities Exemption for Equity Crowdfunding

The number of in-state investors have declined in Ohio over the past few years, and available venture capital, as of 2016, is not expected to meet the needs of early-stage companies.[46] Over the past four years, twenty-six states and the District of Columbia have enacted intrastate securities exemptions that allow equity crowdfunding from non-accredited investors.[47] These exemptions align with updates to the federal exemption for equity crowdfunding under Title III of the JOBS Act.[48]

Establishing this exemption would open up a new pool of investors in Ohio that could invest in local startups. Intrastate exemption rules allow the state to decide limits on equity offerings from companies and maximum investments by non-accredited investors. These limits often exceed federal rules, giving states the ability to compete as the most lucrative option for intrastate investment.[49] In 2015, 102 companies were approved for this exemption; at least one firm moved across state lines to become eligible.[50,51]

Types of Investors

- Accredited Investors are individuals with earned incomes that exceed $200,000 (or $300,000 if married) for three consecutive years or a net worth (not including their home) of $1 million dollars or more.[52]
- Equity Crowdfunders are non-accredited investors allowed to invest in companies with restrictions on how much they can commit. The Invest Georgia Equity Crowdfunding Exemption allows non-accredited Georgia investors to invest up to $10,000 in any company based in the state.[53]

Policy 2: Establish an Early-Stage Capital Gains Tax Exemption

A capital gains tax is applied to the sale of an asset that was purchased at a lower cost than it was sold. For example, if an individual purchases stock in a company and then sells when the company is worth more, the profits made on this sale, or capital gains, are taxed. As a result, high-risk, early-stage companies can have difficulty finding investors.

A state or national policy that eliminates or reduces the rate of capital gains taxes can attract investors. States can use this incentive to spur innovation in specific industries and encourage investors to commit their money to homegrown companies. Ohio could implement an early-stage capital gains tax exemption policy to help incentivize investment in clean energy and additive manufacturing startups. Ohio could reference successful early-stage capital gains tax exemption policies in other states and countries.

Successful Capital Gains Tax Exemption Policies

Similar programs have been successful in the United Kingdom: the Enterprise Investment Scheme (EIS) and Seed Enterprise Investment Scheme (SEIS) are tax-based venture capital schemes that provide tax relief to investors in high-risk companies. The EIS started in 1994 with the aim to help small, high-risk companies build capital by offering tax relief to investors.[54] In 2012, the government established the complementary SEIS, which offers tax relief at a higher rate for early-stage investment.[55] Approximately 22,900 companies have benefited from the EIS, raising over £12.2 billion in funds since the program began in 1994.[56] From 2013 to 2014, SEIS spurred a total of £164 million of investment in nearly 2,000 companies.[57]

Chapter Summary

Ohio has a well-established innovation ecosystem that includes programs to drive research, tax incentives for companies, government grants, low-interest loans, and more. The state's universities, incubators, applied innovation centers, and tax incentives provide Ohio with a broad foundation for spurring growth in advanced energy businesses. Policymakers can maintain Ohio's innovative edge by implementing intrastate equity crowdfunding and capital gains tax exemptions for investments in early-stage Ohio companies. These types of pro-market, forward-thinking policies would allow Ohio's advanced energy entrepreneurs to continue to innovate, bring ideas to market, and create good-paying jobs for residents.

Chapter 5: Workforce Development

Trained and skilled workers are fundamental to the success of an industrial cluster. Sector-based workforce development goes hand-in-hand with cluster development. If firms in the same cluster are able to coordinate with the government, schools, and related nonprofits on policies and programs to train workers for their sector, they will be better equipped to identify their employment needs and find qualified workers with the required skills to fill available jobs.

Ohio has recovered many of the jobs it lost in the Great Recession and therefore has an unemployment rate of 4.4 percent,[1] lower than the national average of 5.0 percent.[2] Despite these gains, many Ohio residents and regions are still struggling to recover economically. Many counties in southeastern Ohio have unemployment rates over 6 percent, with Monroe County on the West Virginia border experiencing a rate of 8.1 percent—nearly double the overall rate in the state.[3] Additionally, much of the job growth in Ohio has been in low-wage fields. The proportion of low-wage jobs has increased from 28 percent to 36 percent of the total jobs available in Ohio during the 2007–2013 period.[4]

Advanced energy sectors offer the opportunity to significantly expand employment and economic opportunities available to Ohio residents. This is especially critical to Ohio's existing manufacturing industry, which accounts for 12.6 percent of all jobs in the state economy.[5] Jobs in the wind energy[6] and advanced manufacturing[7] supply chains pay wages at or above the median salary, offering an opportunity to increase the middle- and high-wage jobs available in the state. These sectors are expected to employ an array of technicians and engineers through diverse opportunities, including manufacturing, maintenance, installation, and metalworking, among others. Overall, the sectors will contribute to the development of important advanced energy technologies and the Ohio economy as a whole.

In order to capitalize on opportunities in the advanced energy space, Ohio's policymakers can take proactive steps to address skill gaps and structural challenges in its workforce. By stoking advanced energy clusters, Ohio can provide more good-paying jobs for its dedicated labor force and encourage Ohioans to pursue careers in their home state.

A thoughtful sector-based workforce development approach should include industry best practices for recruiting, hiring, training, promotion, and compensation; education and training infrastructure (including community colleges, project-based learning experiences, and apprenticeship programs); and public policy, specifically rules, regulations, and funding streams related to workforce and education. Leaders in the state can focus efforts on those regions and populations that are still experiencing high unemployment.

Workforce Development Strengths

Ohio has several workforce development strengths that can be leveraged in order to support the emerging advanced energy sectors in the state. For example, Ohio boasts a robust higher education system, a strong Labor Market Information system that helps connect job seekers with employers, funds available to support worker retraining, and established Science, Technology, Engineering, and Mathematics (STEM) and Career and Technical Education (CTE) groups.

Ohio has a strong higher education system with nearly 600,000 students enrolled in public colleges, universities, and adult workforce education and training programs.[8] This academic network consists of fourteen universities, twenty-three community colleges, and more than 120 adult programs geographically dispersed throughout the state.[9] One of Ohio's greatest assets is the state's system of public universities, which includes world-renowned research universities such as Ohio State University, as well as statewide participation in national centers including America Makes. America Makes is centered in Youngstown and relies on contributions from University of Akron, Case Western Reserve University, Youngstown State University, community colleges, and local employers.[10] Additionally, Ohio State University offers a nationally ranked environmental engineering graduate program, which contributes to the pool of skilled and trained workers available to emerging advanced energy industries.[11] The university also offers an undergraduate minor in environmental engineering, further building the pool of qualified engineers in the state.

Ohio also focuses on skill-building in STEM fields because developing worker competencies in these fields is critical to the success of advanced energy technologies. The Ohio STEM Learning Network (OSLN) connects schools to each other and to national resources in order to produce best practices for the state and improve the student experience. OSLN operates through seven regional hubs that serve as a platform for collaboration among stakeholders in K–12 school districts, colleges, communities, and businesses within each region.[12] Additionally, Ohio is involved in

the national Project Lead the Way network, which allows students to enroll in a high school pre-engineering program.[13] Specialization courses include environmental sustainability, which requires students to investigate and design solutions to real-world matters such as renewable energy.[14] Participating middle schools also have access to Engineering by Design curriculum materials as part of the STEM Center for Teaching and Learning consortium.[15]

As a complement to the state's strong education base, Ohio is also committed to connecting people to careers and offering training opportunities to eligible workers. In 2014, Ohio passed legislation creating the OhioMeansJobs revolving loan fund, which helps workers pursue job training opportunities at eligible institutions, including four-year and community colleges, nonprofits, career technical centers, and private training providers.[16] To become a qualified provider, institutions must apply through a competitive request for proposal (RFP) process; if approved, they can receive up to $100,000 in funds per workforce training program.[17] As part of the RFP process, institutions must identify specific industry partners who will benefit from the training program, which ensures that the training addresses realistic employer needs. The funds are disbursed directly as student loans, and students are responsible for repayment.[18]

Other skill-building and training efforts in the state include CTE programs that focus on critical academic and employability skills, especially in high-demand STEM fields.[19] High school programs are managed by Career-Technical Planning Districts, while adult programs are operated through Ohio's Technical Centers.[20] CTE programs frequently partner with community colleges and local businesses to provide opportunities for students to accelerate their studies and get a head start in the job field. Students can also apply to apprenticeship programs for structured on-the-job mentoring and training. The Ohio Department of Job and Family Services lists more than 1,100 apprenticeship opportunities in a variety of fields, including work with wind turbine technicians.[21] Ohio dovetails efforts with the OhioMeansJobs system, which serves as a one-stop shop resource for employers and job seekers.[22] This system allows businesses to post job openings, search resumes, and explore employment programs, while job seekers can explore career options, search for jobs and training programs, and access resources to help with the job hunt.

Wind Energy: Jobs and Training Needs

Nationally, wind energy-related jobs are projected to increase by 300 percent by 2030.[23] Jobs in the wind industry cover a wide array of professions, including project development, component manufacturing, construction, operations, legal services, data analysis, education, training, and research. As a result, comprehensive workforce development and education programs that foster project management and STEM skills are required to successfully fill jobs in the wind energy industry.

Current Wind Training

Ohio currently offers a variety of training opportunities that specifically address the needs of the wind energy industry. For example, Ohio State University's Agricultural Technical Institute offers an associate degree in renewable energy, which includes a specialization in the production of wind turbines and solar panels.[24] Cuyahoga Community College's Advanced Technology Training Center offers a wind energy program as part of its series of ten- to eighteen-week programs designed to give workers basic skills to succeed in advanced technologies.[25] The Knox County Career Center provides similar wind industry training, and offers financial assistance to cover the program costs to qualified applicants.[26]

Photo Credit. Siemens AG / National Renewable Energy Laboratory

Wind Technician Training Opportunities in Ohio[27]

Wind turbine technician training courses, degrees, and certificates are offered at:

- Eastern Gateway Community College
- James A. Rhodes State College
- Kent State University at Trumbull
- Lakeland Community College
- Lorain County Community College
- Marion Technical College
- Owens Community College
- Stark State College of Technology
- Terra State Community College

Additive Manufacturing: Jobs and Training Needs

Additive manufacturing skills are gaining momentum in engineering fields: over 35 percent of current engineering job listings require skills related to 3D printing.[28] Jobs in the additive manufacturing industry demand a wide spectrum of skills, including engineering printers, manufacturing printing materials, and designing new end uses for 3D-printed products. Research from the Governor's Office of Workforce Transformation shows that advanced manufacturing will "drive Ohio's economy now and into the future," which suggests it is considered an important industry for the state's economic future.[29]

Current Additive Manufacturing Training

Youngstown State University houses the Center for Innovation in Additive Manufacturing, which offers advanced 3D printers for use by students of all levels, including those in the new Ph.D. program in materials science and engineering.[30] America Makes hosts interactive courses for those interested in learning more about 3D printing, some of which are conducted at its Youngstown labs.[31] America Makes also maintains a resource library on 3D printing materials, processes, and education programs. In the community college system, the only additive manufacturing certificate program currently offered is through Cuyahoga Community College. It is a one-year program that prepares students for the Society of Manufacturing Engineers' certificate exam and college engineering programs.[32]

Photo Credit. RDECOM / Foter / CC BY

Policy Recommendations

Ohio policymakers can build upon existing job growth and infrastructure investments in these sectors to help the state capitalize on opportunities in the advanced energy space through workforce development efforts that target skill gaps and specific areas of need.

Policy 1: Develop Regional Strategies for Allocating Training Programs and Ensure Community College Participation in Southeastern Ohio

Led by the Ohio Board of Regents, the state could convene representatives from business, industry, and research institutions to align training strategies to business and employer needs and geographic locations. Focusing on the regional distribution of jobs in the wind and energy sector could improve the effectiveness of higher education degree programs and training opportunities.

As a first step, the Board of Regents could identify where different components of the additive manufacturing and wind industries currently exist in Ohio and set up a framework to build out these existing industry hubs. For example, northwest Ohio produces the vast majority of the state's wind energy.[33] As a result, there is a specific need for workers trained in wind turbine operations and maintenance. Local schools such as Owens Community College can expand existing wind degree programs to provide additional technical and maintenance training programs.[34]

Next, the Board of Regents and industry leaders can collaborate to identify wind and additive manufacturing opportunities in the state. More specifically, leaders can determine whether any training courses or programs are needed in particular regions in order to meet the growing demand for workers. For example, the majority of job growth in Ohio's wind sector will be in wind component manufacturing. Northeast Ohio manufactures wind turbines, nacelles, blades, and other wind components. Wind component manufacturing jobs require workers with a wide skill set, including welding, machining, and electrical engineering. Community colleges in this region, including Lorain County Community College and Cuyahoga Community College, could potentially expand and tailor relevant degree programs to provide workers with the necessary skills to support local manufacturers.

Furthermore, given Ohio's high rate of employment in the manufacturing sector and long track record as an industry hub, establishing regional degree programs could encourage existing companies to expand their operations to include the production of

wind turbine components. This investment in education could be especially beneficial to regions like southeast Ohio with a history of manufacturing but current high levels of unemployment.

Policy 2: Expand Apprenticeship Programs to Support and Foster Career Pathways

Apprenticeships empower students to gain valuable on-the-job skills, industry-recognized certifications and credentials, and incremental wage increases. Ohio has more than 1,100 registered apprentice programs managed by the Ohio State Apprenticeship Council (OSAC), but this system can be improved through increased cooperation among OSAC, businesses, academic institutions, and other workforce development programs.[35] To encourage companies to establish apprenticeship programs, the General Assembly could pass a tax credit that would be available for each apprentice hired and direct state agencies to work with participating companies to tailor requirements, wages, and associated curricula based on each company's needs.

South Carolina's Apprenticeship Tax Credit

South Carolina has demonstrated how a small investment in apprenticeships can have huge payoffs for workers and the state. The state's successful apprenticeship system offers a modest $1,000 state tax credit per apprentice per year.[36] Registered apprenticeship programs have a significant return on investment: over the span of an average U.S. apprentice's career, tax revenues are more than $27 per $1 invested.[37] For the duration of an apprentice's career, the estimated social benefit outweighs the social cost by more than $49,000.[38]

Another effective strategy is to link apprenticeship hours to school credits and certifications. Ohio's Apprenticeship Pathways initiative allows students to participate in apprenticeships and receive academic credit at the same time. Apprenticeship programs in electrical trade, sheet metal, and carpentry have existing partnerships with community colleges to provide pathways to technical associate degrees. Other programs could implement a similar model for advanced energy apprenticeship opportunities.[39] This model could also be reproduced for high school students, allowing them to obtain school credit for participating in a registered apprenticeship with an Ohio employer.

By increasing the number and quality of apprenticeships available in the state, Ohio can better meet the growing demand for skilled workers in manufacturing.

Policy 3: Enable Dislocated Veterans to Return to Work

As of 2014, Ohio's 865,000 veterans represent approximately 7.5 percent of the state's total population.[40] As a major part of the state workforce, veterans have suffered significantly from the economic crisis and experienced disproportionate unemployment outcomes compared to state residents as a whole. The impact has been especially tough for Ohio veterans who served post-9/11. Unemployment rates for this group came in at 11.8 percent in 2014,[41] much higher than the 5.4 percent for non-veterans.[42]

The relatively high unemployment rate of veterans in Ohio offers an opportunity to help this skilled population get back to work. Notably, 42 percent of former military personnel engaged in medium-skill maintenance, machinery, and electrical technician work during their service.[43] This presents the state with a significant opportunity to tap into a well-trained and motivated sector of the workforce to contribute to the growth of advanced manufacturing and energy clusters.

New Jersey's upSKILL Initiative

Ohio could look to the New Jersey Institute of Technology's upSKILL initiative for a successful example of leveraging the veteran workforce.[44] Funded by the U.S. Department of Labor, this program guarantees free job search boot camps in resume skill translation from technical military work to civilian employment in STEM fields.[45] The initiative also offers free consulting services to determine the best technical degree or certification program for veterans based on their past military duties. The program then connects veterans to employers based on their technical training and the company's needs.[46] Finally, this program does not require that veterans use their G.I. Bill benefits, allowing veterans to save their funds for future opportunities to continue their education and workforce training.[47]

Ohio can adopt the upSKILL model through partnerships with local workforce development boards, community colleges, and the Ohio Department of Veterans Services. Local workforce boards and colleges could build awareness of high-paying manufacturing and maintenance positions in the advanced energy industry, especially among the growing wind and 3D printing supply chains. Workforce boards can help translate veterans' technical work to civilian practice and disseminate information regarding specific technical accreditations and up-

and-coming advanced energy jobs. In addition, Ohio could offer specialized college orientations for veterans to ensure that they are aware of relevant credits and certifications they may have already achieved as a result of their prior military service.

Photo Credit. PSNS & IMF / Foter / CC BY-NC-SA

Chapter Summary

Ohio has the potential to expand the state's wind and additive manufacturing energy sectors through targeted workforce development initiatives. By developing certificate and degree programs around wind and additive manufacturing skills, establishing a regional strategy, and increasing apprenticeship opportunities, Ohio can prepare its workforce for the advanced energy economy.

Conclusion

In order to build on Ohio's success in the advanced energy space and position the state for continued growth, policymakers will need to make advanced energy a priority. The purpose of *The Ohio Jobs Project: A Guide to Creating Advanced Energy Jobs* is to analyze the state's advanced energy economy in order to create recommendations specifically tailored to the state's needs. The policies recommended in this report are complementary and intended to help the state grow demand for advanced energy technologies, manufacture products within the state, enable entrepreneurship for technological advances, fund innovation with accessible capital, and equip workers with the skills required for the state's future economy.

Policy leadership in the advanced energy space can play an important role in promoting Ohio's advanced energy clusters and creating quality jobs for Ohioans. Advanced energy clusters focused on wind and additive manufacturing offer great opportunities for the state to grow its economy, create jobs for the state's residents, and become a leader in the production and deployment of advanced energy technology.

If Ohio's policymakers take swift and purposeful action to grow the wind and additive manufacturing clusters, these industries can support up to 26,000 jobs annually through 2030.

Ohio has the right mix of strengths to leverage this opportunity. With smart, forward-thinking policies, the state can diversify its economy and create thousands of middle-class jobs for hard-working Ohioans.

For more information about advanced energy technologies and best practice policies, visit http://americanjobsproject.us/.

Extended Learning Section

Appendix A: Innovation Ecosystem

Ohio Research Universities[1]

Highest Research Universities

- Case Western Reserve University
  - Great Lakes Energy Institute
  - Ohio Wind Energy Research and Commercialization Center
  - Think[Box]
  - Institute for Advanced Materials
- Ohio State University
  - Office of Energy and Environment
- University of Cincinnati

High Research Universities

- Bowling Green State University
- Cleveland State University
- Kent State University
- Miami University
- Ohio University
- University of Akron
- University of Dayton
- University of Toledo
- Wright State University

Doctoral/Research Universities

- Ashland University
- Union Institute & University

Ohio-Based Hackathons

- OHI/O
- Kent Hack Enough

- ACADIA Hackathon
- The Cleveland Medical Hackathon
- Fix 216
- Hack YSU
- A Call to All: Art & Music Hackathon
- HackCWRU
- RevolutionUC

Ohio-Based Maker Faires

- Akron Mini-Maker Faire
- Cleveland Mini-Maker Faire
- Cincinnati Mini-Maker Faire
- Stark County Mini-Maker Faire
- Kent State Mini-Maker Faire

Appendix B: Jobs Modeling Methodology

The American Jobs Project combines existing tools, analysis, and projections from several reputable sources to estimate job creation. Rather than providing a specific estimate, we show jobs potential across a range of possible outcomes. Our estimates of jobs potential are based on job-years that exist during the analysis timeline of 2016 to 2030.

We believe the key to job creation lies in local action. Our estimates are intended to start a conversation about how local stakeholders can work together to set their goals and utilize the same tools and data that we have used to estimate potential impacts.

The onshore wind analysis used the Job and Economic Development Impacts (JEDI) model and evaluated growth estimates across different levels of local spending for Bloomberg New Energy Finance, EERE's Wind Vision, and NREL's Renewable Electricity Futures 80 Percent Accelerated Technology Improvement scenarios. Offshore wind also used JEDI and growth estimates across different levels of local share spending for EERE's Wind Vision, NREL's Renewable Electricity Futures' High Constraint 80 Percent Renewables, and estimates from the Great Lakes Wind Collaborative. The 3D printer manufacturing and 3D printing services analysis utilized IMPLAN and industry growth estimates and bench-

marks from IBIS World to generate impacts across different levels of U.S. market share.

Tools for Economic Impact Analysis

A number of modeling tools are available for estimating economic impacts from advanced energy industry growth. The most commonly used are: the Jobs and Economic Development Impact (JEDI), Impacts for Planning (IMPLAN), and the Regional Economic Models, Inc. (REMI) models. In this report, we employ the JEDI and IMPLAN models. Results from the JEDI model only show job gains and do not evaluate losses in other industries. They are based on approximations of industrial input-output relationships, and do not include intangible effects. The JEDI model is widely used because it estimates construction and other projects' economic impacts at the local (usually state) levels. IMPLAN estimates the economic impact of a dollar invested into a sector and the resulting ripple, or multiplier, effects. Multipliers generate the economic impacts of the project across three different categories: direct, indirect, and induced. Not all advanced energy technologies can be modeled with JEDI. In these cases, IMPLAN is used.

It is important to note the limitations of these modeling methods. As mentioned, the estimates shown are only gross job-year creation and we only include job-years that exist within the timeframe of our analysis. Job losses in industries that compete with those in our analysis are not evaluated. Models do not dictate behavior, so indirect and induced jobs estimates could vary greatly based on the reality of what is actually purchased locally. Also, foreign and domestic competition can play a significant role in limiting the potential for job creation. The estimates presented in this report are highly dependent on sustained local action towards developing and maintaining these industries.

Estimates Used in the Economic Impact Analysis

Onshore and Offshore Wind

JEDI was used to estimate jobs potential for the onshore and offshore wind industry in Ohio. We show the jobs potential from several scenarios based on different percentages of local share, i.e., how much of the total industry supply chain and expenditures could occur in the state to serve local and national demand. In the report, we show a range of local shares: 25 percent to 75 percent. What this number will be is dependent on the options and

incentives for purchasing local goods and hiring local firms to provide services. We assume the most reasonable market would be in-state demand for onshore wind development. We also assume that if Ohio develops the offshore wind manufacturing base, the Buckeye state could serve the entire U.S. Great Lakes region with their products and specialized workforce, including Minnesota, Wisconsin, Illinois, Indiana, Michigan, New York and Pennsylvania. Canadian offshore wind demand in the Great Lakes is not included, but should be considered as another potential market for an offshore industry based in Ohio. Job-years included in this analysis represent all job-years that could exist during the timeframe of 2016–2030.

Wind Vision

The Wind Vision Study Scenario is a scenario that extends wind deployment trends, leverages the domestic wind industry manufacturing base, and complements the broader literature. The Study Scenario is represented by wind power penetration levels of 10 percent by 2020, 20 percent by 2030, and 35 percent by 2050 and includes projections for other renewable energy sources. Study Scenario impacts are compared to a Baseline Scenario in which wind capacity is fixed at 2013 levels. This allowed the team to identify and quantify impacts for future wind deployment. The assessment was the work of more than 100 individuals from major stakeholder sectors (government, industry, electric utilities, and nongovernmental organizations), conducted over a two-year period from 2006–2008. The study analyzed wind energy's potential contributions to economic prosperity, environmental sustainability, and energy security.

National Renewable Energy Laboratory: Renewable Electricity Futures

The National Renewable Energy Laboratory's Renewable Electricity Futures Study examines the extent to which renewable energy supply can meet U.S. electricity demands over the next several decades.[5]

> The study explores electricity grid integration using models with unprecedented geographic and time resolution for the contiguous United States to assess whether the U.S. power system can supply electricity to meet customer demand on an hourly basis with high levels of renewable electricity, including variable wind and solar generation.[6]

The study explores very high renewable electricity generation levels between 30 percent and 90 percent of all U.S. generation in 2050, with a particular focus on 80 percent.[7] The Incremental Technology Improvement scenario was used for our projections.

For offshore wind, the High Demand with 80 Percent Renewables by 2050 and High Constraint forecast was used. For onshore wind, the Baseline Demand with 80 Percent Renewables by 2050 and Accelerated Technology Improvements forecast was used.

Bloomberg New Energy Finance

Bloomberg New Energy Finance (BNEF) has projected the medium-term outlook for U.S. power based on research, market projections, data from the U.S. Energy Information Administration, and interviews with industry stakeholders.[8] These projections are updated and published annually, though the back-end data is private and not shared except by permission. BNEF graciously provided the data to us on the condition we would not publish it and only use it for our economic impact analyses. This in no way implies an endorsement of our project or our projections by BNEF.

Great Lakes Wind Collaborative

The Great Lakes Wind Collaborative considered three offshore wind development scenarios examining different levels of capacity installed, regional supply chain development, and construction and operation costs.[9] Development scenarios were crafted using insight from regional renewable energy experts. Installations range from a low of 1000 MW by 2030 to a high of 5,000 MW by 2030. The high forecast was used in our offshore wind analysis.

3D Printer Manufacturing and 3D Printing Services

3D printer manufacturing and 3D printing services job-year estimates used IBIS World industry data for those industries.[10,11] Direct jobs were estimated using IBIS World industry benchmarks for average revenue per employee. Induced jobs from direct employee spending were estimated through IMPLAN. IBIS World benchmarks for average employee wages were applied to the estimated number of direct employees and added to local spending in IMPLAN for an estimate of induced jobs. Some industry benchmark spending from IBIS World was not included in this estimate, such as rent and utilities, marketing, supply chain purchases,

and “other expenses.” Jobs potential is shown across a range of U.S. market share that could be served by the state of Ohio. The report graphs focus on Ohio-manufactured 3D printers and 3D printing service companies that serve between 4 percent and 10 percent of U.S. demand, an achievable range of goals given Ohio’s current market share of 4 percent.[12]

References

Front Material & Chapter 1: Introduction

1 "Public's Policy Priorities Reflect Changing Conditions at Home and Abroad," *Pew Research Center,* January 15, 2015, accessed August 11, 2015, http://www.people-press.org/2015/01/15/publics-policy-priorities-reflect-changing-conditions-at-home-and-abroad/; Frank Newport, "Economy, Government Top Election Issues for Both Parties," *Gallup,* October 9, 2014, accessed August 11, 2015, http://www.gallup.com/poll/178133/economy-government-top-election-issues-parties.aspx; J. M. Jones, "Americans Want Next President to Prioritize Jobs, Corruption," *Gallup,* July 30, 2012, accessed August 11, 2015, http://www.gallup.com/poll/156347/Americans-Next-President-Prioritize-Jobs-Corruption.aspx; M. Cooper and D. Sussman, "Voters in Poll Want Priority to Be Economy, Their Top Issue," *New York Times,* August 20, 2008, accessed August 11, 2015, http://www.nytimes.com/2008/08/21/us/politics/21poll.html.

2 James Heskett, "Are Factory Jobs Important to the Economy?," *Harvard Business School,* August 10, 2012, accessed August 11, 2015, http://hbswk.hbs.edu/item/6908.html.

3 "The Low-Wage Recovery and Growing Inequality," *National Employment Law Project,* August 2012, http://www.nelp.org/content/uploads/2015/03/LowWageRecovery2012.pdf.

4 Ibid.

5 George W. Bush, *Decision Points* (New York: Crown Publishers, 2010), 427.

6 Martin LaMonica, "John Doerr: Not nearly enough money going to green tech," *CNET,* April 12, 2008, accessed August 11, 2015, http://www.cnet.com/news/john-doerr-not-nearly-enough-money-going-to-green-tech/.

7 "Advanced Energy Now 2015 Market Report," *Advanced Energy Economy*, March 2015.

8 Ibid.

9 "Renewable Energy and Jobs," *International Renewable Energy Agency*, December 2013, http://www.irena.org/rejobs.pdf.

10 Jacob Goldstein, "Manufacturing Jobs Aren't Coming Back, No Matter Who's President," *NPR,* October 17, 2012, accessed August 11, 2015, http://www.npr.org/sections/money/2012/10/17/163074704/manufacturing-jobs-arent-coming-back-no-matter-whos-president.

11 Luke Mills, "Global Trends in Clean Energy Investment," *Bloomberg New Energy Finance,* January 9, 2015, pg. 4, http://about.bnef.com/presentations/clean-energy-investment-q4-2014-fact-pack/content/uploads/sites/4/2015/01/Q4-investment-fact-pack.pdf.

12 "Factbook: U.S. Trend Toward Sustainable Energy Continued in 2014," *Bloomberg New Energy Finance*, February 4, 2015, pg. 1, http://about.bnef.com/content/uploads/sites/4/2015/02/BCSE-BNEF-Factbook-Press-Release-2_04_15.pdf.

13 Jeff McMahon, "Americans Want America to Run on Solar and Wind," *Forbes,* January 1, 2015, accessed August 11, 2015, http://www.forbes.com/sites/jeffmcmahon/2015/01/01/americans-want-america-to-run-on-solar-and-wind/.

14 "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units," *Federal Register,* July 2015, accessed December 8, 2015, https://federalregister.gov/a/2014-13726.

15 "Strong Growth for Renewables Expected through 2030," *Bloomberg New Energy Finance,* April 22, 2013, accessed December 8, 2015, http://about.bnef.com/press-releases/strong-growth-for-renewables-expected-through-to-2030/.

16 Ibid.

17 "Ohio State Profile and Energy Estimates," *U.S. Energy Information Administration,* last modified March 19, 2015, http://www.eia.gov/state/?sid=OH.

18 "Rankings: Total Energy Production, 2013," *U.S. Energy Information Administration,* accessed December 3, 2015, http://www.eia.gov/state/rankings/?sid=US#/series/101.

19 "Rankings: Total Net Energy Generation, September 2015," *U.S. Energy Information Administration,* accessed December 30, 2015, http://www.eia.gov/state/rankings/?sid=US#/series/51.

20 “Ohio: An Energy and Economic Analysis,” *Institute for Energy Research,* September 24, 2013, accessed December 3, 2015, http://instituteforenergyresearch.org/analysis/ohio-an-energy-and-economic-analysis/.

21 “Ohio State Profile and Energy Estimates,” *U.S. Energy Information Administration,* last modified March 19, 2015, http://www.eia.gov/state/?sid=OH.

22 “Ohio Profile Analysis,” *U.S. Energy Information Administration,* last modified March 19, 2015, http://www.eia.gov/state/analysis.cfm?sid=OH.

23 Ibid.

24 Ibid.

25 “Ohio: An Energy and Economic Analysis,” *Institute for Energy Research,* September 24, 2013, accessed December 3, 2015, http://instituteforenergyresearch.org/analysis/ohio-an-energy-and-economic-analysis/.

26 “Ohio Profile Analysis,” *U.S. Energy Information Administration, last modified March 19, 2015,* http://www.eia.gov/state/analysis.cfm?sid=OH.

27 Ibid.

28 “Ohio Senate Bill 221: A Summary of Its Advanced Energy and Energy Efficiency Provisions,” *Bricker & Eckler, Green Strategies Bulletin*, January 2014, http://www.bricker.com/documents/Publications/1533.pdf.

29 “Ohio,” *American Council for an Energy-Efficient Economy,* accessed December 28, 2015, http://database.aceee.org/state/ohio#sthash.XrVdQju7.dpuf.

30 Mary S. Connor, “Final Analysis: Am. Sub. S.B. 221, 127th General Assembly,” *Ohio Legislative Service Commission,* 2008, pg. 38, http://www.lsc.ohio.gov/analyses127/08-sb221-127.pdf.

31 “Ohio’s 21st Century Energy Policy,” *Ohio Office of Budget and Management*, 2012, http://www.dispatch.com/content/downloads/2012/06/SB_315_Energy_FINAL.pdf.

32 Kristina Roegner and Troy Balderson, “The Energy Mandates Study Committee Co-Chairs’ Report,” *Ohio House of Representatives and Ohio Senate,* September 30, 2015, http://emsc.legislature.ohio.gov/Assets/Reports/emsc-final-report.pdf.

33 Richard Martin, “The Battle of Ohio: Clean Energy vs. Coal,” *Fortune,* October 9, 2014, accessed January 6, 2016, http://fortune.com/2014/10/09/ohio-clean-energy-vs-coal/.

34 “Clean Jobs Ohio: Sizing Up Ohio’s Clean Energy Jobs Base and Its Potential,” *Environmental Entrepreneurs*, May 2015, pg. 3, http://www.cleanjobsohio.org/wp-content/uploads/2014/07/FINAL.OhioJobsReport_15014.pdf.

35 Ibid.

36 Ibid, pg. 17.

37 John A. Seryak, “Testimony of Ohio Manufacturer’s Association,” May 14, 2014, pg. 1, http://www.ohiomfg.com/wp-content/uploads/2014-05-20_LB_Energy_SB-310-will-increaseJS.pdf.

38 “Ohio: An Energy and Economic Analysis,” *Institute for Energy Research,* September 24, 2013, accessed December 3, 2015, http://instituteforenergyresearch.org/analysis/ohio-an-energy-and-economic-analysis/.

39 Dan Gearino, “Two Coal Plants in Ohio Part of AEP Closings,” *The Columbus Dispatch,* April 7, 2015, accessed January 6, 2015, http://www.dispatch.com/content/stories/business/2015/04/07/two-coal-plants-in-ohio-part-of-closings.html.

40 Michael E. Porter, “Clusters and the New Economics of Competition,” *Harvard Business Review,* November-December 1998, accessed December 15, 2015, https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition.

41 Ibid.

42 Ibid.

43 “What Are Clusters?,” *Harvard Business School's Institute for Strategy & Competitiveness,* accessed August 18, 2015, http://www.isc.hbs.edu/competitiveness-economic-development/frameworks-and-key-concepts/Pages/clusters.aspx.

44 “New England's Cleantech Innovation Landscape,” *Meister Consultant Group and New England Clean Energy Council*, February 2014, pg. 29, http://www.clustermapping.us/sites/default/files/files/resource/New%20England%27s%20Cleantech%20Innovation%20Landscape-%20A%20Snapshot%20of%20a%20Growing%20Cluster.pdf.

Chapter 2: Wind Energy

1 “Ohio Wind Energy,” *American Wind Energy Association*, http://awea.files.cms-plus.com/FileDownloads/pdfs/Ohio.pdf.

2 “Clean Jobs Ohio: Sizing Up Ohio’s Clean Energy Jobs Base and Its Potential,” *Environmental Entrepreneurs*, May 2015, pg. 10, http://www.cleanjobsohio.org/wp-content/uploads/2014/07/FINAL.OhioJobsReport_15014.pdf.

3 “Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015,” *U.S. Energy Information Administration*, June 2015, pg. 7, http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf.

4 “Offshore Wind Potential Table,” *U.S. Department of Energy*, http://apps2.eere.energy.gov/wind/windexchange/pdfs/offshore/offshore_wind_potential_table.pdf.

5 “Estimates of Land Area and Wind Energy Potential, by State, for Areas >= 35% Capacity Factor at 80, 110, and 140m,” *National Renewable Energy Laboratory*, February 2015, http://apps2.eere.energy.gov/wind/windexchange/docs/wind_potential_80m_110m_140m_35percent.xlsx.

6 “Distributed Wind Vision, 2015-2030,” *Distributed Wind Energy Association*, March 2015, pg. 2, http://distributedwind.org/wp-content/uploads/2012/08/DWEA-Distributed-Wind-Vision.pdf.

7 “Electricity Data Browser: Number of plants for wind, Ohio, all sectors,” *U.S. Energy Information Administration*, accessed December 21, 2015, http://www.eia.gov/electricity/data/browser/#/topic/1?agg=1,0,2&fuel=008&geo=00002&sec=g&freq=A&datecode=2014&rtype=s&pin=&rse=0&maptype=0&ltype=pin&ctype=linechart&end=2014&start=2001; “State Wind Energy Statistics: Ohio,” *American Wind Energy Association*, April 25, 2014, accessed January 5, 2016, http://www.awea.org/Resources/state.aspx?ItemNumber=5395.

8 Alice Orrell and Nikolas Foster, “2014 Distributed Wind Market Report,” *Pacific Northwest National Laboratory*, August 2015, pg. 10, http://energy.gov/sites/prod/files/2015/08/f25/2014-Distributed-Wind-Market-Report-8.7_0.pdf.

9 “Installed Wind Capacity,” *U.S. Department of Energy*, November 11, 2015, accessed December 21, 2015, http://apps2.eere.energy.gov/wind/windexchange/wind_installed_capacity.asp.

10 “Offshore Wind Potential Table,” *U.S. Department of Energy*, http://apps2.eere.energy.gov/wind/windexchange/pdfs/offshore/offshore_wind_potential_table.pdf.

11“Estimates of Land Area and Wind Energy Potential, by State, for Areas >= 35% Capacity Factor at 80, 110, and 140m,” *National Renewable Energy Laboratory*, February 2015, http://apps2.eere.energy.gov/wind/windexchange/docs/wind_potential_80m_110m_140m_35percent.xlsx.

12 “Wind Vision: Projected Growth of the Wind Industry From Now Until 2050,” *U.S. Department of Energy*, accessed December 21, 2015, http://energy.gov/maps/map-projected-growth-wind-industry-now-until-2050.

13 “Wind Vision: A New Era for Wind Power in the United States,” *U.S. Department of Energy*, April 2015, pg. 23, http://www.energy.gov/ sites/prod/files/WindVision_Report_final.pdf.

14 “New Record in Worldwide Wind Installations,” *World Wind Energy Association*, February 5, 2015, accessed December 21, 2015, http://www.wwindea.org/new-record-in-worldwide-wind-installations/.

15 “Global Wind Report Annual Market Update 2014,” *Global Wind Energy Council*, March 2015, pg. 6, http://www.gwec.net/wp-content/uploads/2015/03/GWEC_Global_Wind_2014_Report_LR.pdf.

16 “Offshore Wind Energy,” *Bureau of Ocean Energy Management*, accessed December 21, 2015, http://www.boem.gov/renewable-energy-program/renewable-energy-guide/offshore-wind-energy.aspx.

17 “Wind Vision: A New Era for Wind Power in the United States,” *U.S. Department of Energy*, April 2015, pg. 3, http://www.energy.gov/ sites/prod/files/WindVision_Report_final.pdf.

18 Alice Orrell and Nikolas Foster, “2014 Distributed Wind Market Report,” *Pacific Northwest National Laboratory*, August 2015, pg. 12, http://energy.gov/sites/prod/files/2015/08/f25/2014-Distributed-Wind-Market-Report-8.7_0.pdf.

19 “Wind Vision: A New Era for Wind Power in the United States,” *U.S. Department of Energy*, April 2015, pg. 13, http://www.energy.gov/ sites/prod/files/WindVision_Report_final.pdf.

20 Alice Orrell and Nikolas Foster, “2014 Distributed Wind Market Report,” *Pacific Northwest National Laboratory*, August 2015, pg. 3, http://energy.gov/sites/prod/files/2015/08/f25/2014-Distributed-Wind-Market-Report-8.7_0.pdf.

21 “Distributed Wind Vision, 2015-2030,” *Distributed Wind Energy Association*, March 2015, pg. 19, http://distributedwind.org/wp-content/uploads/2012/08/DWEA-Distributed-Wind-Vision.pdf.

22 “Levelized cost comparisons help explain value of various electric generation technologies,” *U.S. Energy Information Administration*, June 3, 2015, accessed December 21, 2015, http://www.

eia.gov/todayinenergy/detail.cfm?id=21492.

23 Ibid.

24 Eric Lantz, Maureen Hand, and Ryan Wiser, "The Past and Future Costs of Wind Energy," *National Renewable Energy Laboratory*, May 2012, pg. 1, http://www.nrel.gov/docs/fy12osti/54526.pdf.

25 "Wind Vision: A New Era for Wind Power in the United States," *U.S. Department of Energy*, April 2015, pg. xxxiv, http://www.energy.gov/ sites/prod/files/WindVision_Report_final.pdf.

26 Levi Tillemann, "Revolution Now: The Future Arrives for Four Clean Energy Technologies," *U.S. Department of Energy*, September 17, 2013, pg. 2, http://energy.gov/sites/prod/files/2013/09/f2/200130917-revolution-now.pdf.

27 Alice Orrell and Nikolas Foster, "2014 Distributed Wind Market Report," *Pacific Northwest National Laboratory*, August 2015, pg. 26, http://energy.gov/sites/prod/files/2015/08/f25/2014-Distributed-Wind-Market-Report-8.7_0.pdf.

28 "Distributed Wind Vision, 2015-2030," *Distributed Wind Energy Association*, March 2015, pg. 2, http://distributedwind.org/wp-content/uploads/2012/08/DWEA-Distributed-Wind-Vision.pdf.

29 "Transparent Cost Database," *OpenEI*, accessed January 5, 2016, http://en.openei.org/apps/TCDB/.

30 "Blue Creek Wind Farm pays another $2.7M to Van Wert and Paulding counties and schools," *Ohio Advanced Energy Economy*, February 27, 2015, accessed January 6, 2016, http://ohioadvancedenergy.org/blue-creek-wind-farm-pays-another-2-7m-van-wert-paulding-counties-schools/.

31 Ibid.

32 "Blue Creek Wind Farm," *Iberdrola Renewables*, September 19, 2013, http://iberdrolarenewables.us.files.s3.amazonaws.com/pdf/blue-creek-fact-sheet.pdf.

33 "Blue Creek Wind Farm pays another $2.7M to Van Wert and Paulding counties and schools," *Ohio Advanced Energy Economy*, February 27, 2015, accessed January 6, 2016, http://ohioadvancedenergy.org/blue-creek-wind-farm-pays-another-2-7m-van-wert-paulding-counties-schools/.

34 "Ohio's Energy Future Tour: Final Report," *Ohio Advanced Energy Economy*, 2014, pg. 13, http://ohioadvancedenergy.org/wp-content/uploads/2015/09/OEF-FINAL.pdf.

35 "Blue Creek Wind Farm," *Iberdrola Renewables*, September 19, 2013, http://iberdrolarenewables.us.files.s3.amazonaws.com/pdf/blue-creek-fact-sheet.pdf.

36 "Blue Creek Wind Farm pays another $2.7M to Van Wert and Paulding counties and schools," *Ohio Advanced Energy Economy*, February 27, 2015, accessed January 6, 2016, http://ohioadvancedenergy.org/blue-creek-wind-farm-pays-another-2-7m-van-wert-paulding-counties-schools/.

37 "Ohio agriculture industry in spotlight with business profiles," *Dayton Business Journal*, April 7, 2015, accessed March 2, 2016, http://www.bizjournals.com/dayton/blog/morning_call/2015/04/ohio-agriculture-industry-in-spotlight-with.html.

38 "Blue Creek Wind Farm pays another $2.7M to Van Wert and Paulding counties and schools," *Ohio Advanced Energy Economy*, February 27, 2015, accessed January 6, 2016, http://ohioadvancedenergy.org/blue-creek-wind-farm-pays-another-2-7m-van-wert-paulding-counties-schools/.

39 Jon Seewer, "Cleveland to Soon Harvest Power from Lake Erie Wind Farm," *Manufacturing.net*, December 9, 2015, accessed December 17, 2015, http://www.manufacturing.net/news/2015/12/cleveland-soon-harvest-power-lake-erie-wind-farm.

40 "Vision & Timeline," *LEEDCo*, accessed January 6, 2016, http://www.leedco.org/icebreaker/vision-timeline.

41 "Icebreaker," *LEEDCo*, accessed January 6, 2016, http://www.leedco.org/icebreaker.

42 "Icebreaker Offshore Wind Project to Incorporate New Foundation Design," *LEEDCo*, June 2, 2015, accessed December 21, 2015, http://www.leedco.org/press-releases/icebreaker-offshore-wind-project-to-incorporate-new-foundation-design.

43 "Strategic Partners," *LEEDCo*, accessed December 21, 2015, http://www.leedco.org/icebreaker/strategic-partners.

44 "Lake Erie wind farm could blow away last vestiges of Cleveland Rust Belt," *Cleveland.com*, December 15, 2015, accessed December 17, 2015, http://www.cleveland.com/opinion/index.ssf/2015/12/lake_erie_wind_farm_blows_away.html; John Funk, "LEEDCo lands a third DOE grant

to develop Lake Erie wind project," *Cleveland.com*, November 16, 2015, accessed March 2, 2016, http://www.cleveland.com/business/index.ssf/2015/11/leedco_lands_a_third_doe_grant.html.

45 "Foreign Direct Investment," *Jobs Ohio*, 2012, http://jobs-ohio.com/images/SF_Foreign_Direct_Investment.pdf.

46 Jennifer A. Parker et al., "Bill Analysis: Am. Sub. H.B. 483, 130th General Assembly," *Ohio Legislative Service Commission*, 2014, pg. 165, http://www.lsc.ohio.gov/analyses130/14-hb483-130.pdf.

47 Ibid, pg. 166.

48 "1509.021 Surface locations of new wells," *Ohio Revised Code*, last modified September 29, 2011, http://codes.ohio.gov/orc/1509.021.

49 Jennifer A. Parker et al., "Bill Analysis: Am. Sub. H.B. 483, 130th General Assembly," *Ohio Legislative Service Commission*, 2014, pg. 165, http://www.lsc.ohio.gov/analyses130/14-hb483-130.pdf.

50 "Mid-Size 500kW Turbines," *Distributed Generation Limited*, accessed December 3, 2015, http://www.distgen.co/turbines/.

51 "V112-3.45 at a Glance," *Vestas*, accessed December 3, 2015, https://www.vestas.com/en/products_and_services/turbines/v112-3_3_mw#!technical-specifications.

52 "How big are wind turbines?," *Windustry,* accessed January 6, 2016, http://www.windustry.org/how_big_are_wind_turbines.

53 Tom Stanton, "Put it There! Wind Energy & Wind-Park Siting and Zoning Best Practices and Guidance for States," *National Regulatory Research Institute*, January 2012, pgs. 6-10, http://www.naruc.org/Publications/FINAL%20FINAL%20NRRI_Wind_Siting_Jan12-03.pdf.

54 "Model Wind Ordinance for Local Governments," *DSIRE*, last modified December 1, 2014, http://programs.dsireusa.org/system/program/detail/3067.

55 "Wind Vision: A New Era for Wind Power in the United States," *U.S. Department of Energy*, April 2015, pg. xxxviii, http://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf.

56 Ben Hoen et al., "A Spatial Hedonic Analysis of the Effects of Wind Energy Facilities on the Surrounding Property Values in the United States," *Lawrence Berkeley National Laboratory*, August 2013, pg. iii, https://emp.lbl.gov/sites/all/files/lbnl-6362e.pdf.

57 Kathiann M. Kowalski, "Industry: Setback changes will end new wind farms in Ohio," *Midwest Energy News*, June 19, 2014, accessed December 3, 2015, http://midwestenergynews.com/2014/06/19/industry-setback-changes-will-end-new-wind-farms-in-ohio/.

58 "Ohio's Energy Future Tour: Final Report," *Ohio Advanced Energy Economy*, 2014, pg. 14, http://ohioadvancedenergy.org/wp-content/uploads/2015/09/OEF-FINAL.pdf.

59 "Wind Vision: A New Era for Wind Power in the United States," *U.S. Department of Energy*, April 2015, pg. xxxvii, http://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf.

60 Ibid, pg. 24.

61 Jason P. Brown et al., "Ex post analysis of economic impacts from wind power development in U.S. counties," *Energy Economics* 34 (2012): 1743, http://digitalcommons.unl.edu/usdaarsfacpub/1144/.

62 "Ohio Wind Energy," *American Wind Energy Association*, http://awea.files.cms-plus.com/FileDownloads/pdfs/Ohio.pdf.

63 "Clean Jobs Ohio: Sizing Up Ohio's Clean Energy Jobs Base and Its Potential," *Environmental Entrepreneurs*, May 2015, pg. 10, http://www.cleanjobsohio.org/wp-content/uploads/2014/07/FINAL.OhioJobsReport_15014.pdf.

64 "Installed Wind Capacity," *U.S. Department of Energy*, November 11, 2015, accessed December 21, 2015, http://apps2.eere.energy.gov/wind/windexchange/wind_installed_capacity.asp.

65 Jon Seewer, "Cleveland to Soon Harvest Power from Lake Erie Wind Farm," *Manufacturing.net*, December 9, 2015, accessed December 17, 2015, http://www.manufacturing.net/news/2015/12/cleveland-soon-harvest-power-lake-erie-wind-farm.

66 Will Murtha, "Get in Line: New Mexico's Renewable Energy Production Tax Credit," *Clean Energy Finance Forum*, December 23, 2014, accessed January 6, 2016, http://cleanenergyfinanceforum.com/2014/12/23/get-in-line-new-mexicos-renewable-energy-production-tax-credit.

67 Ibid.

68 Ibid.

69 "Public Land Ownership by State," *Natural Resources Council of Maine*, accessed December 17, 2015, http://www.nrcm.org/documents/publiclandownership.pdf.

70 John Funk, "Norwegian Wind Company to Build LEEDCo Offshore Turbine Project," *Cleveland.com*, December 7, 2015, accessed December 17, 2015, http://www.cleveland.com/business/index.ssf/2015/12/norwegian_wind_company_to_buil.html.

71 "Anatomy of a Wind Turbine," *American Wind Energy Association*, accessed December 21, 2015, http://www.awea.org/Resources/Content.aspx?ItemNumber=5083.

72 "Anchor Institution Tax Credit," *Rhode Island Commerce Corporation*, accessed January 6, 2016, http://commerceri.com/finance-business/taxes-incentives/anchor-institution-tax-credit/.

73 "Offshore Wind Market and Economic Analysis," *Navigant Consulting*, February 2013, pg. 77, https://www1.eere.energy.gov/wind/pdfs/offshore_wind_market_and_economic_analysis.pdf.

74 "Offshore Wind Industrial Strategy: Business and Government Action," *HM Government*, August 2013, pg. 22, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/243987/bis-13-1092-offshore-wind-industrial-strategy.pdf.

75 Anamaria Deduleasa, "IN DEPTH: Grimsby -- UK offshore wind's new home town," December 4, 2014, accessed August 16, 2015, http://www.rechargenews.com/wind/offshore/1385093/IN-DEPTH-Grimsby-%E2%80%93-UK-offshore-winds-new-home-town.

76 "Working for a Green Britain & Northern Ireland 2013–23: Employment in the UK Wind & Marine Energy Industries," *RenewableUK*, September 2013, pg. 4, http://www.renewableuk.com/download.cfm/docid/82BF89A1-9EA2-4D77-8E9B1B986BE8B727.

77 "About," *Offshoreenergy.dk*, accessed December 21, 2015, http://www.offshoreenergy.dk/offshoreenergy/about.aspx.

78 "Offshore wind farms mean big business for the Port of Esbjerg," *Ministry of Foreign Affairs of Denmark*, March 26, 2009, accessed December 21, 2015, http://www.investindk.com/News-and-events/News/2009/Offshore-wind-farms-mean-big-business-for-the-Port-of-Esbjerg.

79 "The Port of Esbjerg delivers historic operating profit," *Port of Esbjerg*, 2014, accessed December 22, 2015, http://portesbjerg.dk/en/about/news/port-esbjerg-delivers-historic-operating-profit.

80 "Offshore Wind Market and Economic Analysis," *Navigant Consulting*, February 2013, pg. xvii, https://www1.eere.energy.gov/wind/pdfs/us_offshore_wind_supply_chain_and_manufacturing_development.pdf.

81 "State Infrastructure Bank," *Ohio Department of Transportation*, accessed December 21, 2015, http://www.dot.state.oh.us/Divisions/Finance/Pages/StateInfrastructureBank.aspx.

Chapter 3: Additive Manufacturing

1 "Additive Manufacturing: Pursuing the Promise," *Advanced Manufacturing Office of the Department of Energy*, August 2012, www.energy.gov/sites/prod/files/2013/12/f5/additive_manufacturing.pdf; "Home," *Normal*, accessed January 12, 2016, http://www.nrml.com/; "3D Printing: Opportunities, Challenges, and Policy Implications of Additive Manufacturing," *U.S. Government Accountability Office*, June 2015, http://www.gao.gov/assets/680/670960.pdf.

2 "3D Printing–The Education Sector is on the Cusp of Adoption," *Sophic Capital*, March 16, 2015, accessed January 14, 2016, http://sophiccapital.com/3d-printing-the-education-sector-is-on-the-cusp-of-adoption/.

3 N. Hopkinson, and P. Dickens, "Analysis of Rapid Manufacturing—Using Layer Manufacturing Processes for Production," *Journal of Mechanical Engineering Science* 217 (2003): 31–39.

4 Joan Horvath, "A Brief History of 3D Printing," in *Mastering 3D Printing* (New York: Apress, 2014), 5.

5 Luke Chilson, "The Difference Between ABS and PLA for 3D Printing," *ProtoParadigm*, January 26, 2013, accessed January 12, 2016, http://www.protoparadigm.com/news-updates/the-difference-between-abs-and-pla-for-3d-printing/.

6 Douglas Thomas and Stanley Gilbert, "Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion," *National Institute of Standards and Technology at the U.S. Department of Commerce*, December 2014, pg. 6, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf.

7 James Crompton, "IBISWorld Industry Report OD4428: 3D Printer Manufacturing in the U.S.," *IBISWorld,* January 2015.

8 Brittany Carter, "IBISWorld Industry Report OD4581: 3D Printing & Rapid Prototyping Services in the U.S.," *IBISWorld,* October 2015, pg. 8.

9 Ryan Dehoff et al., "Additive Manufacturing of Aerospace Brackets," *Advanced Materials & Processes* 171, March 2013.

10 "How 3D Printers Work," *U.S. Department of Energy,* June 19, 2014, accessed January 12, 2016, http://energy.gov/articles/how-3d-printers-work.

11 "Additive Manufacturing: Pursuing the Promise," *Advanced Manufacturing Office, U.S. Department of Energy,* August 2012, http://www1.eere.energy.gov/manufacturing/pdfs/additive_manufacturing.pdf.

12 Douglas Thomas and Stanley Gilbert, "Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion," *National Institute of Standards and Technology,* December 2014, pg. 11, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf.

13 "How 3D Printers Work," *U.S. Department of Energy,* June 19, 2014, accessed January 12, 2016, http://energy.gov/articles/how-3d-printers-work.

14 R. Huang et al., "Energy and emissions saving potential of additive manufacturing: the case of lightweight aircraft components," *Journal of Cleaner Production* (2015): 10, http://dx.doi.org/10.1016/j.jclepro.2015.04.109.

15 Michael Lewis, "Additive Manufacturing Puts Its Clean-Tech Face Forward in Federally Funded Development Program," *ThomasNet,* August 29, 2012, accessed January 12, 2016, http://news.thomasnet.com/imt/2012/08/29/additive-manufacturing-puts-its-clean-tech-face-forward-in-federally-funded-development-program.

16 R. Huang et al., "Energy and emissions saving potential of additive manufacturing: the case of lightweight aircraft components," *Journal of Cleaner Production* (2015): 6, http://dx.doi.org/10.1016/j.jclepro.2015.04.109.

17 Brittany Carter, "IBISWorld Industry Report OD4581: 3D Printing & Rapid Prototyping Services in the U.S.," *IBISWorld,* October 2015, pg. 4.

18 Ibid, pgs. 6 and 14.

19 "Additive Manufacturing: Pursuing the Promise," *Advanced Manufacturing Office, U.S. Department of Energy*, August 2012, http://www1.eere.energy.gov/manufacturing/pdfs/additive_manufacturing.pdf.

20 Richard D'Aveni, "The 3D Printing Revolution," *Harvard Business Review,* May 2015, accessed January 14, 2015, https://hbr.org/2015/05/the-3-d-printing-revolution.

21 Brittany Carter, "IBISWorld Industry Report OD4581: 3D Printing & Rapid Prototyping Services in the U.S.," *IBISWorld,* October 2015, pg. 8.

22 "3D Systems Presentation: Manufacturing the Future," *3D Systems,* March 2015, http://www.3dsystems.com/sites/www.3dsystems.com/files/downloads/3d-systems-investor-presentation-March-2015.pdf.

23 Brett Conner et al., "Making Sense of 3-D printing: Creating a Map of Additive Manufacturing Products and Services," *Additive Manufacturing* 1-4, (2014), pgs. 64–76, accessed January 14, 2016, http://dx.doi.org/10.1016/j.addma.2014.08.005.

24 "Home," *Normal,* accessed January 14, 2016, http://www.nrml.com/.

25 "New Balance Launches First 3D-Printed Running Shoe," *New Balance Inc.,* November 19, 2015, accessed January 14, 2016, http://newbalance.newsmarket.com/LATEST-NEWS/new-balance-launches-first-3d-printed-running-shoe/s/945ADE0F-1185-4CE0-AE3B-A857F8D2A445.

26 "Home," *Twikit,* accessed January 9, 2016, http://www.twikit.com/.

27 Michael Lewis, "Additive Manufacturing Puts Its Clean-Tech Face Forward in Federally Funded Development Program," *ThomasNet,* August 29, 2012, accessed January 14, 2016, http://news.thomasnet.com/imt/2012/08/29/additive-manufacturing-puts-its-clean-tech-face-forward-in-federally-funded-development-program.

28 Phillip Cullom, "5 Things to Know About Navy 3D Printing," *Navy Live,* July 15, 2014, accessed January 14, 2016, http://navylive.dodlive.mil/2014/07/15/5-things-to-know-about-navy-3d-printing/.

29 "Additive Manufacturing: Pursuing the Promise," *Advanced Manufacturing Office, U.S. Department of Energy,* August 2012, http://www1.eere.energy.gov/manufacturing/pdfs/additive_manufacturing.pdf.

30 "About America Makes," *America Makes,* accessed November 16, 2015, https://americamakes.us/about/overview.

31 "Ohio Manufacturing Facts," *National Association of Manufacturers,* February 2015, accessed January 14, 2016, http://www.nam.org/Data-and-Reports/State-Manufactur-

ing-Data/2014-State-Manufacturing-Data/Manufacturing-Facts--Ohio/.

32 "Executive Budget for FYs 2016 and 2017," *The State of Ohio,* accessed January 14, 2016, pg. 5, http://obm.ohio.gov/Budget/operating/doc/fy-16-17/budget/Section-A.pdf.

33 "Ohio's Third Frontier: Targeting Growth Opportunities for the Next 3-5 Years," *Battelle Technology Partnership Practice,* November 2011, http://www.development.ohio.gov/files/otf/OTFTargetingGrowthOpportunitiesFINAL.pdf.

34 "ASTM and ISO Sign PDSO Agreement," *ASTM Standardization News,* June 3, 2013, accessed January 14, 2016, http://www.astmnewsroom.org/default.aspx?pageid=3108.

35 Alan Earls and Vinod Baya, "The Future Of 3-D Printing: Moving Beyond Prototyping To Finished Products," *PwC Technology Forecast,* 2014, pg. 3.

36 James Crompton, "IBISWorld Industry Report OD4428: 3D Printer Manufacturing in the U.S.," *IBISWorld,* January 2015, pg. 8.

37 Mark J. Cotteleer, "3D opportunity: Additive manufacturing paths to performance, innovation, and growth," *Delloite Services LP,* October 1, 2014, pg. 17, http://simt.com/uploads/4881/SIMT_AM_Conference_Keynote.pdf.

38 Sandra Zistl, "3D Printing: Facts and Forecasts," *Siemens,* October 1, 2014, accessed November 17, 2015, http://www.siemens.com/innovation/en/home/pictures-of-the-future/industry-and-automation/Additive-manufacturing-facts-and-forecasts.html.

39 Mark J. Cotteleer, "3D opportunity: Additive manufacturing paths to performance, innovation, and growth," *Delloite Services LP,* October 1, 2014, pg. 7, http://simt.com/uploads/4881/SIMT_AM_Conference_Keynote.pdf.

40 "Governor Cuomo Announces 1366 Technologies to Construct Advanced Manufacturing Facility in Genesee County," *New York State,* October 7, 2015, accessed January 14, 2016, https://www.governor.ny.gov/news/governor-cuomo-announces-1366-technologies-construct-advanced-manufacturing-facility-genesee.

41 "We Can't Wait: Obama Administration Announces New Public-Private Partnership to Support," *The White House Office of the Press Secretary*, August 16, 2012, accessed April 1, 2015, https://www.whitehouse.gov/the-press-office/2012/08/16/we-can-t-wait-obama-administration-announces-new-public-private-partners.

42 Ibid.

43 Terry Wohlers and Tim Caffey, "Wohlers Report 2015: 3D Printing and Additive Manufacturing State of the Industry," *Wohlers Associates, Inc.,* 2015, pg. 4.

44 Luke Heemsbergen and Robbie Fordyce, "Interview with Terry Wohlers: The Past & Future of 3D Printing," *3D Printing Industry,* June 2, 2015, accessed January 9, 2016, http://3dprintingindustry.com/2015/06/02/interview-with-terry-wohlers-the-past-future-of-3d-printing/.

45 "3D Printing Services Market: Global Trends and Forecast 2015-2019 Summary," *Technavio,* July 01, 2015, accessed January 14, 2016, http://www.technavio.com/report/3d-printing-services-market-global-trends-and-forecast-2015-2019.

46 Sandra Zistl, "3D Printing: Facts and Forecasts," *Siemens*, October 1, 2014, accessed November 17, 2015, http://www.siemens.com/innovation/en/home/pictures-of-the-future/industry-and-automation/Additive-manufacturing-facts-and-forecasts.html.

47 Louis Columbus, "Roundup Of 3D Printing Market Forecasts And Estimates, 2014," *Forbes,* August 9, 2014, accessed January 14, 2016, http://www.forbes.com/sites/louiscolumbus/2014/08/09/roundup-of-3d-printing-market-forecasts-and-estimates-2014/.

48 James Crompton, "IBISWorld Industry Report OD4428: 3D Printer Manufacturing in the U.S.," *IBISWorld,* January 2015, pg. 30.

49 Douglas Thomas and Stanley Gilbert, "Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion," *National Institute of Standards and Technology, U.S. Department of Commerce*, December 2014, pg. 3, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf.

50 Ibid.

51 Terry Wohlers and Tim Caffey, "Wohlers Report 2015: 3D Printing and Additive Manufacturing State of the Industry, Executive Summary," *Wohlers Associates, Inc.,* 2015, pg. 4.

52 Yuchen Wu, "Falling Costs Open 3D Printing to the Masses," *Bizwest,* November 28, 2014, accessed January 14, 2016, http://bizwest.com/falling-costs-open-3-d-printing-to-the-masses/.

53 Terry Wohlers and Tim Caffey, "Wohlers Report 2015: 3D Printing and Additive Manufacturing State of the Industry, Executive Summary," *Wohlers Associates, Inc.,* 2015, pg. 4.

54 “3D Systems Presentation: Manufacturing the Future,” *3D Systems,* March 2015, http://www.3dsystems.com/sites/www.3dsystems.com/files/downloads/3d-systems-investor-presentation-March-2015.pdf.

55 “3D Printing Services Market: Global trends and forecast 2015-2019 Summary,” *Research and Markets,* July 2015, accessed January 9, 2016, http://www.researchandmarkets.com/research/hrt3x2/3d_printing.

56 Ibid.

57 Ibid.

58 “Additive Manufacturing,” *General Electric,* accessed December 8, 2015, http://www.ge.com/stories/advanced-manufacturing.

59 Tomas Kellner, “The FAA Cleared the First 3D Printed Part to Fly in a Commercial Jet Engine from GE,” *GE Reports,* April 14, 2015, accessed December 8, 2015, http://www.gereports.com/post/116402870270/the-faa-cleared-the-first-3d-printed-part-to-fly/.

60 Tomas Kellner, “Fit to Print: New Plant Will Assemble World’s First Passenger Jet Engine With 3D Printed Fuel Nozzles, Next-Gen Materials,” *GE Reports,* June 23, 2014, accessed December 8, 2015, http://www.gereports.com/post/80701924024/fit-to-print.

61 Rick Smith, “3D Printing is About to Change the World Forever,” *Forbes,* June 15, 2015, accessed December 8, 2015, http://www.forbes.com/sites/ricksmith/2015/06/15/3d-printing-is-about-to-change-the-world-forever/.

62 Tomas Kellner, “Fit to Print: New Plant Will Assemble World’s First Passenger Jet Engine With 3D Printed Fuel Nozzles, Next-Gen Materials,” *GE Reports,* June 23, 2014, accessed December 8, 2015, http://www.gereports.com/post/80701924024/fit-to-print.

63 Ibid.

64 Ibid.

65 “DoD Maintenance 2014 Fact Book,” *U.S. Department of Defense*, pg. 3, http://www.acq.osd.mil/log/mpp/.factbook.html/Fact_Book_2014_final_ecopy.pdf.

66 MuShawn D. Smith, “Technologies to Sustain the Army of 2025 and Beyond,” *U.S. Army,* September 8, 2014, accessed January 9, 2016, http://www.army.mil/article/132473/Technologies_to_sustain_the_Army_of_2025_and_beyond/.

67 Phillip Cullom, “5 Things to Know About Navy 3D Printing,” *Navy Live,* July 15, 2014, accessed January 9, 2016, http://navylive.dodlive.mil/2014/07/15/5-things-to-know-about-navy-3d-printing/.

68 David Szondy, “Upgrades to extend B-52 Bomber’s lifespan until 2044,” *Gizmag,* October 9, 2011, accessed January 9, 2016, http://www.gizmag.com/b52-upgrade/20098/.

69 “3D Systems Presentation: Manufacturing the Future,” *3D Systems,* March 2015, http://www.3dsystems.com/sites/www.3dsystems.com/files/downloads/3d-systems-investor-presentation-March-2015.pdf.

70 Richard D’Aveni, “The 3D Printing Revolution,” *Harvard Business Review,* May 2015, accessed December 14, 2015, https://hbr.org/2015/05/the-3-d-printing-revolution.

71 Michael Dhar, “Surgeons Get Practice Using Brains Made on 3D Printers,” *LiveScience*, November 18, 2013, accessed January 9, 2016 http://www.livescience.com/41309-brain-surgeons-practice-3d-printing.html.

72 "3D Printing: Opportunities, Challenges, and Policy Implications of Additive Manufacturing,” *U.S. Government Accountability Office*, June 2015, pg. 21, http://www.gao.gov/assets/680/670960.pdf.

73 Ibid, pg. 18.

74 Ibid, pg. 13.

75 Douglas Thomas and Stanley Gilbert, “Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion,” *National Institute of Standards and Technology, U.S. Department of Commerce*, December 2014, pg. 1, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf.

76 James Crompton, “IBISWorld Industry Report OD4428: 3D Printer Manufacturing in the U.S.,” *IBISWorld*, January 2015, pg. 9.

77 Ibid, pg. 6.

78 Richard D’Aveni, “The 3D Printing Revolution,” *Harvard Business Review*, May 2015, accessed December 14, 2015, https://hbr.org/2015/05/the-3-d-printing-revolution.

79 Douglas Thomas and Stanley Gilbert, "Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion," *National Institute of Standards and Technology, U.S. Department of Commerce*, December 2014, pg. 19, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf

80 Yuchen Wu, "Falling Costs Open 3D Printing to the Masses," *Bizwest*, November 28, 2014, accessed December 15, 2015, http://bizwest.com/falling-costs-open-3-d-printing-to-the-masses/.

81 Sandra Zistl, "3D Printing: Facts and Forecasts," *Siemens*, October 1, 2014, accessed November 17, 2015, http://www.siemens.com/innovation/en/home/pictures-of-the-future/industry-and-automation/Additive-manufacturing-facts-and-forecasts.html.

82 "Additive Manufacturing: A Game Changer for the Manufacturing Industry?," *Roland Berger Strategy Consultants*, November 2013, pg. 5.

83 Kira Charron, "Engineer creates a 3D metal printer prototype for $2 using electroplating technology," *3Ders*, March 1, 2015, accessed January 9, 2016, http://www.3ders.org/articles/20150301-low-cost-metal-3d-printing-made-possible-with-electroplating-technology-and-prototype.html.

84 Alan Earls and Vinod Baya, "The Future Of 3-D Printing: Moving Beyond Prototyping To Finished Products," *PwC Technology Forecast,* 2014, pg. 3.

85 Agam Shah, "3D printer price drops could lure home users," *PC World*, April 4, 2014, accessed December 8, 2015, http://www.pcworld.com/article/2140360/3d-printer-price-drops-could-lure-home-users.html.

86 "3D Printing: Opportunities, Challenges, and Policy Implications of Additive Manufacturing," *U.S. Government Accountability Office*, June 2015, pg. 13, http://www.gao.gov/assets/680/670960.pdf.

87 "Advanced Manufacturing," *JobsOhio*, accessed December 16, 2015, http://jobs-ohio.com/industries/advanced-manufacturing/.

88 Ibid.

89 "3D Systems Presentation: Manufacturing the Future," *3D Systems*, March 2015, pg. 17, http://www.3dsystems.com/sites/www.3dsystems.com/files/downloads/3d-systems-investor-presentation-March-2015.pdf.

90 Douglas Thomas and Stanley Gilbert, "Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion," *National Institute of Standards and Technology, U.S. Department of Commerce*, December 2014, pg. 1, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf.

91 "Technology Roadmap of Additive Manufacturing in Ohio: Exploring Opportunities to Cultivate Ohio's Additive Manufacturing Sector," *FASTLANE and University of Dayton*, January 30, 2015, pg. 48, https://omi.osu.edu/sites/omi.osu.edu/files/uploads/fastlane_additive_manufacturing_in_ohio_2015.pdf.

92 "Center for Innovation in Additive Manufacturing," *Youngstown State University*, accessed January 16, 2016, http://ciam.ysustem.com/.

93 "New Additive Manufacturing Center in Cleveland," *Case Western Reserve University*, accessed January 9, 2016, http://engineering.case.edu/rpm-thinkbox.

94 Ibid.

95 "ORNL, Cincinnati Partner to Develop Commercial Large-Scale Additive Manufacturing System," *Oak Ridge National Lab*, February 17, 2014, accessed December 22, 2015, https://www.ornl.gov/news/ornl-cincinnati-partner-develop-commercial-large-scale-additive-manufacturing-system.

96 "Technology Roadmap of Additive Manufacturing in Ohio: Exploring Opportunities to Cultivate Ohio's Additive Manufacturing Sector," *FASTLANE and University of Dayton*, January 30, 2015, pg. 48, https://omi.osu.edu/sites/omi.osu.edu/files/uploads/fastlane_additive_manufacturing_in_ohio_2015.pdf.

97 "Youngstown Business Incubator again ranked top in country," *WKBN*, December 16, 2015, accessed January 9, 2016, http://wkbn.com/2015/12/16/youngstown-business-incubator-again-ranked-top-in-country/.

98 "Additive Manufacturing," *Youngstown Business Incubator*, accessed January 12, 2016, http://ybi.org/additive-manufacturing/.

99 "Homepage," *JuggerBot 3D*, accessed December 16, 2015, http://www.juggerbot3d.com/.

100 "About Us," *MakerGear*, accessed January 9, 2016, http://www.makergear.com/pages/about-us.

101 “3D Systems Acquires Laser Reproductions Further Expanding Its Quickparts Network,” *3D Systems*, August 6, 2014, accessed December 15, 2015, http://www.3dsystems.com/press-releases/3d-systems-acquires-laser-reproductions-further-expanding-its-quickparts-network.

102 “3D Systems Acquires Village Plastics,” *3D Systems*, December 13, 2013, accessed December 22, 2015, http://www.3dsystems.com/press-releases/3d-systems-acquires-village-plastics.

103 “3D Systems Expands 3D Printer Filament Materials Manufacturing Capacity in New Facility in Ohio,” *3D Systems*, August 14, 2015 accessed December 16, 2015, http://www.3dsystems.com/press-releases/3d-systems-expands-3d-printer-filament-materials-manufacturing-capacity-new-facility.

104 “Technology Roadmap of Additive Manufacturing in Ohio: Exploring Opportunities to Cultivate Ohio’s Additive Manufacturing Sector,” *FASTLANE and University of Dayton*, January 30, 2015, pg. 48, https://omi.osu.edu/sites/omi.osu.edu/files/uploads/fastlane_additive_manufacturing_in_ohio_2015.pdf.

105 Britanny Carter, "IBIS World Industry Report OD4581: 3D Printing and Rapid Prototyping Services in the US, Breaking the Mold: Developing Technologies and a Growing Customer Base will Boost Revenue,” October 2015, accessed on March 7, 2016, http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=4581; Max Oston, "IBIS World Industry Report OD4428: 3D Printer Manufacturing in the US, New Dimension: Revenue will Rise as Demand from Aerospace and Medical Fields Takes Off,” January 2016, accessed on March 7, 2016, http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=4428.

106 “Homepage,” *Ultimaker*, accessed January 15, 2015, https://ultimaker.com/.

107 “Homepage,” *Dynamo*, accessed January 15, 2015, http://www.dynamo3d.com/.

108 “Homepage,” *Hoganas*, accessed January 15, 2015, https://www.hoganas.com/en.

109 “About,” *Stratasys*, accessed January 15, 2015, http://www.arcam.com/company/about-arcam/.

110 “Locations,” *Materialise*, accessed January 15, 2015, http://www.materialise.com/contact-locations?l=42.

111 Terry Wohlers and Tim Caffey, “Wohlers Report 2015: 3D Printing and Additive Manufacturing State of the Industry, Executive Summary,” *Wohlers Associates, Inc.*, 2015, pg. 5.

112 “Homepage,” *Zortrax,* accessed January 15, 2015, https://zortrax.com/.

113 "Homepage," *Norsk Titanium,* accessed January 15, 2015, http://www.norsktitanium.no/.

114 “Foreign Direct Investment into Ohio,” *Select USA*, March 16, 2015, http://selectusa.commerce.gov/state-fact-sheets/2015-03-16%20FDI%20State%20Fact%20Sheet%20-%20Ohio.pdf.

115 Dan O’Brien, “Initiatives Funded by America Makes Lead to Commercialization,” *Business Journal Daily*, February 14, 2016, accessed March 3, 2016, http://businessjournaldaily.com/initiatives-funded-by-america-makes-lead-to-commercialization/.

116 Cynthia McIntyre, “Hearing: American Competitiveness Worldwide: Impacts on Small Businesses and Entrepreneurs,” *U.S. House of Representatives, Committee on Small Business*, July 9, 2013, pg. 2, http://smallbusiness.house.gov/uploadedfiles/7-9-2013_mcintyre_testimony.pdf.

117 Cynthia McIntyre, “How a New Partnership Can Help Smaller Firms Win,” *Harvard Business Review*, March 9, 2012, accessed December 9, 2015, https://hbr.org/2012/03/how-a-new-partnership-can-help.

118 “Michigan Announces Innovation Center to Accelerate Manufacturing Across State,” *National Center for Manufacturing Sciences*, November 12, 2012, accessed December 6, 2015, http://www.ncms.org/index.php/2012/11/michigan-announces-innovation-center-to-accelerate-manufacturing-across-state/.

119 “Digital Manufacturing and Simulation (DMS) Lab,” *Ohio Northern University*, accessed January 9, 2016, http://www.onu.edu/arts_sciences/technology_studies/facilities/digital_manufacturing_and_simulation_dms_lab.

120 “Northern Michigan’s Mobile Digital Manufacturing Lab,” *Northern Lakes Economic Alliance*, http://is0.gaslightmedia.com/northernlakeseconomicalliance/_ORIGINAL_/fs19-1381259459-70887.pdf.

121 “Modeling, Simulation, and Analysis, and High Performance Computing,” *National Digital Engineering and Manufacturing Consortium*, March 9, 2015, pg. 20, http://www.compete.org/storage/documents/NDEMC_Final_Report_030915.pdf.

122 Ibid, pg. 28.

123 “Technology Roadmap of Additive Manufacturing in Ohio: Exploring Opportunities to

Cultivate Ohio's Additive Manufacturing Sector," *FASTLANE and University of Dayton*, January 30, 2015, pg. 36, https://omi.osu.edu/sites/omi.osu.edu/files/uploads/fastlane_additive_manufacturing_in_ohio_2015.pdf.

124 "Prospect Brochure," *New Mexico Small Business Assistance Program*, January 2015, http://www.nmsbaprogram.org/userfiles/2014_NMSBA_ProspectBro_January_2015_FNL.pdf.

125 "America's Advanced Industries," *Brookings Advanced Industries Project*, February 2015, pg. 78. http://www.brookings.edu/~/media/Research/Files/Reports/2015/02/03-advanced-industries/final/AdvancedIndustry_FinalFeb2lores.pdf?la=en.

126 Ibid, pg. 78.

127 "Powering Advanced Industries," *Brookings Advanced Industries Series*, February 2014, http://www.brookings.edu/~/media/research/files/papers/2014/02/19-ai/advancedindustriesstatebystate.pdf.

128 "Revv Success Stories," *Oak Ridge National Lab*, accessed January 9, 2016, https://www.ornl.gov/content/revv-success-stories.

129 James Crompton, "IBISWorld Industry Report OD4428: 3D Printer Manufacturing in the U.S.," *IBISWorld*, January 2015, pg. 18.

130 "Technology Roadmap of Additive Manufacturing in Ohio: Exploring Opportunities to Cultivate Ohio's Additive Manufacturing Sector," *FASTLANE and University of Dayton*, January 30, 2015, pgs. 4 and 16, https://omi.osu.edu/sites/omi.osu.edu/files/uploads/fastlane_additive_manufacturing_in_ohio_2015.pdf.

131 "Clean Energy Manufacturing Revolving Loan Fund," *Wisconsin State Energy Office*, accessed January 9, 2016, http://www.stateenergyoffice.wi.gov/section.asp?linkid=1846&locid=160.

132 Ibid.

133 Thomas Content, "Mukwonago company finds its place in the wind turbine industry," *Journal Sentinel*, June 19, 2014, accessed January 9, 2016, http://www.jsonline.com/business/mukwonago-company-finds-its-place-in-the-wind-turbine-industry-b99295199z1-263911801.html.

134 "EPA's Guide for Industrial Waste Management," *U.S. Environmental Protection Agency*, accessed January 9, 2016, http://www.epa.gov/wastes/nonhaz/industrial/guide/.

135 Brittany Carter, "IBISWorld Industry Report OD4581: 3D Printing & Rapid Prototyping Services in the U.S.," *IBISWorld*, October 2015, pg. 8.

136 "Environmental Protection Agency Bluebook," *Ohio Environmental Protection Agency*, accessed January 9, 2016, pg. D-213, http://obm.ohio.gov/budget/operating/doc/fy-14-15/bluebook/budget/Section-D_EPA.pdf.

137 Ibid, pg. D-211.

138 "Air Quality Improvement Tax Incentives," *NC Clean Energy Technology Center*, April 30, 2015, accessed January 9, 2016, http://programs.dsireusa.org/system/program/detail/78.

139 "3706.15 Exemption from taxes and assessments," *LAWriter Ohio Laws and Rules*, accessed January 9, 2016, http://codes.ohio.gov/orc/3706.15.

140 "3734.50 State solid waste management plan," *LAWriter Ohio Laws and Rules*, accessed January 9, 2016, http://codes.ohio.gov/orc/3734.50v1.

141 "Success Stories - State Government," *U.S. Environmental Protection Agency*, last modified June 15, 2012, http://www3.epa.gov/epawaste/conserve/smm/wastewise/success/state.htm.

142 "Additive Manufacturing: Pursuing the Promise," *Advanced Manufacturing Office, U.S. Department of Energy*, August 2012, http://www1.eere.energy.gov/manufacturing/pdfs/additive_manufacturing.pdf.

143 "Additive Manufacturing Consortium," *EWI*, accessed January 9, 2016, https://ewi.org/additive-manufacturing-consortium/.

144 "Advanced Manufacturing," *JobsOhio*, accessed December 16, 2015, http://jobs-ohio.com/industries/advanced-manufacturing/.

Chapter 4: Innovation Ecosystem and Access to Capital

1 "About Us," *Battelle*, accessed January 17, 2016, http://www.battelle.org/about-us.

2 Sue Marquette Poremba, "Battelle: Taking Invention to Market," *Innovation*, February 2009, accessed January 17, 2016, http://www.innovation-america.org/battelle-taking-invention-market.

3 "Advanced Energy: Ohio Centers of Excellence," *Board of Regents - University System of Ohio*, accessed January 16, 2016, https://www.ohiohighered.org/files/uploads/coe/docs/COE_AE_pack.pdf.

4 "Offshore Wind Projects 2006-2012," *U.S. Department of Energy, Wind and Water Technologies Office*, December 2012, http://www.wind.energy.gov/pdfs/offshore_energy_projects.pdf.

5 "New additive manufacturing center in Cleveland," *Case Western Reserve University, Case School of Engineering*, accessed January 16, 2016, http://engineering.case.edu/rpm-thinkbox.

6 "About: Science and Technology Campus Corporation," *Scitech*, accessed January 16, 2016, http://www.stcc.org/about/.

7 Ibid.

8 "Ohio Third Frontier Technology Validation and Start-Up Fund," *Ohio Development Services Agency*, February 6, 2015, pg. 8, https://development.ohio.gov/files/otf/TVSF_CY2015_final_rounds_10_11.pdf.

9 Ibid, pgs. 8-9.

10 "Ohio Venture Report 2014," *Venture Ohio*, October 2015, http://www.ventureohio.org/wp-content/uploads/2015/10/2014_venturereport_digital_update2.pdf.

11 Tristan Navera, "Major Ohio research network gets state funding," *Dayton Business Journal*, July 2, 2015, accessed on March 2, 2016, http://www.bizjournals.com/dayton/news/2015/07/02/major-ohio-research-network-gets-state-funding.html.

12 Ibid.

13 Ibid.

14 Ibid.

15 Liz Segrist, "Q&A with Steve Case on Rise of the Rest bus tour," *Charleston Regional Business Journal*, May 7, 2015, accessed August 24, 2015, http://www.charlestonbusiness.com/news/54439-q-amp-a-with-steve-case-on-rise-of-the-rest-bus-tour; "Historical Trend Data," *PWC MoneyTree*, accessed February 19, 2016, https://www.pwcmoneytree.com/HistoricTrends/CustomQueryHistoricTrend.

16 "150.07 Authorizing Tax Credits," *LAWriter Ohio Laws and Rules*, accessed January 17, 2016, http://codes.ohio.gov/orc/150.07v1.

17 "ORC 150.04 Terms and conditions for tax credits; Security against losses," *LAWriter Ohio Laws and Rules*, accessed January 16, 2016, http://codes.ohio.gov/orc/150.04v1.

18 Evan Weese, "Ohio Capital Fund 'Well Within the Plan' With 8% Return Since 2006," *Columbus Business First*, November 4, 2014, accessed on January 16, 2016, http://www.bizjournals.com/columbus/news/2014/11/04/ohio-capital-fund-well-within-the-plan-with-8.html?page=all.

19 "Making an Impact," *SRI International*, September 2009, pg. 30, http://www.ohiocapitalfund.com/pdf/Ohio_Impact_Rep_SRI.pdf.

20 "2014 Annual Report," *Ohio Capital Fund Annual Report*, 2014, p. 5, http://www.ohiocapitalfund.com/pdf/OCF-annual-report-2014.pdf.

21 Ibid.

22 "Ohio Venture Report 2014," *Venture Ohio*, pg. 4, http://www.ventureohio.org/wp-content/uploads/2015/10/2014_venturereport_digital_update2.pdf.

23 Ibid, pg. 12.

24 Ibid.

25 "Ohio Advanced Manufacturing Program Grant (AMP)," *Ohio Development Services Agency*, accessed January 16, 2016, http://development.ohio.gov/bs_thirdfrontier/amp.htm.

26 "Business Grants, Loans and Tax Credits," *Ohio Development Services Agency*, accessed January 16, 2016, http://development.ohio.gov/bs/bs_seprogram.htm.

27 Ibid.

28 “GrowNOW,” *Josh Mandel: Treasurer of Ohio*, accessed January 16, 2016, http://www.tos.ohio.gov/grownow.

29 Ibid.

30 “ReEnergize Ohio,” *Josh Mandel: Treasurer of Ohio*, accessed January 16, 2016, http://www.tos.ohio.gov/ReEnergizeOhio.

31 Ibid.

32 Ibid.

33 “Ohio Minority Business Direct Loan Program,” *Ohio Development Services Agency*, accessed January 16, 2016, http://development.ohio.gov/bs/bs_ombdlp.htm.

34 Ibid, “Terms.”

35 Ibid,“Eligible Borrowers.”

36 “Business Grants, Loans, and Tax Credits,” *Ohio Development Services Agency*, accessed January 17, 2016, http://development.ohio.gov/bs/bs_titc_faq.htm.

37 Ibid.

38 Ibid.

39 “Making an Impact,” *SRI International*, September 2009, pg. 60, http://www.ohiocapitalfund.com/pdf/Ohio_Impact_Rep_SRI.pdf.

40 “Technology Investment Tax Credit,” *Ohio Development Services Agency*, accessed January 17, 2016, http://development.ohio.gov/bs/bs_titc.htm.

41 “122.86 Small Business Investment Certificate; Tax Credit; InvestOhio Support Fund,” *LAWriter Ohio Laws and Rules*, accessed January 16, 2016, http://codes.ohio.gov/orc/122.86.

42 Ibid.

43 Ibid.

44 Ibid.

45 “Ohio Development Services Agency Annual Report,” 2014, pg. 5, https://development.ohio.gov/files/reports/2014DEVAnnualReport.pdf.

46 “Ohio Venture Report 2014,” *Venture Ohio*, October 2015, pg. 12, http://www.ventureohio.org/wp-content/uploads/2015/10/2014_venturereport_digital_update2.pdf.

47 David M. Freedman and Matthew R. Nutting, “Interstate Securities Exemptions: With Interstate Equity Crowdfunding Rules,” accessed December 18, 2015, http://freedman-chicago.com/ec4i/Intrastate-Securities-Exemptions.pdf.

48 “Crowdfunding Final Rule,” *U.S. Securities and Exchange Commission*, 2015, http://www.sec.gov/rules/final/2015/33-9974.pdf.

49 David M. Freedman and Matthew R. Nutting, “Interstate Securities Exemptions: With Interstate Equity Crowdfunding Rules,” accessed December 18, 2015, http://freedman-chicago.com/ec4i/Intrastate-Securities-Exemptions.pdf.

50 “2015 Legislative Summit: State Crowdfunding Update,” *National Conference of State Legislatures,* pg. 7, http://nasaa.cdn.s3.amazonaws.com/wp-content/uploads/2014/12/Intrastate-Crowdfunding-Overview-2015.pdf.

51 Amy Cortese, “Georgia, a Crowdfunding Pioneer, Marks Another First for Intrastate Crowdfunding,” *Locavesting*, accessed December 14, 2015, http://www.locavesting.com/crowdfunding/georgia-a-crowdfunding-pioneer-marks-another-first-for-intrastate-crowdfunding/.

52 “Investor Bulletin: Accredited Investors,” *U.S. Securities and Exchange Commission*, September 23, 2013, accessed December 22, 2015, http://www.investor.gov/news-alerts/investor-bulletins/investor-bulletin-accredited-investors.

53 “Understanding the Invest Georgia Exemption,” *Securities Division*, April 2014, http://sos.ga.gov/admin/uploads/Understanding_the_IGE_SS-FINAL-2.pdf.

54 “Enterprise Investment Scheme and Seed Enterprise Investment Scheme,” *HM Revenue and Customs*, July 2015, pg. 5, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/448308/July_2015_Commentary_EIS_SEIS_Official_Statistics.pdf.

55 Ibid.

56 Ibid.

57 Ibid.

Chapter 5: Workforce Development

1 "Unemployment Rates for States," *U.S. Bureau of Labor Statistics,* last modified November 20, 2015, http://www.bls.gov/web/laus/laumstrk.htm.

2 "Labor Force Statistics from the Current Population Survey," *U.S. Bureau of Labor Statistics,* last modified December 17, 2015, http://data.bls.gov/timeseries/LNS14000000.

3 "Ohio Unemployment Rates," *Ohio Department of Job and Family Services*, October 2015, http://ohiolmi.com/laus/ColorRateMap.pdf.

4 "Ohio's Low-Wage Recovery Post-Recession, Low-Wage Jobs Now Make Up Largest Share of State's Employment," *Innovation Ohio*, August 20, 2014, pg. 2, http://innovationohio.org/wp-content/uploads/2014/08/IO_Wages_082014.pdf.

5 "2014 State Manufacturing Data Table," *National Association of Manufacturers,* 2014, accessed December 16, 2015, http://www.nam.org/Data-and-Reports/State-Manufacturing-Data/2014-State-Manufacturing-Data/2014-State-Manufacturing-Data-Table/.

6 "May 2014 State Occupational Employment and Wage Estimates: Ohio," *U.S. Bureau of Labor Statistics,* last modified March 25, 2015, http://www.bls.gov/oes/current/oes_oh.htm.

7 "High Growth Industry Profile: Advanced Manufacturing," *U.S. Employment and Training Administration,* last modified December 11, 2015, http://www.doleta.gov/brg/indprof/manufacturing_profile.cfm.

8 "Ohio's Campuses," *Ohio Department of Higher Education,* accessed December 16, 2015, https://www.ohiohighered.org/campuses.

9 Ibid.

10 "NCDMM is Chosen to Manage National Additive Manufacturing Innovation Institute (NAMII)," *National Center for Defense Manufacturing and Machining,* August 16, 2012, accessed December 16, 2015, http://ncdmm.org/2012/08/14/namii-press-release/.

11 "Graduate Tracks," *Ohio State University Department of Civil, Environmental, and Geodetic Engineering,* accessed December 16, 2015, https://ceg.osu.edu/graduate-tracks.

12 "OSLN Hubs," *Ohio STEM Learning Network,* accessed December 16, 2015, http://www.osln.org/hubs/.

13 "Pre-Engineering," *Project Lead the Way Ohio,* accessed December 16, 2015, http://www.pltwohio.org/preeng_index.php.

14 Ibid.

15 "STEM - Science, Technology, Engineering and Mathematics," *Ohio Department of Education,* last modified November 16, 2015, http://education.ohio.gov/Topics/Career-Tech/STEM.

16 David J. Robinson, "Ohio Board of Regents to Implement Workforce Revolving Loan Fund," *Montrose Group, LLC.,* May 1, 2014, accessed December 16, 2015, http://montrosegroupllc.com/ohio-board-of-regents-to-implement-workforce-revolving-loan-fund/.

17 "OhioMeansJobs Workforce Revolving Loan Program Request for Proposals," *Ohio Board of Regents*, May 19, 2015, pg. 3, https://www.ohiohighered.org/sites/ohiohighered.org/files/uploads/Link/OMJ%20Workforce%20RLF%20%20RFP%20-%20Final%20_revised_052115.pdf.

18 Ibid, pg. 1.

19 "Ohio Fact Sheet," *Association for Career and Technical Education*, 2015, https://www.acteonline.org/OhioStateFactSheet2015/.

20 Ibid.

21 "Apprenticeship Occupations," *Ohio Department of Job and Family Services,* accessed December 16, 2015, http://jfs.ohio.gov/apprenticeship/program/index.stm.

22 "Homepage," *OhioMeansJobs,* accessed December 16, 2015, https://jobseeker.ohiomeansjobs.monster.com/home.aspx.

23 "Wind Vision: A New Era for Wind Power in the United States," *U.S. Department of Energy,* April 2015, pgs. xlix and 4, http://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf.

24 "Renewable Energy," *Ohio State University,* accessed December 16, 2015, http://ati.osu.edu/renewable-energy.

25 "Advanced Technology Training Center," *Cuyahoga Community College,* accessed December 16, 2015, http://www.tri-c.edu/campuses-and-locations/attc/index.html.

26 "Wind Energy Professional," *Knox County Career Center,* accessed December 16, 2015, http://careertraining.ed2go.com/kcccae/training-programs/wind-energy-courses-details?Category=sustainable-energy-green.

27 “Renewable Energy,” *Ohio Energy Pathways,* accessed December 16, 2015, http://www.ohioenergypathways.org/renew.cfm.

28 John R. Platt, “Thirty-Five Percent of Engineering Jobs Now Require 3-D Printing Skills,” *The Institute,* April 3, 2015, accessed December 16, 2015, http://theinstitute.ieee.org/career-and-education/career-guidance/thirtyfive-percent-of-engineering-jobs-now-require-3d-printing-skills.

29 “2014 Annual Report,” *Ohio Governor’s Office of Workforce Transformation*, February 27, 2015, pg. 7, http://workforce.ohio.gov/Portals/0/Workforce%202014%20Annual%20Report.pdf.

30 “YSU Opens Center for Innovation in Additive Manufacturing,” *YSU News Center,* January 27, 2014, accessed December 16, 2015, http://newsroom.ysu.edu/ysu-opens-center-for-innovation-in-additive-manufacturing/.

31 “Training and Education,” *AmericaMakes,* accessed December 16, 2015, https://americamakes.us/resources/training.

32 “3D Digital Design and Manufacturing Technology,” *Cuyahoga Community College,* accessed December 16, 2015, http://www.tri-c.edu/programs/engineering-technology/manufacturing-engineering/3d-digital-design-and-manufacturing-technology/index.html.

33 “Wind Power Cases,” *Ohio Power Siting Board*, November 13, 2015, http://www.opsb.ohio.gov/opsb/?LinkServID=895FE98C-C363-FCF9-6BFDC7DF3A3F7AA2.

34 “Alternative Energy and Sustainable Systems Technology, AAS,” *Owens Community College,* 2013, accessed December 16, 2015, http://catalog.owens.edu/preview_program.php?catoid=4&poid=900.

35 “Apprenticeship,” *Ohio Department of Job and Family Services,* accessed December 16, 2015, http://jfs.ohio.gov/apprenticeship/index.stm.

36 “Resources,” *Apprenticeship South Carolina,* accessed December 16, 2015, http://www.apprenticeshipcarolina.com/resources.html.

37 Debbie Reed et al., “An Effectiveness Assessment and Cost-Benefit Analysis of Registered Apprenticeship in 10 States,” *Mathematica Policy Research,* July 25, 2012, pg. 40, http://wdr.doleta.gov/research/FullText_Documents/ETAOP_2012_10.pdf.

38 Ibid, pg. xiv.

39 “Apprenticeship Pathways,” *Ohio Department of Higher Education,* accessed December 16, 2015, https://www.ohiohighered.org/transfer/apprenticeship-pathways.

40 “State and County Quick Facts: Ohio,” *U.S. Census Bureau,* last modified December 1, 2015, http://quickfacts.census.gov/qfd/states/39000.html.

41 Brian Bondus, “Veteran Unemployment Rate High,” *Springfield News*, May 29, 2014, accessed December 16, 2015, http://www.springfieldnewssun.com/news/news/local-military/veteran-unemployment-rate-high/nf9SR/.

42 “Employment Situation of Veterans – 2014,” *U.S. Bureau of Labor Statistics*, March 18, 2015, pg. 19, http://www.bls.gov/news.release/pdf/vet.pdf.

43 “Military Careers,” *U.S. Bureau of Labor Statistics,* January 8, 2014, accessed December 16, 2015, http://www.bls.gov/ooh/military/military-careers.htm.

44 Shydale James, “Training Day: NJIT and WOS Offer Free Technical Training to Veterans in Need of Employment,” *New Jersey Institute of Technology,* accessed December 16, 2015, http://www.njit.edu/features/sceneandheard/CPE-WOS.php.

45 “upSKILL Job Search Boot Camp,” *upSKILL,* accessed December 16, 2015, http://upskillnj.org/students/upskill-job-search-boot-camp/.

46 “Frequently Asked Questions,” *upSKILL,* accessed December 16, 2015, http://upskillnj.org/students/frequently-asked-questions.

47 Ibid.

Appendix A: Innovation Ecosystem

1 “The Carnegie Classification of Institutions of Higher Education (n.d.),” *About Carnegie Classification*, accessed January 16, 2016, http://carnegieclassifications.iu.edu/.

Appendix B: Jobs Modeling Methodology

1 “Wind Vision: A New Era for Wind Power in the United States,” *U.S. Department of Energy*, pg. xxxi, http://www.nrel.gov/docs/fy15osti/63197-2.pdf.

2 Ibid, pg. xxxii.

3 Ibid, pg. xxxiii.

4 Ibid.

5 “Renewable Electricity Futures Report,” *National Renewable Energy Laboratory*, 2012, accessed March 14, 2016, http://www.nrel.gov/analysis/re_futures/.

6 Ibid.

7 Ibid.

8 "Medium-term outlook for US power: 2015 = deepest de-carbonization ever," *Bloomberg New Energy Finance,* April 8, 2015, http://about.bnef.com/content/uploads/sites/4/2015/04/BNEF_2015-02_AMER_US-Power-Fleet-De-Carbonisation-WP.pdf.

9 Great Lakes Wind Collaborative, "Potential Economic Impacts from Offshore Wind in the Great Lakes Region," January 2014, http://www1.eere.energy.gov/wind/pdfs/57511.pdf

10 Britanny Carter, "IBIS World Industry Report OD4581: 3D Printing and Rapid Prototyping Services in the US, Breaking the Mold: Developing Technologies and a Growing Customer Base will Boost Revenue,” October 2015, accessed on March 7, 2016, http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=4581.

11 Max Oston, "IBIS World Industry Report OD4428: 3D Printer Manufacturing in the US, New Dimension: Revenue will Rise as Demand from Aerospace and Medical Fields Takes Off,” January 2016, accessed on March 7, 2016, http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=4428.

12 Britanny Carter, "IBIS World Industry Report OD4581: 3D Printing and Rapid Prototyping Services in the US, Breaking the Mold: Developing Technologies and a Growing Customer Base will Boost Revenue,” October 2015, accessed on March 7, 2016, http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=4581; Max Oston, "IBIS World Industry Report OD4428: 3D Printer Manufacturing in the US, New Dimension: Revenue will Rise as Demand from Aerospace and Medical Fields Takes Off,” January 2016, accessed on March 7, 2016, http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=4428.


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