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Advanced Manufacturing: A New Policy Challenge

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Advanced Manufacturing: A New Policy Challenge

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ABSTRACT

In 2016 the political system experienced significant disruption in part due to a working class voting block suffering from a long decline in American manufacturing, which became particularly acute in the decade of the 2000s. Manufacturing employment fell by one-third in this period, 64,000 factories closed, manufacturing capital investment and output suffered, and the productivity rate dropped. The U.S. had been systematically shifting production abroad, and experts began to realize as the next decade began that the decline in its production capability was starting to affect its innovation capacity — which had long been viewed as its core economic strength.

This article reviews the origins of the policy response to this dilemma, which came to be called "advanced manufacturing." Implementation has just begun and the next several years should reveal whether these policies could begin to have

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William B. Bonvillian (2017), "Advanced Manufacturing: A New Policy Challenge", Annals of Science and Technology Policy: Vol. 1, No. 1, pp 1–131. DOI: 10.1561/110.00000001.

an effect on American manufacturing decline. The article traces the way the foundational concepts were developed in a series of reports from in and out of government. It explores how, for the first time, an innovation system response was considered and developed to strengthen the U.S. production system. It examines the key new policy mechanism created by the administration and supported by Congress, the manufacturing innovation institutes, a complex public–private collaborative model to develop new production technologies and processes, with supporting workforce education. It reviews how the new institutes are working, lessons learned as they have started up and possible enhancements that could expand their policy reach.

While this model may create efficiencies and productivity gains to help put existing U.S. manufacturers back in competition with lower cost and lower wage competitors abroad, the article finds there is a second problem. The U.S. developed in the 1980s and 1990s a new innovation system based on venture capital for entrepreneurial startup firms for implementing the IT and biotech innovation waves. That venture system has now largely shifted to support software firms, and has abandoned startups planning to manufacture "hard" technologies. In effect, the U.S. is fencing off firms that manufacture from its venture-based innovation system. This is now driving the next generation of manufacturers to production abroad, which will have significant societal consequences longer term. This article reviews new models to tackle this problem, essentially substituting technology and know-how rich spaces for capital.

These new approaches — an advanced manufacturing program — if implemented, could play a role in reconstituting the manufacturing sector, broaden the startup model, and start to reverse the serious social disruption the manufacturing decline has led to.

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Introduction — The Decline of American Manufacturing and its Social Cost

The 2016 American Presidential Election told a story of social disruption: the political system had to confront a large group of dissenting voters who had left the existing political establishment.[1] Observers called them angry, but anger has root causes and grievances. A December 2015 Post-ABC poll told what most sensed — these voters tilted toward male, white, and poor.[2] Other polls told us the most important single predictor for these Donald Trump voters was they didn't go to college.[3] A study from the Hamilton Project informs this picture: full year employment of men with a high school but without a college degree dropped from 76%

[1]This section draws from, William B. Bonvillian (2016) "Donald Trump's Voters and the Decline of American Manufacturing", *Issues in Science and Technology*, Summer, 27–39. The editor's approval to use this material is sincerely appreciated.

[2]Janell Ross, (2015) Who Really Supports Donald Trump, *Washington Post*, Dec. 15, 2015 (summary of Washington Post-ABC News poll), July 27, 2015, Available at: https://www.washingtonpost.com/news/the-fix/wp/2015/12/15/who-really-supports-donald-trump-ted-cruz-ben-carson-marco-rubio-and-jeb-bush-in-5-charts/; Janell Ross, Donald Trump's Surge is All About Less-educated Americans, Washington Post, July 27, 2015. (summary of Wash. Post-ABC News poll), https://www.washingtonpost.com/news/the-fix/wp/2015/07/27/donald-trumps-surge-is-heavily-reliant-on-less-educated-americans-heres-why/?tid$=$a_inl.

[3]See generally, Derek Thompson, Who are Donald Trump's Supporters, Really, *The Atlantic*, March 1, 2016, relied on in this section.

in 1990 to 68% in 2013; the share of these men who did not work at all rose from 11% to 18%. While real wages have grown for men and women with college degrees, they have fallen for men without college degrees: the median income of men without high school diplomas fell by 20%, and fell 13% for men with high school diplomas or some college, between 1990 and 2013.[4] A Rand survey tells us another key feature: voters who agreed with the statement "voters like me don't have any say about what the government does" were 86% more likely to vote for Trump.[5] They felt they have no voice and no power. These voters also resented trade agreements, resented immigrants competing for jobs and more come from areas where racism historically has been more prevalent.

So there are a number of strands to this voter dissent but the economic elements tell us an evolving story that we are only starting to face. Americans in the postwar era developed a myth of classlessness — we were all middle class. Development in the postwar period of an innovation-based growth model and expansion of mass higher education made the nation rich, enabling rising expectations and a dream of egalitarian democracy. Then Donald Trump woke the country up to see a working class out there, cut adrift from the middle class and in tough economic straits. It began to blow up the myth of the American middle class.

Part of the story is education. Higher education since the industrial revolution has become increasingly tied to economic wellbeing. Economists Claudia Goldin, Lawrence Katz, and David Autor argue that the continuing advances in industry since the industrial revolution require an ever-increasing level of technological skill in the workforce.[6]

[4]Melissa S. Kearney, Brad Hershbein and Elisa Jacome, Profiles of Change: Employment, Earnings and Occupations from 1990–2013 (Hamilton Project paper, Brookings April 20, 2015).

[5]Michael Pollard and Joshua Mendelsohn (2016). Rand Commentary, Rand Kicks Off 2016 Presidential Election Panel Survey, March 28, 2016. Available at: http://www.rand.org/blog/2016/01/rand-kicks-off-2016-presidential-election-panel-survey.html.

[6]Claudia Goldin and Lawrence F. Katz, (2008). *The Race Between Education and Technology*. Cambridge, MA: Harvard University Press; David Autor, (2014). "Skills, Education and Rise of Earnings Inequality Among the 99 Percent," *Science*, 344, (6186), 843–850.

They portray two curves: (1) an ever-growing curve of the technological advance implemented by industry, and (2) a corresponding rising curve in the technological skill base in the workforce needed to support this technological advance. In a successful, technologically advanced economy, the societal skill base curve must stay parallel to and ahead of the technology implementation curve. The U.S. created a system for public mass higher education through the Land Grant College Act in 1862 which gradually scaled then dramatically enlarged access through GI Bill — these were perhaps its most important social legislation ever. For a hundred years, the education curve stayed ahead of the technology implementation curve, but starting in the 1970s, the U.S. allowed the higher education graduation rate to stagnate while the required skills expanded. These economists argue that this development is a major cause of the growing income disparity in the U.S.. While the U.S. upper middle class kept ahead of the technological skill curve, increasing its graduation rate, the lower middle and lower classes did not. This created a gap in the skill base, allowing the upper middle class to ride the technological advance earning a wage premium and leaving the other classes behind, with a significant income gap growing in recent decades between the two. Education is an important story helping to explain growing economic inequality and Trump voters.

But lurking among the other strands is a deep manufacturing story that arguably has made this problem more acute. The public didn't take manufacturing seriously in recent decades because a series of well-established economic views reassured them. Economists offered a number of perspectives: manufacturing was agriculture — we were losing manufacturing jobs because of major productivity gains; the production economy would naturally be replaced by a services economy; low wage, low cost producers must inevitably displace higher cost ones; don't worry about loss of commodity production, the U.S. will retain a lead in producing the high value advanced technologies; the benefits of free trade always outweigh any adverse effects; and innovation is distinct from production — innovation capacity remains even if the production is distributed worldwide. None are correct.

1.1 Manufacturing in decline — the decade of the 2000s

The U.S. manufacturing sector had a devastating decade between 2000–2010 and has only partially recovered.[7] The decline is illustrated by four measures: employment, investment, output, and productivity assumptions.[8]

Employment: Over the past 50 years manufacturing's share of GDP shrank from 27% to 12%. For most of this period (1965–2000), manufacturing employment generally remained constant at 17 million; in the decade from 2000 to 2010 it fell precipitously by almost one-third, to under 12 million, recovering by 2015 to only 12.3 million.[9] All manufacturing sectors saw job losses between 2000 and 2010,[10] with sectors most prone to globalization, led by textiles and furniture, suffering massive job losses.

Investment: Manufacturing fixed capital investment (plant, equipment, and IT), if cost adjusted, actually declined in the 2000s (down 1.8%) — the first decade this has occurred since data collection began.[11] It declined in 15 of 19 industrial sectors.[12] Some 64,000 manufacturing

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[7]ITIF (Adams Nager and Robert Atkinson), The Myth of America's Manufacturing Renaissance: the Real State of U.S. Manufacturing (Washington, DC: ITIF report, Jan. 20, 2015).

[8]See generally, ITIF (Robert Atkinson, Luke Steward, Scott Andes, and Stephen Ezell), Worse Than the Great Depression: What the Experts are Missing About U.S. Manufacturing Decline (Washington, DC: ITIF report, March 19, 2012).

[9]Bureau of Labor Statistics (BLS), Current Labor Statistics (CES) (manufacturing employment-Analytical Tables, Table 7 Jan. 2017), https://www.bls.gov/web/empsit/tab7.txt See detailed review of manufacturing job loss in ITIF, Worse Than the Great Depression, 4–19; Robert E. Scott, (2015) Economic Policy Institute, Manufacturing Job Loss: Trade not Productivity is the Culprit, EPI report, August 11, 2015. Available at: http://www.epi.org/publication/manufacturing-job-loss-trade-not-productivity-is-the-culprit/ (citing BLS data).

[10]BLS, CES (employment in manufacturing industries).

[11]Bureau of Economic Analysis (BEA), Fixed Assets Accounts (investments in private fixed assets by industry, http://bea.gov; see analysis in ITIF, Worse Than the Great Depression, 47–58.

[12]ITIF (Luke A. Stewart and Robert D. Atkinson), Restoring America's Lagging Investment in Capital Goods. Washington, DC: ITIF Oct. 2013, p. 1, http://www2.itif.org/2013-restoring-americas-lagging-investment.pdf.

plants closed between 2000 and 2013, with only a slight recovery since then.[13]

Output: Data shows U.S. manufacturing output growth of only 0.5%/year between 2000–2007 (before the Great Recession hit), and zero output growth/year between 2007–2014, despite the gradual overall economic recovery following 2008.[14] This was behind both GDP growth and population growth. In the Great Recession itself, manufacturing output fell dramatically, 10.3%, between 2007 and 2009, followed by the slowest economic recovery in total GDP in 60 years.[15]

Productivity: Recent analysis shows that while the productivity growth rate in manufacturing averaged 4.1%/year between 1989–2000, while the sector was absorbing the gains of the IT revolution, between 2007–2014, it fell to only 1.7% a year.[16] Because productivity and output are tied, the decline and stagnation in output cited above is a major cause of the lower level of productivity in that period. Adjusted against 19 other leading manufacturing nations, the U.S. was 10th in productivity growth and 17th in net output growth.[17] So productivity increases were not the significant cause of the one-third decline in manufacturing employment many thought.[18] Political economist Suzanne Berger has noted that economists thought manufacturing was agriculture — a story of relentless productivity gains allowing an ever smaller workforce ever greater output. She found the ag analogy was simply incorrect in recent years.[19] This means we have to look at an overall decline in the sector itself for reasons why manufacturing lost nearly one-third of its workforce in a decade.

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[13] BLS, Databases, Tables & Calculators, Quarterly Census, Manufacturing Establishments 2001–2015, http://data.bls.gov/pdq/SurveyOutputServlet.

[14] Scott, EPI Manufacturing Job Loss.

[15] ITIF, Worse than the Great Depression, 30–42.

[16] BLS, Labor Productivity and Costs, Productivity Change in the Manufacturing sector, http://www.bls.gov/lpc/prodybar.htm.

[17] ITIF, Worse than the Great Depression, 42 (adjusted from BLS data).

[18] Scott, EPI Manufacturing Job Loss; ITIF, "Worse than the Great Depression," 39.

[19] Suzanne Berger and the MIT Task Force on Production in the Innovation Economy (2014) *Making in America*. Cambridge, MA: MIT Press, pp. 28–33.

To summarize, U.S. manufacturing employment was down, manufacturing capital investment was down, manufacturing output was down, and manufacturing productivity was lower than previously assumed. Overall, the U.S. manufacturing sector has been hollowing out. The post 2009 manufacturing recovery from a recession has been the slowest in history; while there has been some manufacturing job and output recovery they remain below pre- recession levels. The underlying structural problems in the sector still need addressing.

1.2 Manufacturing and trade

Success in a highly competitive world rewards nations and regions that produce complex, value-added goods and sell them in international trade. While world trade in services is growing, world trade in goods is four times trade in services.[20] Complex, high value goods (including capital goods, industrial supplies, energy technologies, communication and computing, transport, and medicines) make up over 80% of U.S. exports and a significant majority of imports. The currency of world trade is in such high value goods, and will remain so indefinitely. Yet, the U.S. in 2015 ran a trade deficit (balance of payments in imports over exports) of $832 billion in manufactured goods in 2015.[21] As of 2015, that total included a $92 billion deficit in advanced technology products which keeps growing.[22] The theory that the U.S. could keep moving up a production food chain — it could lose commodity production and keep leading production of advanced technology goods[23] — is undermined by this data. Gradual growth in the services trade surplus ($227 billion

[20] DG Trade Statistics (Jan. 2016). *World Trade in Goods, Services*. FDI, Available at: http://trade.ec.europa.eu/doclib/docs/2013/may/tradoc_151348.pdf.

[21] BEA, (2015). Foreign Trade, Exports, Imports and Balance of Goods by Selected NAICS-Based Product Code, Exhibit 1 in FT-900 Supplement for 12/15, Feb. 5, 2016. Aailable at: https://www.census.gov/foreign-trade/Press-Release/2015pr/12/ft900.pdf.

[22] BEA, (2015). Trade in Goods with Advanced Technology Products, Exhibit 16, Available at: https://www.census.gov/foreign-trade/balance/c0007.html.

[23] See, for example, Catherine L. Mann, Institute for International Economics, International Economics Policy Briefs, Globalization of IT Services and White Collar Jobs, N. PB03-11 (Dec. 2003), http://www.iie.com/publications/pb/pb03-11.pdf.

in 2015)[24] is dwarfed by the size and continuing growth of the U.S. deficit in goods; the former will not offset the latter anytime in the foreseeable future. So a services economy does not allow us to dispense with a production economy.

1.3 Macro-economic factors

US policy makers, under the influence of standard macro-economic theory, were largely content to allow US manufacturing capacity to erode and shift offshore because they were confident that the knowledge and service economy would readily replace lost jobs and salaries from lost manufacturing; it hasn't worked.

Recent decades have seen extended periods (1982–1987; 1998–2004; 2014–2016) where the dollar had high value against leading foreign currencies, with Treasury secretaries and Federal Reserve chairs generally supportive of a strong dollar.[25] This tended to put manufacturing exporters at a disadvantage by raising their prices in foreign markets. In parallel, from 1981 on, U.S. consumption as a share of GDP began rising, reaching 69% in 2011, higher than the level in other developed economies.[26] The strong dollar also helped push the country toward what many consider over-consumption compared to savings and investment; there was a growing production/consumption imbalance. The combination of an open trading regime, generally strong dollar, high consumption rates and open financial markets created advantages for competitor nations' exports.

The situation between China and the U.S. substantiates the point: the U.S. runs a deficit-ridden, effectively import-oriented economic policy while China has been able to force savings rates and investment to

[24]BEA, U.S. International Trade in Goods and Services, Exhibit 1, Feb. 5, 2016. Available at: https://www.census.gov/foreign-trade/Press-Release/2015pr/12/ft900.pdf.

[25]Federal Reserve Bank of St. Louis, Economic Research, Trade Weighted U.S. Dollar Index: Major Currencies. Available at: https://research.stlouisfed.org/fred2/series/DTWEXM (Updated September 5, 2016).

[26]World Bank Data, Household Final Consumption Expenditure (% of GDP), Table, Available at: http://data.worldbank.org/indicator/NE.CON.PETC.ZS (accessed May 14, 2015).

record levels and subsidize and grow exports. This contrast suggests policy differences not an inherent and inevitable manufacturing employment or sectoral decline in advanced economies. Germany's continuing strong manufacturing sector is the obvious counter example. Its manufacturing workers are much more highly paid than their U.S. equivalents, it employs 20% of its workforce in manufacturing[27] and runs a major manufacturing trade surplus, including with China.[28] It tells us a high-cost, high-wage production sector doesn't inevitably lose out to a low-cost one.

1.4 China's manufacturing rise

China, after a three decade effort, is now the largest manufacturing economy in the world; a MAPI study found its share grew by 2012 to 22.4% of world manufacturing activity, with the U.S. in second place with 17.4%.[29] China has four times the population of the U.S. although its manufacturing intensity of $1,856 per capita value-added in 2012 is high for a developing economy, it is well behind advanced countries such as the U.S. (at $6,280) — so its growth trend will likely continue over time. Chinese global exports in manufactured goods in the first half of 2016 of $935 billion were 68% larger than the $555 billion of U.S. exports; this is striking because in 2000, U.S. manufactured exports were three times larger than Chinese exports.[30]

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[27]Federal Reserve Bank of St. Louis. Economic Research (FRED) (2010). Percent of Employment in Manufacturing in Germany, Available at: https://fred.stlouisfed.org/series/DEUPEFANA.

[28]Michael Hennigan (2015) *finfacts*, Germany's Record Trade Surplus in 2015, Feb. 10, 2016 (citing Statistisches Bundesamt, Wiesbaden 2015), Available at: http://www.finfacts.ie/Irish_finance_news/articleDetail.php?Germany-s-record-trade-surplus-in-2015-US-UK-France-in-deficit-520. Germany benefits from participating in the European-wide currency (Euro), which, in effect, subsidizes its exports.

[29]Manufacturers Association for Productivity and Investment (MAPI) (Dan Meckstroth, Chief Economist), China has a Dominant Share of World Manufacturing, MAPI paper, Jan. 2014, https://www.mapi.net/blog/2014/01/china-has-dominant-share-world-manufacturing.

[30]Ernie Preeg, (2016) Senior Advisory for Trade and Finance, MAPI, Farewell Report on U.S. Trade in Manufactures, August 15, 2016. Available at: https://www.mapi.net/forecasts-data/my-farewell-report-us-trade-manufactures.

What led to this rapid shift in a field the U.S. dominated for a century? Part of the story is deliberately neo-mercantilist policies to mandate technology shifts and to dominate markets by flooding them with below cost goods. There is an IP theft story, too.[31] But there is another less recognized factor we can no longer ignore. Most have assumed China's rise is predominately due to low production costs from cheap labor and cheap parts. There is also an assumption in the U.S. that manufacturing must naturally migrate to low cost producers and that the knowledge required for production processes is relatively trivial and readily replicable; neither is true. As Jonas Nahm and Edward Steinfeld argue, neither explains China's rise.[32] Instead, they find that China has undertaken a new link between process innovation and manufacturing.

They find that China's form of innovative manufacturing specializes in rapid scale-up and cost reduction. It has joined together previously unparalleled skills in simultaneous management of tempo, production volume, and cost, which enables production to scale up quickly and with major reductions in unit cost. This capability has allowed China to expand even in industries that are highly automated or not on governmental priority and support lists, despite limited labor cost advantage or government subsidies, respectively. So low labor costs and government subsidies and support are not sufficient to explain China's success in manufacturing.

China has developed production processes that were previously considered in developed nations fully mature and impervious to further cost reductions or technological improvements. The key to this ability to innovate new production processes has been the ability of Chinese firms to accumulate of firm-specific expertise in manufacturing

[31] See generally, Carl J. Dahlman (2013). *The World Under Pressure; How China and India are Influencing the Global Economy and Environment.* (Stanford, CA.: Stanford University Press.)

[32] Jonas Nahm and Edward S. Steinfeld (2011) Scale-Up Nation: China's Specialization in Innovative Manufacturing, *World Development* 54, 288. See also, Daniel Breznitz and Michael Murphree, (2011) *Run of the Red Queen: Government, Innovation, Globalization and Economic Growth in China.* New Haven, CT: Yale University Press.

through extensive, multidirectional inter-firm learning, taking advantage of international knowhow from multinationals and building on it.[33]

1.5 Trade effects

How has this rise played out in the U.S. Economists long held that free trade gains always offset losses as trading partners played to their comparative advantage. Paul Samuelson moved toward a more realistic perspective in a noted 2004 article: while unemployment due to trade may eventually be made up, "the new labor-market clearing real wage has been lowered by this vision of dynamic fair trade" creating "new net harmful U.S. terms of trade."[34]

Economists David Autor, David Dorn and Gordon Hanson have been substantiating this picture.[35] They find that the trade relationship between the U.S. and China, formed in the 1990s and formally recognized in the 2001 WTO agreement, affected a large number of labor-intensive industries in the U.S., where significant numbers of those jobs shifted to China. Their study finds this shift came with a heavy cost to U.S. workers, where many blue-collar jobs particularly disappeared, with the communities where they worked also punished economically on a continuing basis. Their findings that adverse consequences of trade are so enduring — the U.S. hasn't yet been able to get past the shock of the loss of millions of jobs in numerous communities — is counter to traditional economic assumptions about the ultimate gains of trade. The net impact on workers in U.S. regions heavily affected by competition from China was particu-

[33] Nahm and Steinfeld, Scale-Up Nation.

[34] Paul A. Samuelson, "Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization," *Journal of Economic Perspectives*, 18(3) (Summer 2004), 135–137, 144–145. This work builds on his earlier Stolper–Samuelson theorem (where there are two goods and two factors of production (capital and labor), and specialization remains incomplete, one of the two factors — the one that is scarce — must end up worse off as a result of opening up to international trade, in in absolute terms; anticipates effect of globalization on developed nation income distribution). Wolfgang Stolper and Paul A. Samuelson, "Protection and Real Wages," *Review of Economic Studies*, 9(1941), 58–73.

[35] David Autor, David Dorn, and Gordon Hanson (January 2016). The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade, NBER Working Paper No. 21906.

larly serious. The study examined the direct impact of Chinese industry on incomes in some 700 urban areas ("commuting zones") reviewed, comparing workers in heavily impacted areas (at the 75th percentile of exposure to Chinese competition) with workers in less affected areas (at the 25th percentile). They found a reduction in annual income of $549 per adult between the two, while per-capita income from offsetting federal assistance only rose by $58. The growth of trade with China, they find, has tended to make lower skilled workers worse off on a sustained, ongoing basis. There was no relatively "frictionless" economic adjustment to other industries; there was so much "friction" that middle class workers out of jobs still haven't recovered. Little offsetting growth was found in industries not affected by this "China shock." Instead, workers did not make up lost wages and their communities entered a slow, continuing decline.

As economics Nobelist A. Michael Spence has noted, "Globalization hurts some subgroups within some countries, including the advanced economies . . . The result is growing disparities in income and employment across the U.S. economy, with highly educated workers enjoying more opportunities and workers with less education facing declining employment prospects and stagnant incomes."[36] Just as manufacturing employment was a key to enabling less educated workers to enter the middle class after World War II, the loss of manufacturing jobs is correspondingly a key element in the decline in real income for a significant part of the American middle class in the past few decades. Obviously the 2008–2009 Great Recession, where manufacturing was a leading victim, played a role, but there appears no getting around the trade effects, which have been longer term.

But are these macro and trade factors don't appear to be a complete explanation for U.S. manufacturing decline — we must also look at what was happening at ground level — at the innovation level.

[36] A. Michael Spence (2011). "The Impact of Globalization on Income and Employment: The Downside of Integrating Markets," *Foreign Affairs* 90(4), July–August 28–41, Available at: https://www.foreignaffairs.com/articles/united-states/2011-06-02/globalization-and-unemployment.

1.6 The "innovate here/produce there" assumption

Since World War II, the U.S. economy has been organized around leading the world in technology advance. It developed a comparative advantage over other nations in innovation, and as a result, it led all but one of the significant innovation waves of the twentieth century, in aviation, electronics, space, computing, the internet, and biotech, although it had to play catch-up to Japan on quality manufacturing. Its operating assumption was that it would innovate and translate those innovations into products. By *innovating here/ producing here*, it would realize the "full spectrum" of economic gains from innovation at all the stages, from research and development, to demonstration and testbeds, to initial market creation, to production at scale, and to the follow-on life cycle of the product.[37] This "full spectrum" worked — the U.S. became the richest economy the world had ever seen. The U.S. for the past two-thirds of a century has been playing out economic growth theory — that the predominant factor in economic growth is technological and related innovation — and demonstrating that it works.

But in recent years, with the advent of a global economy, the "innovate here/produce here" model no longer holds. In some industrial sectors, firms can now sever R&D and design from production. Codeable IT-based specifications for goods that tie to software controlled production equipment have enabled this "distributed" manufacturing.[38] While manufacturing once had to be integrated and vertical, firms using the distributed model can *innovate here/produce there*. It appears this distributed model works well for many IT products, as well as for commodity products.[39] Apple is the standard-bearer for this model,

[37]This discussion draws on William B. Bonvillian (2012). Reinventing American Manufacturing — The Role of Innovation, *Innovations*, 7(3), 99–100. See also, William B. Bonvillian and Charles Weiss (2016), *Technological Innovation in Legacy Sectors*. New York: Oxford University Press, pp. 37–54, 87–95.

[38]Suzanne Berger (2005). *How We Compete: What Companies Around the World Are Doing to Make it in Today's Global Economy*. New York: Doubleday Currency, pp. 251–277.

[39]Gary Pisano and Willy Shih (2009). Restoring American Competitiveness, *Harvard Business Review*, July–August, 114–125, Available at: http://hbr.org/2009/07/restoring-american-competitiveness.

continuing to lead in dramatic IT innovations, but distributing virtually all its production to Asia.

However, there appear to be many sectors where the distributed model doesn't work well, that still require a close connection between research, design, and production. Capital goods, aerospace products, energy equipment, and complex pharmaceuticals appear to be examples of this phenomenon. In these sectors, production and R&D/design are the yin and yang of innovation. Here, the production infrastructure provides constant feedback to the R&D/design infrastructure. Product design and innovation is most efficient when tied to a close understanding and linkage to manufacturing processes. However, if R&D/design and production must be tightly linked, the innovation stages — R&D and design — may have to follow production offshore. "*Produce there/innovate there*" may be even more disruptive than "*Innovate here/produce there*." These twin developments bring the economic foundations of U.S. innovation-based economic success into question. It means that innovation investments won't lead to "full spectrum" economic gains. What good, taxpayers might ponder, is a world-leading innovation system if much of the gains flow elsewhere?

1.7 The innovation perspective

If the picture on the U.S. production side is problematic, what of the innovation side of the equation? The U.S. retains the world's strongest early stage innovation system in the face of growing competition. Any manufacturing strategy must seek leverage from this comparative innovation advantage. However, U.S. R&D in the past has had only a very limited focus on the advanced technologies and processes needed for production leadership. This is in sharp contrast to the approach to manufacturing R&D taken by Germany, Japan, Korea, Taiwan and now China, which have "manufacturing led" innovation.[40] The U.S. has simply not applied its innovation system to what turns out to be a crucial innovation stage, production, particularly initial production of complex, high value technologies. This stage involves highly creative en-

[40] Bonvillian and Weiss, *Legacy Sectors*, 25, 184–185.

gineering and design, and often entails rethinking the underlying science and invention — it is part of the innovation process not severed from it. So innovation is not just R&D distinct from production, innovation capacity includes the production stage. Missing this created a major gap in its innovation system.

While the major U.S.-based multinational manufacturing firms fund most of the nation's technology development stage and so have the capacity to keep up on the innovation front, the majority of the U.S. manufacturing sector belongs to the 250,000 small and mid-sized firms lacking this capacity. The base of small and mid-sized manufacturers represents 86% of U.S. manufacturing establishments, and employs more than half of its manufacturing workforce. It is largely outside the innovation system.

1.8 The reach of manufacturing into the American economy

Manufacturing remains a major sector of the U.S. economy: official statistics tell us manufacturing is approximately 12.1% of U.S. GDP contributing $2.09 trillion to our $17.3 trillion economy and employs 12.3 million in a total employed workforce of some 150 million.[41] Manufacturing workers are paid substantially more than service sector workers, 20% higher than nonmanufacturing.[42] Growth economists tell us that 60% or more of historic U.S. economic growth comes from technological and related innovation; as the dominant implementation stage for innovation, manufacturing is a critical element in the innovation system, although the U.S. hasn't understood it this way. Industrial firms employ 64% of our scientists and engineers, and this sector performs 70% of industrial R&D.[43] Thus our manufacturing strength and the strength

[41] BLS, Industries at a Glance, Manufacturing: NAICS 31–33, Workforce Statistics (July 2016), Available at: http://www.bls.gov/iag/tgs/iag31-33.htm.

[42] Susan Helper, Timothy Kruger and Howard Wial (2012). *Why Does Manufacturing Matter? Which Manufacturing Matters?*, Washington, DC: Brookings, pp. 4–5, https://www.brookings.edu/wp-content/uploads/2016/06/0222_manufacturing_helper_krueger_wial.pdf.

[43] Gregory Tassey (2010). Rationales and Mechanisms for Revitalizing U.S. Manufacturing and R&D Strategies, *Journal of Technology Transfer*, 35(3), 301, citing BEA and NSF data.

of our innovation system are directly linked.

Despite the decline in the manufacturing employment base, manufacturing remains a major workforce employment source for the economy, measured largely by workers at the production stage. But the official data is collected at the establishment level not firm levels. Should we limit the view of manufacturing to the production moment? Why is manufacturing measured at the factory? This arguably only provides a partial perspective on the role of this sector.

The manufacturing sector, instead, can be better viewed as an hourglass.[44] At the center, the narrow point of the hourglass, is the production moment. But manufacturing employment can't be looked as simply the production moment. Pouring into the production moment is a much larger employment base, which includes those working in resources, those employed by a wide range of suppliers and component makers, and the innovation work force, the very large percentage of scientists and engineers employed by industrial firms. Flowing out of the production moment is another host of jobs, those working in the distribution system, retail and sales, and on the life cycle of the product. The employment base at the top and bottom of the hourglass is far bigger than the production moment itself.

Arranged throughout the hourglass are lengthy and complex value chains of firms involved in the production of the goods — from resources to suppliers of components to innovation, through production, to distribution, retail and life cycle — a great array of skills and firms, and largely what we would count as services. But they are tied to manufacturing. If we removed the production element, the value chains of connected companies are snapped and face significant disruption. While the lower base of the hourglass, the output end, may be partially restored if a foreign good is substituted for a domestic good, the particular firms involved will be disrupted. The upper part of the hourglass, the input end, with its firms and their employees, doesn't get restored.

When these complex value chains are disrupted, it is very difficult to put them back together. That's why, historically, once the U.S. loses an economic sector, it is so hard to resurrect — it doesn't come back.

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[44] Bonvillian, Reinventing American Manufacturing, 118–119.

We don't collect data in this "value chain" way on our industrial sector; the closest data we have is job multiplier data, which doesn't tell the full story. Understanding manufacturing in terms of the hourglass and the value chains within it may provide part of the explanation for the economy's current predicament over job loss, job creation, and declining median income.

A recent Manufacturers Alliance for Productivity and Innovation (MAPI) study developed new data perspectives to tell more of this value chain story[45]:

- The manufactured goods value chain plus manufacturing for other industries' supply chains accounts for about one-third of GDP and employment in the U.S.
- The domestic manufacturing value-added multiplier is 3.6, which is much higher than conventional calculations. For every dollar of domestic manufacturing value-added destined for manufactured goods for final demand, another $3.60 of value-added is generated elsewhere in the economy.
- For each full-time equivalent job in manufacturing dedicated to producing value for final demand, there are 3.4 full-time equivalent jobs created in nonmanufacturing industries; this job multiplier is far higher than in any other sector. Higher value-added production industries appear to have even higher multipliers.

The report's central finding is that the current estimates of manufacturing's share of the GDP are partial and seriously understated; when the full scope of the manufacturing footprint is examined, it could amount to around one-third of the U.S. economy, not one-tenth. The studies by Autor and colleagues noted above tend to bear out the widespread economic effects of its decline.

There is not only a macro-economic story in U.S. manufacturing but also an innovation system story. The failure of the U.S. innovation

[45] Manufacturers Alliance for Productivity and Innovation (MAPI) Foundation (Dan Meckstroth, Chief Economist), The Manufacturing Value Chain is Bigger than You Think (Washington, DC: MAPI Foundation report Feb. 16, 2016).

system to consider the production stage as an important element of that system is problematic enough when the scope and role of manufacturing is judged according to current estimates; if manufacturing is viewed through this larger value chain lens, the consequences really must be reckoned with.

1.9 Manufacturing and democracy

New work by Autor and coauthors tends to bear out the relationship of disruption in the manufacturing sector to disruption in the political system.[46] Analyzing Congressional elections between 2002 and 2010, they found that increased exposure of local labor markets to foreign competition, particularly from China, tended to push both political parties toward candidates at their ideological extremes, polarizing the political process. The Trump candidacy is an extension of this development.

The frustrated voters identified at the outset have now completely disrupted one of the nation's two major political parties. There may be potential long term consequences for the political system, which is indeed being pushed to its ideological edges. These voters appear stuck in their declining industrial communities strewn across the midwest, the northeast, and parts of the industrial south — where could they move, to do software in Silicon Valley, biotech in Boston? As a number of economists are grasping, their cities and towns have gone into failure mode. But they latched onto a new voice, a profoundly disturbing voice to many. The voice of confrontational messages dominated night after night of evening news. This working class was the historic base of Roosevelt's Democratic Party, they backed JFK, began to shift parties in the Reagan era, and they have now blown up the Republican party — the party of Main Street and Wall Street, of Lincoln and Taft, of country club and corner store, even of Rand Paul and the Kochs. It is now clear they are so sizable neither party can afford to ignore them — the parties must find a way to work through their issues that have been long ignored as if this community was invisible. It's not only elective politics;

[46] David Autor, David Dorn, Gordon Hanson, and Kaveh Majlesi, Importing Political Polarization? The Electoral Consequences of Rising Trade Exposure, paper, MIT economics website, April 25, 2016.

the ideological disruption of longstanding party doctrine is potentially powerful as well, because the parties had embraced or tolerated a series of economic views that cast these people out. Will the political system be flexible enough to accommodate these recent outcasts? What would such a policy accommodation look like? In particular, could the political parties rethink their stance on policies on manufacturing?

This is not the first time the parties have had to confront a manufacturing challenge. In the 1980s, as the realization dawned on industrialists and policymakers that Japan had launched a new kind of manufacturing system, heavily innovation-oriented around quality in production, the political system was forced to react. Japan's quality revolution was built on new precision in production technologies, tied to new production processes and new enabling business models. U.S. industry took a long time to understand and to try to catch up, and meanwhile the U.S. lost innovation leadership of two major sectors, auto and consumer electronics. As Kent Hughes has described, the political system was affected by anxiety and frustration, particularly in the region most disrupted by Japan's new quality manufacturing system, the industrial Midwest — the origin of the term "rustbelt." [47] There was a political outcry, comparable but not as pervasive as the current one.

The Republican Party response was around its traditional mantra of capital supply: Congressman Jack Kemp from Buffalo and Senator Bill Roth from Delaware proposed significant changes in marginal tax rates.[48] Traditional Democrats called for what was known at the time as "industrial policy."[49] Noting the industry interventionist policies of Japan's Ministry of International Trade and Industry (MITI),[50] they called for sustaining failing firms and sectors, and their employees, to enable a turnaround. Labor retraining, education, and assistance were part of the proposals, essentially a labor supply approach, a longstand-

[47]The story of the U.S. response to Japan's quality manufacturing paradigm is detailed in, Kent Hughes (2005). *Building the Next American Century — The Past and Future of American Economic Competitiveness*. Washington, DC: Wilson Center Press, drawn on here.

[48]Hughes, *Building the Next American Century*, pp. 60–61.

[49]Hughes, *Building the Next American Century,* pp. 45–49.

[50]Hughes, *Building the Next American Century*, pp. 50–51, pp. 74–77, 85.

ing Democratic mantra. It was classical economics all over again — each party locked in on one of the two major elements of classical economics' growth theory, capital supply and labor supply, solutions long imbedded in their political philosophies. But classical economics, as Robert Solow demonstrated, lacked a sound theory of economic growth.[51] Both parties, then, lacked workable growth policies. They had missed the advent of growth economics (often termed innovation economics), initially articulated by Solow, which found that technological and related innovation was the dominant causative factor in growth. Capital supply and labor supply remained significant factors, but were not close to the importance of technological innovation.

There were glimmers of this recognition within in the parties. President Ronald Regan named John Young, CEO of Hewlett Packard to lead a Commission on Industrial Competitiveness (the "Young Commission"), given the Japan challenge. Young's Commission argued for R&D growth and new public-private partnerships to accelerate technology advances.[52] Its 1984 recommendations were largely ignored by the Republican administration, but a number of the ideas were picked up in Congress' Omnibus Foreign Trade and Competitiveness Act of 1988.[53] A few "Atari Democrats," including Senators Gary Hart[54] and Al Gore,[55] began to focus on the importance to growth of "sunrise" industries, and this "future" perspective was adopted by the House Democratic caucus, which led to the 1988 Act and other legislation.[56] This included efforts to bring basic research closer to the market, and Sematech, the early

[51] Robert M. Solow (1987). *Growth Theory, An Exposition.* 2nd edn. New York, Oxford: Oxford University Press, pp. ix–xxvi (Nobel Prize Lecture, Dec. 8, 1987), Available at: http://nobelprize.org/nobel_prizes/economics/laureates/1987/solow-lecture.html/

[52] Hughes, *Building the Next American Century*, 153–168.

[53] Omnibus Foreign Trade and Competitiveness Act of 1988, P.L. 100–418, 19 U.S.C., sec. 2901, et seq.

[54] Hughes, *Building the Next American Century,* 137–141.

[55] Hughes, Building the Next American Century, 290. Gore led passage of the High Performance Computing Act, passed in 1991, P.L. 102–194, 105 Stat. 1594, 15 USC 5501, to support the emerging "information superhighway."

[56] See, Hughes, *Building the Next American Century*, 170–198. Technology legislation of the period is summarized in, William B. Bonvillian (2014). "The New Model Innovation Agencies: An Overview," *Science and Public Policy*, 42(4), 28–29.

model of a successful public–private collaboration on manufacturing innovation that brought significant advances to semiconductor equipment production to retain U.S. semiconductor technology leadership.[57]

However, the political need to respond with new manufacturing policies was swept away by the success of the innovation-induced information technology innovation wave.[58] The IT wave transformed the decade of the 1990s into one of the strongest growth spurts in recent U.S. history, with strong GDP and productivity gains. The lessons of the manufacturing challenge of the 1980's went largely unlearned.

As the IT boom moderated, as China offered a new manufacturing challenge, and as the Great Recession threw the economy and the manufacturing sector in particular into a nosedive, a new kind of social disruption accelerated, and the political system had to pay attention again. This time the administration in power pursued a manufacturing innovation agenda.

1.10 The response — advanced manufacturing

The Obama Administration promised in 2012 to deliver one million new manufacturing jobs by 2016; only half materialized by then. But they did make manufacturing innovation the centerpiece of their technology agenda, hoping to have 15 advanced manufacturing institutes in place or selected by the beginning of 2017. These are organized around advanced production technologies, promising dramatic production efficiencies to offset U.S. higher wage levels to restore manufacturing competitiveness. They aim to reconnect the innovation system to the production system, trying to rebuild a manufacturing ecosystem to better link small and large production firms and university engineering and science. It was a promising start, but more is mandated. The R&D system could do much more to focus on new manufacturing technologies and processes. Innovative startups that could manufacture high value goods either lack scaleup financing or are shifting production to contract manufacturers in places like Shenzhen. Could there be new technology and know-how

[57] Larry D. Browning and Judy C. Shetler, *Sematech: Saving the U.S. Semiconductor Industry*. College Station, Texas: Texas A&M Press 2000.

[58] Dale Jorgenson, (2001). U.S. Economic Growth in the Information Age, *Issues in Science and Technology*. Available at: http://www.issues.org/18.1/jorgenson.html.

rich spaces in the U.S. where they could test and launch pilot production here not there? These three developments — the new focus on manufacturing innovation, the development of manufacturing innovation institutes, and a new support system for manufacturing startups — amount to a major shift in U.S. technology policy. This new innovation focus can be termed Advanced Manufacturing. These developments are the subject of this work.

An innovation response is not the only step required; manufacturing is a complex system, there is no single silver bullet. The Obama Administration tried hard to increase college graduation rates, grow community college attendance and improve workforce training — more is needed, including new online and blended learning systems for training. New thinking on macro, fiscal, tax and trade policies and adjustments, and on longstanding economic assumptions, is still required. Trade-affected community assistance and job retraining must be rethought. The current political denouement tells us more will be needed from future Administrations. But there will be no going back to the GM plants of the 1950s; the next generation of manufacturing will look very different, organized around advanced technologies, and the jobs in the hourglass of manufacturing value chains, not simply at the factory, will be the real way of evaluating the sector's strength. None of these steps requires counter-productive industrial policy.[59] But innovation policy with public–private collaborations will need to be a centerpiece.

There are major policy implications here. The U.S. can continue to ignore the manufacturing sector and let it slide, but the consequences — to its innovation system, and therefore to economic growth, and therefore to social wellbeing — now appear significant. But there also appear to be consequences for its democracy and its inclusive ideals; it can continue to write off a working class community but this will pay dividends in social and political disruption and affect governance. The study below explores the innovation policy alternatives around the new effort toward Advanced Manufacturing.

[59]See, for example, Charles L. Schultze (Fall 1983). Industrial Policy: A Dissent, The Brookings Review, 2(1), 3–12, Available at: https://www.jstor.org/stable/20068627?seq=1#page_scan_tab_contents.

2

Advanced Manufacturing Emerges at the Federal Level

As Barack Obama was sworn in as President in January 20, 2008 he faced the Great Recession, the first economic shutdown since the 1930s to approach Depression levels of economic decline, with a 10% unemployment rate, the highest long term unemployment rate since the Depression[60] and over 15 million unemployed. Neoclassical economists were at the helm pressing their menu of fiscal and monetary plans, joined to "shovel ready" economic stimulus efforts, to coax the price signals that could restore investment to nurture positive rates of growth.

The problem was that these stabilization policies were limited in their ability to offset long term underinvestment in the economic assets and factors that create the larger growth multipliers needed — including in R&D and manufacturing innovation. For a significant period, as NIST's former chief economist Gregory Tassey has argued, this longer term underinvestment had led to declining U.S. competitiveness and slower rates of growth. In other words, short term stabilization was simply not

[60] Bureau of Labor Statistics (2012). *Spotlight on Statistics, The Recession of 2007–2009*. Washington, DC: BLS, p. 2, Available at: http://www.bls.gov/spotlight/2012/recession/pdf/recession_bls_spotlight.pdf.

enough, the problems were deeply structural and required a structural response.[61]

2.1 White house 2011 advanced manufacturing report

Against a backdrop of economic crisis and a series of new studies,[62] a small group in the White House Office of Science and Technology Policy (OSTP) had been developing a report urging a strong new commitment by the administration to manufacturing, as a longer term, more structural approach. But the report had been delayed in internal debates over manufacturing economics.

In the final version of the 2011 manufacturing report, issued through the White House's PCAST, wording to accommodate traditional

[61] Gregory Tassey (2012). *Beyond the Business Cycle: the Need for a Technology-Based Growth Strategy*. Washington, DC: NIST Economic Analysis Office Feb. 2012), 2, http://www.nist.gov/director/planning/upload/beyond-business-cycle.pdf.

[62] In this period there were a number of significant articles on the U.S. manufacturing predicament that provided a foundation for the studies reviewed below, although the MIT study discussed below was perhaps the most extensive and far reaching. These included: Gregory Tassey (2010). "Rationales and Mechanisms for Revitalizing U.S. Manufacturing R&D Strategies," *Journal of Technology Transfer,* 35(3); Erica Fuchs and Randolph Kirchain. (December 2010) "Design for Location? The Impact of Manufacturing Offshore on Technology Competitiveness in the Optoelectronics Industry," *Management Science* 56(12), 2323–2349; Susan Houseman, Christopher Kurz, Paul Lengermann, and Benjamin Mandel (2011). "Offshoring Bias in U.S. Manufacturing," *Journal of Economic Perspectives,* 25(2); Dan Breznitz and Peter Cowhey (2012). *America's Two Systems of Innovation: Recommendations for Policy Changes to Support Innovation Production and Job Creation*. San Diego, CA: Connect Innovation Institute, ITIF (2012) *Worse than the Great Depression: What the Experts Are Missing about American Manufacturing Decline*. Washington, DC: ITIF; Susan Helper, Timothy Kruger, and Howard Wial (2012). *Why Does Manufacturing Matter? Which Manufacturing Matters?* Washington, DC: Brookings; Stephanie Shipp, *et al.* (2012). *Emerging Global Trends in Advanced Manufacturing*, Report P-4603. Arlington, VA: Institute for Defense Analysis. Available at: https://www.wilsoncenter.org/sites/default/files/Emerging_Global_Trends_in_Advanced_Manufacturing.pdf; William B. Bonvillian (2012). "Reinventing American Manufacturing: The Role of Innovation," *Innovations*, 7(3); Gary P. Pisano and Willy C. Shih (2012). *Producing Prosperity*. Numerous reports on manufacturing in this period are listed and summarized in, MIT Washington Office (Yiliu Zhang, Daniel Kuhner, Kathryn Hewitt, Queenie Chan), Future of U.S. Manufacturing — A Literature Review, Parts I–III, August 2011, Jan. 2012, July 2012, Available at: http://dc.mit.edu/resources/policy-resources.

economists was included, including a market failure rationale and national security justification.[63] It asserted that the report's proposals were not heavy-handed "industrial policy," where government invests in particular sectors or firms, but simply an extension of long-established government support for "innovation policy."[64]

The final report, entitled "Ensuring American Leadership in Advanced Manufacturing," defined advanced manufacturing as the manufacture of conventional or novel products through processes that depend on the coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting edge materials and emerging scientific capabilities.[65] The report argued that federal investments in such manufacturing could enable the U.S. to regain its status as a global leader in manufacturing, which would yield high-paying jobs, support domestic innovation, and enhance national security. However, the failure to lead in production would potentially jeopardize the nation's ability to develop the next generation of advanced products. Retention of manufacturing would enable new synergies, whereby design, engineering, scale-up, and production processes provide the feedback for the conception and innovation sectors to generate both new technologies and new later-generation products.

The report proposed "shared facilities and infrastructure" where small and mid-sized manufacturing firms could develop new production approaches embodying productivity gains, allowing these firms to more rapidly prototype, test and make new products.[66] It recommended federal applied research support of "advanced manufacturing" processes that cut across a range of production sectors to enable producers to more rapidly develop new U.S.-made sectors. This included, interestingly, "supporting the creation and dissemination of powerful design

[63]President's Council of Advisors on Science and Technology (PCAST), Report to the President on Ensuring American Leadership in Advanced Manufacturing (Washington, DC: PCAST June 2011), Available at: https://energy.gov/sites/prod/files/2013/11/f4/pcast_june2011.pdf.

[64]PCAST, Ensuring American Leadership in Advanced Manufacturing, PCAST Chairs' introductory letter, i.

[65]PCAST, Ensuring American Leadership in Advanced Manufacturing, ii.

[66]PCAST, Ensuring American Leadership in Advanced Manufacturing, v.

methodologies that dramatically expand the ability of entrepreneurs to design products and processes."[67]

It further recommended partnerships between industry, universities and government, with government and industry co-investment, that could develop emerging technologies, such as "nanomanufacturing, flexible electronics, electronics, information technology-enabled manufacturing, and advanced materials," that could lead to transformation of U.S. manufacturing.[68] Included in the recommendations was a proposed "Advanced Manufacturing Initiative" across government agencies that could link to industry–university collaborations to develop more detailed approaches.[69] The report was released in June 2011, and provided material and perspectives for such an initiative to work from. The strands identified, then, included "shared facilities" for SMEs, industry–university partnerships around manufacturing technologies, R&D on new processes, developing new manufacturing design methodologies and a cross-agency government effort. Most importantly, the report and the parallel announcement of an "Advanced Manufacturing Partnership" (AMP) locked-in a White House commitment to a manufacturing innovation strategy.

2.2 The advanced manufacturing partnership begins

The White House announced AMP on June 24, 2011, naming Dow Chemical's CEO and MIT's President as cochairs of a consortium rounded up by senior White House staff for the President.

On the industry side AMP included CEO's from a diverse group of major companies, spread across a landscape of industrial sectors. On the university side it included Presidents of five schools with very strong engineering and applied science.[70] On the government side, the

[67] PCAST, Ensuring American Leadership in Advanced Manufacturing, iii.

[68] PCAST, Ensuring American Leadership in Advanced Manufacturing, iii–v, 33.

[69] PCAST, Ensuring American Leadership in Advanced Manufacturing, iv.

[70] Names of AMP1.0 Steering Committee Members from companies and universities can be found in, The White House, Office of the Press Secretary, Press Release, "Report to President Outlines Approaches to Spur Domestic Manufacturing Investment and Innovation, July 12, 2012, Available at: https://obamawhitehouse.archives.gov/the-press-office/2012/07/17/report-president-outlines-approaches-spur-domestic-manufacturing-investm

Chair of the National Economic Council and the Acting Commerce Secretary, co-led a cross agency effort. Within the White House, NEC and OSTP staff provided leadership. The agencies deeply involved in supporting the effort were NIST, NSF (through its Engineering Division), DOE (through its Energy Efficiency and Renewable Energy office), and DOD (through its Manufacturing and Industrial Base office and its Mantech program). The President's Council of Advisors on Science and Technology (PCAST) based in the White House OSTP provided an administrative home for the effort; it formally issued the AMP report although it was written by AMP.

In launching the new partnership, President Obama highlighted the need to "reinvigorate" American manufacturing, once "the ticket to a middle-class life." He called for "developing new technologies that will dramatically reduce the time required to design, build, and test manufactured goods" with leading universities and companies complementing federal efforts "to invent, deploy and scale these cutting-edge technologies." He argued that, "With these key investments, we can ensure that the U.S. remains a nation that 'invents it here and manufactures it here'."[71] "We have not run out of stuff to make," he said, citing robotics, materials, solar energy, and automobiles as examples of fields where new technology may prove revolutionary; he argued inventing and commercializing this technology will create jobs and export opportunities for the U.S.[72] The White House report on "Ensuring American Leadership on Advanced Manufacturing" was released on the same day that AMP was announced, as noted, to help buttress the rationale for new partnership.

The White House aimed to form a strong public–private partnership to design an enduring innovation policy effort for manufacturing with industry and university buy-in. The firms and universities organized and staffed the effort with support from agency staff, forming a series

[71]White House Office of the Press Secretary, Release (2011). President Obama Launches Advanced Manufacturing Partnership, Statement at Carnegie Mellon University, June. Available at: https://obamawhitehouse.archives.gov/the-press-office/2011/06/24/president-obama-launches-advanced-manufacturing-partnership

[72]MIT News Office (2011). Release, Hockfield to co-chair U.S. manufacturing partnership, June 24, Available at: http://news.mit.edu/2011/hockfield-obama-manufacturing-0624.

of topical task forces under two supervising "technical co-leads" from Dow and MIT.[73]

The companies and universities that were part of AMP with few exceptions committed significant time from at least one senior employee, and often teams of them, to help staff the AMP effort. The participating government agencies likewise made parallel staff commitments. Ambitious working groups jointly led by industry, university and government were created around key topics, including technology development, shared infrastructure and facilities, education and workforce, business climate policy, and outreach, with industry and university co-leads for each.[74] Frequent live meetings, extensive prep work, and nearly constant group calls were the standard. Dozens of outside organizations and experts were consulted and their ideas were brought into the process. The universities on the Steering Committee, in cooperation with Committee companies, hosted four major regional meetings, each with hundreds of participants from small and large area firms and other organizations, featuring discussions of AMP ideas and seeking new ones.[75] The AMP

[73] Overseen by the AMP Steering Committee (which consisted of the industry CEOs and university Presidents), the effort was led by staff from the firms, universities and agencies who are listed (mixed in with outside experts consulted) in Appendix B, 47–50 and vi, in, President's Council of Advisors on Science and Technology (PCAST), Advanced Manufacturing Partnership, Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing (Washington, DC: PCAST July 2012), Available at: https://www1.eere.energy.gov/manufacturing/pdfs/pcast_july2012.pdf For disclosure, author Bonvillian worked on the AMP1.0 and AMP2.0 reports as a member of the assigned MIT support group.

[74] Regarding the workgroups, Appendix B lists names of both outside experts and AMP participants from its member universities and companies; names from the participant organizations identify those who participated on the workgroups and in development of the report proposals. See, PCAST, Advanced Manufacturing Partnership Steering Committee, Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing (Washington, DC: PCAST July 2012), Appendix B, 47-50. Annexes to the Report containing detailed reports from each workgroup Available at: https://www1.eere.energy.gov/manufacturing/pdfs/pcast_july2012.pdf

[75] PCAST (July 2012). Report to the President on Capturing Domestic Competitive Advantage, Annex 6, Regional Meeting Summaries, Available at: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/amp_final_report_annex_6_amp_regional_meeting_summaries_july_update.pdf

group was outcome oriented not simply report oriented, aiming for "actionable recommendations" that the agencies and participants were prepared to help implement. The level of commitment was highly unusual and the one-year project kept to an intense schedule, pushed hard by its Dow and MIT co-leads. The Steering Committee of CEOs, university presidents and top government officials, including the President, met periodically to review progress and ideas.

An early Administration and AMP concept was to create Fraunhofer Institute-like "Advanced Manufacturing Institutes" to creatively bring together into single, public–private entities the technology development ideas being evaluated by AMP workgroups. Although there were governmental programs related to manufacturing,[76] this was a dramatic new thrust. It was snapped up as an idea for implementation by the Administration long before AMP submitted its final report containing this recommendation. The President called for a strong manufacturing effort in his February 2012 State of the Union address,[77] and a month later, at a visit to an aircraft engine factory, called for 15 manufacturing institutes.[78] This was an early example of the dynamic of close interaction between AMP, the White House and the agencies. AMP came to represent a new innovation model — a deep, public–private collaboration, bringing together tightly connected industry, universities and government agencies for policy design and implementation at a major scale.

[76]MIT Washington Office (Eliza Eddison) (Sept. 2010). Survey of Federal Manufacturing Efforts; MIT Washington Office (Aneesh Anand) (Sept. 2014). Survery of Selected Federal Manufacturing Programs at NIST, DOE, DOE, and NSF, Available at: http://dc.mit.edu/resources/policy-resources. (both reports).

[77] *Wall Street Journal*, (Feb. 12, 2012) Full Text, President's State of the Union Address, Available at: http://blogs.wsj.com/washwire/2013/02/12/full-text-obamas-state-of-the-union-address/

[78]White House (2012). President Obama to Announce New Efforts to Support Manufacturing — Administration Proposes New National Network to Support Manufacturing, March 9, Available at: https://obamawhitehouse.archives.gov/the-press-office/2012/03/09/president-obama-announce-new-efforts-support-manufacturing-innovation-en

2.3 AMP1.0 July 2012 report — "capturing domestic competitive advantage in advanced manufacturing"

Shortly after AMP was created by the President, it moved to create five work groups, co-led by industry and university leaders, around key manufacturing topics: (1) "Technology Development," to identify a mechanism for evaluating manufacturing technology priority areas and nurturing these key manufacturing technologies; (2) "Shared Infrastructure and Facilities," to assess de-risking and scaling new technologies through the production stage via joint facilities serving the manufacturing community particularly small and mid-sized firms; (3) "Workforce Development," to identify ways to better supply the talent needed for advanced manufacturing, (4) "Policy," to recommend economic and innovation policies to improve research collaboration on manufacturing; and (5) "Outreach," to link to manufacturing firms and organizations for input, and to help organize regional meetings around the country.[79] The work group assignments provide a good picture of the tasks and policy directions AMP pursued.

The focus of AMP was on "advanced manufacturing" which the report defined as encompassing "all aspects of manufacturing, including the ability to quickly respond to customer needs, through innovations in production processes and innovations in the supply chain," which are increasingly "knowledge intensive, relying on information technologies, modeling, and simulation." It noted that manufacturing, "creates more value across the economy per dollar spent than any other sector," and that manufacturing was an enabler to "fundamentally change or create new services and sectors." However, it found the U.S. was losing ability to adequately use manufacturing for these ends: "The hard truth is that the U.S. is lagging behind in innovation in the manufacturing sector."[80] While manufacturing trade associations and firms had long focused their agenda with the federal government on tax and trade policy, AMP's focus on advanced manufacturing through an innovation agenda marked

[79] PCAST, Report to the President on Capturing Domestic Competitive Advantage, July 2012, 4.

[80] PCAST, Report to the President for Capturing Domestic Competitive Advantage, July 2012, 1–2.

an entirely new policy approach for this sector. It called out the deep, interactive relationship between manufacturing and innovation.[81]

The report called for an "advanced manufacturing strategy" based on a "systematic process to identify and prioritize critical cross-cutting technologies."[82] That process should lead to an ongoing strategy, which in turn could be translated into more detailed technology roadmaps for each of the new technology paradigms, and the report developed a framework for prioritizing federal investments in such technologies based on such factors as national need, global demand, U.S. manufacturing competitiveness in the field, technology readiness, and an assessment of industry, university research and government commitment to the technology (such as whether, in the case of government, it could serve national security needs).[83] Surveying groups of manufacturers and university experts, the report developed a preliminary priority list of technology areas to be pursued[84]: Advancing Sensing, Measurement, and Process Control; Advanced Materials Design, Synthesis, and Processing; Visualization, Informatics, and Digital Manufacturing Technologies; Sustainable Manufacturing; Nanomanufacturing, Flexible Electronics Manufacturing, Biomanufacturing and Bioinformatics; Additive Manufacturing; Advanced Manufacturing and Testing Equipment; Industrial Robotics; Advanced Forming and Joining Technologies. Again, strategies for these were to be developed over time into true technology roadmaps that were to be coordinated across technologies and periodically updated.

[81] PCAST, Report to the President for Capturing Domestic Competitive Advantage, July 2012, 9.

[82] PCAST, Report to the President for Capturing Domestic Competitive Advantage, July 2012, 12.

[83] PCAST, Report to the President for Capturing Domestic Competitive Advantage, July 2012, 17.

[84] AMP's focus was on production technologies, but it was not the first to pursue development of critical technology lists. Senator Jeff Bingaman(D-N.Mex.) in 1989 pushed the Defense Department and the White House Office of Science and Technology Policy to study and develop critical technologies needed across civilian and military sectors. This effort was also taken up by the Young Commission (see Section 1), which surveyed nine industries on their critical technology needs. Hughes, *Building the Next American Century*, 249, 255–257.

To nurture these production technologies, it called for building R&D efforts around them. Significantly, it also called for Manufacturing Innovation Institutes (MIIs) of small-and mid-sized firms linked to larger firms, backed by multidisciplinary university applied science and engineering, with cost-shared funding support from government (federal and state) and participating industry.[85] The idea was a translation into a U.S. context of the successful German Fraunhofer Institutes, 60 of which were spread across Germany, in a wide range of technology focus areas The U.S. version was to be an industry-led model, shared and cost-shared, like the Fraunhofer Institutes, across small- and mid-sized firms, with a supporting university technology development role in applied science and engineering, and support from both national and state government. The U.S. Institutes were to operate at the regional level to take advantage of area industrial clusters, but be able to translate their technology and process learning to manufacturers at a national scale. To facilitate this national translation and to tie together the MII's around joint lessons learned, the report proposed a National Network of Manufacturing Innovation Institutes (NNMI). These policies were guided by a vision that there was a gap between R&D supported by government and the product development role of industry where a support system for the stages of technology development, technology demonstration and system/subsystem development — technology readiness levels 4–7[86] — was too often simply missing in action. The Institute role was to fill that gap, as Figure 2.1 from the report illustrates.

The institutes were to support the technology's development, offer shared facilities where firms could experiment with and adapt the evolving technologies, and train their workforces around it in coordination with area community colleges and universities. No one expected there could be a single "place" with everything present; networks

[85] PCAST (July 2012). Report to the President for Capturing Domestic Competitive Advantage, 21–24.

[86] In the U.S., both the Defense Department DOD and the National Aeronautics and Space Administration (NASA) have developed similar but somewhat different Technology Readiness Levels (TRLs); AMP applied the DOD terminology. See, DOD, Assistant Secretary for Research and Engineering, Technology Readiness Levels Guidance, Available at: http://www.acq.osd.mil/chieftechnologist/publications/docs/TRA2011.pdf (updated May 13, 2011).

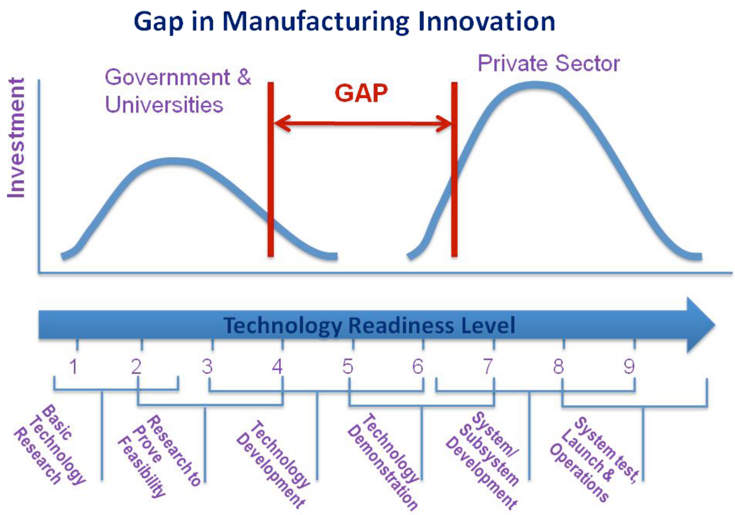

Figure 2.1: Gap in Manufacturing innovation.
Source: AMP1.0 Report (2012), p. 21.

of such shared facilities in multiple support nodes were understood to be required. The facilities, then, would primarily serve collaborative advanced prototyping, testing and workforce training — a new kind of facility by now gone from the U.S. industrial landscape except perhaps in the largest firms. The idea was that these new institutes would recreate an industrial ecosystem missing since pressures of global competition, information technologies and the distributed production they enabled, and a financial services model of core competency that made firms less vertically connected, and slimmed. Figure 2.2 from the report, below illustrates the manufacturing innovation institute model.

AMP also looked closely at the talent base required for advanced manufacturing. It noted surveys for the Manufacturing Institute by Deloitte that found that 86% believed manufacturing was critical to American economic prosperity, that 85% believed it was key to the standard of living, and that of the types of new facilities that could be located in their communities, manufacturing plants ranked number

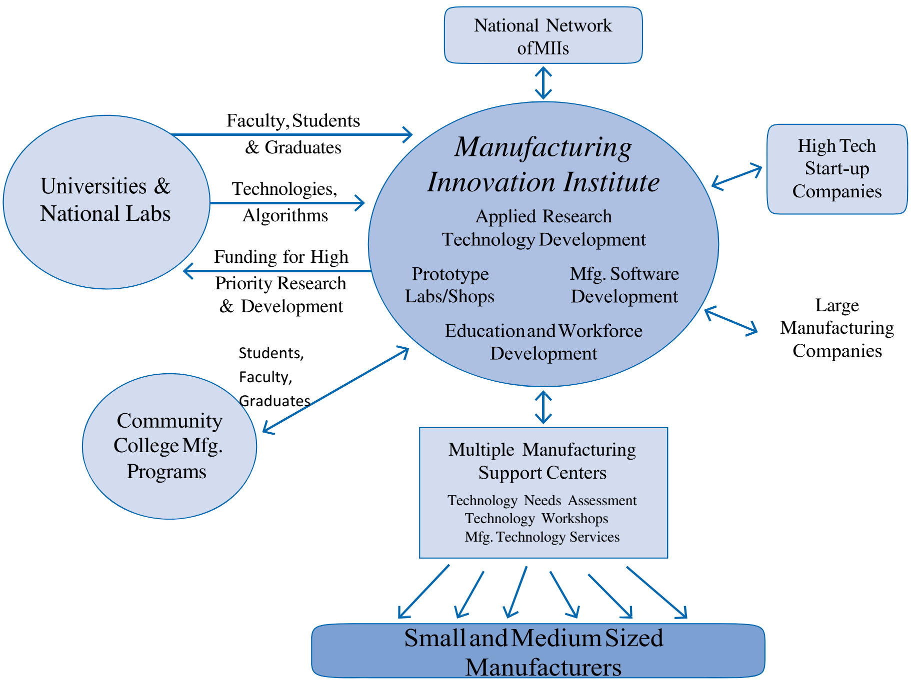

Figure 2.2: Manufacturing innovation institute model.
Source: AMP1.0 Report (2012), p. 23.

one.[87] AMP made a series of workforce recommendations; the two with the broadest potential effect were to improve the links between manufacturing firms and community colleges to significantly expand advanced manufacturing training, and to develop industry-community college partnerships to develop nationwide systems for highly marketable and transferable skills certification. After all, if there was no available talent base educated to use it, advanced manufacturing could never be implemented.

Could the AMP proposal — for networked manufacturing institutes, and new training models — work? Could it help restore production leadership and help reconnect innovation and production? The AMP report

[87] PCAST (July 2012). Report to the President for Capturing Domestic Competitive Advantage, 28–29.

did not elaborate on these questions, but by creating and enabling new production technologies and processes, the core notion was U.S. producers would be better able to compete, through new efficiencies, growing productivity and quality, against low cost producers abroad, offsetting a wage advantage. Such innovation itself could also lead to competitive advantages through improved products. Would these new technologies and processes emigrate abroad over time? Of course, but there would be three reasons why an innovation-based lead could continue: (1) there would be a "first mover" advantage that would endure for a time for the developer of the new approaches, (2) low wage economies needing high employment levels for social and political reasons would have more difficulty shifting to a high productivity model, and (3) once a strong process was put in place for creating and implementing these new manufacturing systems the lead on oncoming new developments might continue.

2.4 MIT's "production in the innovation economy" study

Meanwhile, a major study at MIT had been informing the AMP process. Called "Production in the Innovation Economy," the final PIE report emerged in 2013 after the AMP 2012 study. It was foundation and gift funded and engaged a "commission" of 20 senior faculty and 9 graduate student researchers, with frequent meetings on campus and investigative studies in Europe, Asia, and the U.S..[88] The group starting in 2010 focused on regional industry case studies in Ohio, Georgia, Arizona and in their own neighborhood, Massachusetts, as well as in China and Germany. Throughout, the group was informing the Administration and AMP participants of findings. While the final study was not released until 2013 and early 2014, in two volumes published by the MIT Press, its ideas were in circulation throughout the period. One high point was when Prof. Suzanne Berger, the political economist who led the MIT faculty task force, directly briefed President Obama on key findings;

[88] The faculty commission and researchers are named at the front of the first volume, Suzanne Berger and the MIT Task Force on Production in the Innovation Economy (2013). *Making in America.* Cambridge, MA: MIT Press 2013, pp. ii–iv. For disclosure, author Bonvillian was advisor to the study.

this clearly wasn't a typical academic exercise. The first volume, *Making in America*,[89] was drafted by Berger, who led the project, as a report overview; the second volume, *Production in the Innovation Economy*,[90] contained in depth backup chapters drafted by faculty and researcher teams. These were rich and detailed volumes amounting to a historic and influential study of U.S. manufacturing. They told a complex story of what had happened and why, not fully glimpsed elsewhere. The summary here of core findings can only capture the surface of the story.

The research group examined a series of industrial actors and areas.[91] First, U.S. multinationals were reviewed; these firms had moved from predominately U.S. to global operations in three decades. Interviews with senior managers and reviews of firm data evaluated strategies for locating R&D, testing, pilot production, and full-scale manufacturing in the U.S. and overseas. Next, the other end of the industrial chain was examined.[92] Tracking a group of startups in the Boston area from lab idea toward production, the study looked at the barriers these new firms faced in getting to products, particularly in financing scaleup. Third, the study looked at "Main Street manufacturers" — small- and mid-sized manufacturers — and the problems they faced in innovating in product, process supporting services, and business models.[93] This work was undertaken in four representative U.S. regions, as noted earlier. There was also in depth study of firms in Germany and China and the innovation they have introduced in scaling up to production and in production itself.[94] Each worked off different models but both offered important lessons. Fifth, the group undertook research on advanced manufacturing technologies and the potential role innovation in the production process could play in reviving U.S. manufacturing.[95] Finally,

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[89] Berger *Making in America* (2013).

[90] Richard M. Locke and Rachel L. Wellhausen (2014) (eds.), The MIT Task Force *Production in the Innovation Economy*. Cambridge, MA: MIT Press.

[91] These study areas are delineated in more detail on the MIT Production in the Innovation Economy (PIE) website, http://web.mit.edu/pie/research/index.html.

[92] The major and Main Street firms are discussed in Berger (2013). *Making in America*, pp. 25–64, 91–120.

[93] Berger (2013). *Making in America*, pp. 65–90.

[94] Berger (2013). *Making in America*, pp. 121–154.

[95] Berger (2013). *Making in America*, pp. 155–178.

there was research on skill training, which examined the extent of a manufacturing skills shortage, and the needs of advanced manufacturing for improved skills education.[96]

At heart, the PIE study asked "one big question:" what production capabilities are needed to support innovation and to realize its benefits in quality jobs, strong firms, new business creation, and sustainable economic growth?[97] Assuming what economists had long accepted, that innovation is required for economic growth and a corresponding productive economy, the study examined "what it takes to sustain innovation over time and what it takes to bring innovation into the economy,"[98] reviewing innovation in products, in processes, in types of firms, in other nations, through technology advances and workforce improvements. The focus that PIE helped initiate, starting in 2010, was the application of innovation theory to production. While such theory had been applied many times to particular new technologies, it had not been systematically applied to the U.S. production system. It was a new look.[99] The five overall areas it examined in turn led to a series of new policy approaches for each.

The PIE report found a globalized world economy of distributed production — research, development, production, and distribution had become fragmented and dispersed. Enabling this was a shift in corporate ownership and control, where major, vertically integrated corporations began to divest many of their attributes, from R&D to production to post-sales services. Few fully vertically integrated firms remained. They had been reorganized under pressure from a financial services sector that beginning in the 1980s required firms seeking capital to reorganize around "core competency" — leaner, "asset light" firms received higher stock valuations by weeding out their less profitable divisions.[100] One of the first functions at many firms to go outside corporate boundaries

[96] Berger (2013). *Making in America*, pp. 179–198.

[97] Berger (2013). *Making in America*, pp. 6–7. See also, statement on the PIE website, http://web.mit.edu/pie/research/index.html.

[98] Berger (2013). *Making in America*, p. 7.

[99] As listed in an earlier footnote, a number of articles and studies had considered aspects of innovation in developing manufacturing policies, although the MIT PIE study was the most far reaching.

[100] Berger (2013). *Making in America*, pp. 17–20, 44–64.

was manufacturing, which reduced capital obligations and "headcount" commitments — it was often shifted abroad. IT advances helped enabled this development — computer driven equipment using digital specifications allow firms to produce goods without the vertical linkages previously required. Reduction of trade barriers worldwide and China's entry into the World Trade Organization were further enablers.

The shift to core competency plus competition from abroad thinned out the manufacturing ecosystem. Support for training systems, inducements for suppliers to adopt best practices, the depth of supply chains all declined. While major firms had once supported strong industrial labs that undertook basic and applied research, basic research at the industrial level dropped, and applied work became much more focused on incremental development that could translate to the bottom line. Expansion was more frequently accomplished through mergers and acquisitions, not through in-house innovation. While large, vertically organized firms had created numerous "public goods" — in research, training, transfer of technology, and expertise to suppliers — that populated the ecosystem with spillovers that helped small and mid-size firms, this declined.

The growing gaps in the ecosystem could be characterized as "market failures" because the declining network of "complementary capabilities" made firms less capable as they found it harder to access the former industrial commons. So larger firms dropped a vertical model, hunkered down to "core competency," went "asset light," and distributed production. Small- and mid-sized firms were increasingly what the study termed "home alone,"[101] operating in a thinned-out industrial ecosystem. The end of local banking hit them as well; as financial services pursued national and international investment models, the home town banker with personal knowledge of those he or she was lending to was disappearing. Capital became harder to get, so small- and mid-sized firms had more difficulty getting resources to scale up production of new innovations. The industrial ocean the Main Street manufacturer used to swim in began to dry up.

[101] Berger (2013). *Making in American*, p. 20.

The researchers who studied German firms found a very different story. Its “mittelstand” firms were not home alone — they were swimming in a rich ocean of trade associations, shared institutions for developing new technologies across collaborating firms, supportive engineering centers, strong technical education and training systems producing highly qualified employees, and readily available local financing for scaleup. The system of 60 regional Fraunhofer Institutes, in particular, links them to larger firms through production technology collaborations between regional supply chains and engineering experts at universities and technical institutes. A strong program of apprenticeship training assures them a highly skilled workforce. American small manufacturers lacked such support systems.

The researchers studying China, as noted in Section 1.4, found a production system that was increasingly innovative in its ability to rapidly scale up production levels to remarkable levels through methods for regional, cross-firm collaboration.[102] For example, in wind turbine production, Chinese firms rapidly absorbed lessons from international competitors then modified them to create designs to fit their own markets, created production systems fully capable of established production capabilities, nurtured cutting edge technologies such as advanced aerospace designs for blades, drew on materials science and systems engineering in production that could be both labor and capital intensive, and rapidly scaled production.[103] And there was a strong prototyping capability for redesigning and reengineering goods to their cut costs to make them affordable to Chinese markets. Too many American firms, increasingly home alone in the case of smaller firms, or dispersed in the case of larger firms, seemed to have lost these rapid scaleup and rapid prototyping strengths.

[102] Jonas Nahm and Edward S. Steinfeld (2014). “The Role of innovative Manufacturing in High-Tech Product Development: Evidence form China’s Renewable Energy Sector,” in Locke and Wellhausen, eds., *Production in the Innovation Economy*, pp. 139–174.

[103] Nahm and Steinfled, “The Role of Innovative Manufacturing; Jonas Nahm and Edward S. Steinfeld (2014). “Scale-up Nation: China’s Specialization in Innovative Manufacturing,” *World Development*, xx, pp. 289–300.

There was an additional challenge. Examining a wide range of firms, the study noted that small- and mid-sized firms to survive in the decade of the 2000s and the Great Recession had to find ways to be innovative. This was usually not innovation in sense of taking advances from lab to product through R&D, but in modifying existing product lines to fit new needs and market niches, or finding new functions and therefore markets for existing components.[104] In particular, the PIE study found that successful manufacturing firms were increasingly blending products and services, offering customers solutions to their problems through products and the related services to install apply it.[105] Large firms — IBM and Apple were good examples — were also merging products and services as a new way of creating value for customers. Blending these two usually disparate worlds, which looked to be the future of most firms, was an additional new challenge.

These were the stories for major and Main Street manufacturers, but what was going on with startups, which had become key to the dynamic, innovation driven part of the U.S. economy, starting with the IT revolution and backed by a new venture financing system? As will be elaborated on later, the researchers studied a group of Boston-area startups that had survived for a decade or more.[106] Boston was an ideal cluster for startups — strong university research, great talent, great science, capital support — if they couldn't make it there, it would be harder elsewhere. If the startups weren't in the IT or biotech space, which had well-established development timetables and pathways, they had trouble scaling up. Their timeframe wasn't the 5–7 years of IT firms, it was a decade or more. These firms would go past the 5 year period that venture firms were organized around to recoup their investors' funding; if they were promising, the venture firms would remain in because they didn't want to dilute their holdings, but put the startup on what could be termed "income maintenance". When the non-IT startup was finally

[104] Berger (2013). *Making in American*, pp. 91–102, 104–111.

[105] Berger (2013). *Making in American*, pp. 111–114.

[106] Elizabeth Reynolds, Hiram Semel, and Joyce Lawrence (2014). "Learning by Building: Complementary Assets and the Migration of Capabilities in U.S. Innovative Firms," in Locke and Wellhausen (eds.), *Production in the Innovation Economy*, pp. 51–80.

well through product design, the venture firm typically indicated that it didn't have the financing for production scaleup and referred the startup to contract manufacturers abroad.

There was good news here for the startup — it could start to scale up. But its innovation team would have to start living for months at a time in, say, Shenzhen educating the contract maker's engineers on the new technology as they designed for production. The locus of innovation began to shift abroad, and if there were incremental advances in the product, they tended to be developed by the contract manufacturer. Sometimes the venture firm sent the startup to a foreign sovereign wealth fund, but the effect was similar. The problem for the U.S. is that if its startups represents the next generation of technology advance, their scaleup may shift outside the U.S..

The PIE study also told a technology story. A major example was studied in depth to evaluate the possibilities of innovation for production: a case study on a mix of very challenging technologies to enable "mass customization."[107] This entailed small-scale, local production using 3D printing and computer driven standard equipment that could make small lots of uniquely designed products as cost efficiently as uniform mass-production. The case study elaborated on the technologies to enable this and found this model possible. It would mark a dramatic turn in the history of production. Manufacturing had always involved scaleup of ever increasing production levels; the new technologies meant not scaleup but scale down of production. Just as there was a local food movement there could be a local production movement. And consumers could participate in designing to match their precise needs and taste. If production was local, small-scale, and highly efficient, then overseas production advantage would be erased. An innovation in production could be transformative. Obviously, this would only work for some goods, and obviously there were other technology paradigms aside from mass customization that await development. But the "advanced manufacturing" innovation model for production was found promising, an organizing principal for restoration of the manufacturing ecosystem.

[107] Berger (2013). *Making in America*, pp. 155–178. Prof. Sanjay Sarma of MIT was the major contributor on the "mass customization" model.

Finally, PIE examined workforce needs. Earlier reports tended to query manufacturing senior management who unfailingly complained that they weren't able to find skilled workers.[108] But if this sector had shed almost one-third of its workers in the decade of the 2000s, was there really a shortage? The PIE study queried firms' hiring officials not about availability of skilled workers but more pointedly about how long it took to fill jobs; the answer was that open positions were being promptly filled in 76% of cases.[109] There was no skills emergency. Why did managers assert the opposite? Perhaps, it was in the interest of all managers to beat the drums on skill shortages so educational institutions would respond to their needs. But there were still the 24% of manufacturing establishments that reported some level of long-term vacancies — what was their story? This is where the story got more interesting. A subset in this group tended to include newer firms, working in more advanced technologies; these firms did face skill needs. So if PIE was proposing the adoption of advanced manufacturing driven by new technologies and processes, it was clear that the training system would need work to meet this challenge. The recommendations called for "a new skill production system" requiring employers to engage with community colleges, supporting government programs at the federal, state, and regional levels, and intermediary organizations to help manage the linkages and communications.[110]

Overall, the PIE study was called for rebuilding a thinned out industrial ecosystem.[111] New shared facilities and capabilities across firms and industrial sectors were required for manufacturing innovation, and larger firms and government could perform a convening function,

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[108]See, for example, Deloitte and the Manufacturing Institute, Boiling Point? The Skills Gap in U.S. Manufacturing (2011), p. 6, Available at: www.themanufacturinginstitute.org/~/media/A07730B2A798437D98501E798C2E13AA.ashx, which found that 82% of manufacturing senior executives reported moderate to serious gaps in availability of qualified, skilled candidates; 74% of manufacturers reported these shortages affected their ability to expand operations.

[109]Paul Osterman and Andrew Weaver, "Skills and Skills Gaps in Manufacturing," in Locke and Rachel Wellhausen (eds.), *Production in the Innovation Economy*, pp. 17–50.

[110]Osterman and Weaver, "The New Skill Production System," in *Production in the Innovation Economy*, pp. 76–77.

[111]Berger (2013). *Making in America*. pp. 21–23.

comparable to what Sematech achieved in semiconductor production in the late 1980s and 1990s. Examples of this were cited in upstate New York and in Ohio. A similar collaboration across firms, education institutions and public intermediaries could also work in the skills training context.

2.5 AMP2.0 October 2014 report — "accelerating U.S. advanced manufacturing"

The President "rechartered" the Advanced Manufacturing Partnership in September 2013 to work on implementation of the 2012 report and to identify new strategies building on the earlier AMP1.0 report. This project marked the next major step in advanced manufacturing policy development.

Most of the prior participating firms and universities from AMP1.0 became part of "AMP2.0," with presidents of two community colleges, a regional state university, two smaller firms, and a major union added to the team.[112] The CEO of Dow was joined by MIT's new President, as cochairs of the AMP2.0 Steering Committee; again, Dow and MIT provided the "technical co-leads" coordinating the highly active workgroups. On the administration side, the National Economic Council provided agency coordination and overall guidance.[113] As with AMP1.0, heavily attended regional workshops were held in Georgia, Ohio, New York, Massachusetts, and Michigan to develop and share policy ideas.

Since the administration was in the process of creating manufacturing institutes, the AMP2.0 report focused on complementary policies. In the technology policy area,[114] it called for a national strategy coordinated across public and private sectors for "emerging manufacturing

[112]PCAST (2014). Advanced Manufacturing Partnership 2.0 Steering Committee, Report to the President on Accelerating U.S. Advanced Manufacturing. Washington, DC: PCAST October 2014, p. vii (list of AMP2.0 participants) https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/amp20_report_final.pdf.

[113]Participants in AMP2.0 from Steering Committee firms and schools, as well as Administration participants are listed in PCAST, Accelerating U.S. Advanced Manufacturing (2014), pp. 52–55. For disclosure, author Bonvillian was a participant for MIT.

[114]PCAST (2014). *Accelerating U.S. Advanced Manufacturing*, p. 17.

technologies." This would include "prioritized manufacturing technology areas," which should be used to manage a "portfolio" of federal "advanced manufacturing technology investments." To show that this strategy concept could work, the AMP2.0 group surveyed priority emerging manufacturing technology areas and developed their own pilot strategies in three areas identified by the study as priorities: advanced sensing, control and platforms for manufacturing; visualization, informatics and digital manufacturing, and advanced materials manufacturing.[115] The administration subsequently worked to create manufacturing institutes to cover these identified priority areas, drawing on the strategies. The federal investment wasn't solely to be manufacturing institutes — establishment of R&D support for manufacturing technologies was needed, and additional institutional entities were called for. These mechanisms included manufacturing centers of excellence, technology testbeds which could be additional infrastructure backing up the institutes. The R&D and support infrastructure were to be developed cooperatively with industry; an advanced manufacturing advisory consortium was called for to provide private sector input on both the strategy and the R&D infrastructure. The report foresaw that to thrive over time the manufacturing institutes had to be connected to a robust R&D effort and infrastructure for ongoing advances in the technologies the institutes were supporting. In addition, a "shared National Network for Manufacturing Innovation (NNMI)" was called for to network the manufacturing institute so ideas, technologies, and best practices could be shared across institutes. Shared processes and standards to spread implementation of new manufacturing technologies was also recommended.

In the area of workforce training and development,[116] the report recommended a national system of portable, stackable manufacturing skill certifications to be used by employers in hiring and promotion, to help production workers obtain readily transferable and recognizable skills. Development of online training and accreditation programs with federal support through job training programs were also proposed. AMP2.0 members themselves developed extensive manufacturing training toolk-

[115] PCAST (2014). *Accelerating U.S. Advanced Manufacturing*, pp. 66–70.
[116] PCAST (2014). *Accelerating U.S. Advanced Manufacturing*, p. 18.

its and playbooks, as well as a pilot apprenticeship training program. The report proposed continuing to support these and similar efforts by industry and community colleges. Finally, the report proposed a national campaign to change the image of manufacturing around the advanced manufacturing that would be required in the future, taking advantage of the new fall “Manufacturing Day” of open plants and programs to highlight this.

The report also had a workgroup on “Scaleup Policy” examining the difficulty of small- and mid-sized firms and startups in obtaining financing for scaling up production of new innovations. This problem had been identified in the MIT PIE study, and extensive discussions were held with venture capital firms, corporate venture, private equity, and other possible sources for scaleup financing through multicity workshops on this problem. An ambitious public–private scale up investment fund was envisioned for pilot production sites for new technologies. In addition, a better system for linkages between manufacturers with potential strategic partners who could aid in scaleup of production was called for. Work on this scaleup gap became one of the key focus areas of the report.

The AMP2.0 project was not only about policy recommendations. The AMP industry–university–labor participants emphasized their own hands-on efforts to develop apprenticeship programs, training toolkits, technology strategies in three promising areas, and manufacturing scaleup support concepts.

The AMP2.0 report findings were presented directly to President Obama on October 27, 2014 by the 18 members of the Steering Committee, with Dow’s CEO and MIT’s President as lead presenters. The Commerce Secretary, National Economic Council Director, and Office of Science and Technology Policy Director discussed steps for implementing the report’s proposals with the President and the Steering Committee.[117] Simultaneously, the White House announced implementation programs, including a new apprenticeship training program and three

[117] Peter Dizikes (2014). MIT News Office, Reif briefs Obama in White House — Advanced Manufacturing Partnership 2.0 Delivers Report on Developing Innovation Based Growth, October 28, Available at: http://news.mit.edu/2014/reif-briefs-obama-innovation-economy-1028.

new manufacturing institutes around advanced materials, advanced sensing and control and digital manufacturing, tracking with report recommendations. That afternoon, the National Academies hosted a forum[118] on the report with AMP2.0 industry and university experts and involved agency and White House officials publically presenting the recommendations and findings.

2.6 National academy of engineering study — "making value for America"

Two more background elements are required to round out our story on the evolution of the advanced manufacturing policy movement, first from the National Academies and, last, from a historically divided Congress.

The National Academy of Engineering (NAE) report "Making Value for America" was released in March 2015.[119] It was initiated by the late NAE President Chuck Vest, who saw clearly the significance of the manufacturing decline as it evolved, and pressed for the report. It began with an interesting quote from him: "Far too much of our nation is waiting for new ways of working to arrive. We hear lots of rhetoric about how the nature of work will change, as if it relates to some unknown distant future. The fact is that it is happening now, and we need a broader recognition of this fact and policies and education that reflect it." The NAE Committee had distinguished leadership[120] and went off in a somewhat different direction than the earlier reports discussed earlier. Rather than re-plow that ground, it looked at the implications of advanced manufacturing, operating, as Vest's quote

[118]National Academies (2014). Board on Science, Technology and Economic Policy, Innovation Policy Forum on Reinventing U.S. Advanced Manufacturing — A Review of the Advanced Manufacturing Partnership 2.0 Report, Oct. 27, Available at: http://sites.nationalacademies.org/PGA/step/PGA_152473.

[119]National Academy of Engineering (NAE) (2016). *Making Value for America.* Washington, DC: National Academies Press, Available at: http://www.nap.edu/catalog/19483/making-value-for-america-embracing-the-future-of- manufacturing-technology

[120]NAE (2015). Making Value for America, p. vii.

suggests, on the assumption that it was going to happen. It therefore represents an interesting bookend to the sequence of reports we have been discussing.

It found that technology advances and new industry business models would dramatically alter both the way products are made and distributed but also the nature work in creating those products.[121] It argued that the U.S. needed to embrace those possibilities if it was to remain a leading innovation center — a core strength. It posited that firms would have to shift from making products to making value,[122] which blended services with product and endured through the life cycle of the product. Crucial in this process would be the value chains[123] of firms and capabilities that would serve as linked enablers. Firms had a central role in these steps but government policies and investments in new kinds of education and training and in evolving technology advances would be required.

The report was pointing out one of the major implications of "advanced" manufacturing. The introduction of the new technologies to achieve the efficiency and productivity gains[124] required to pursue leadership in important manufacturing sectors was going to change the nature of work. Introduction of digital technologies and sensor systems throughout the production process — smart manufacturing — meant streamlining and automation which meant altering jobs and requiring more education and ingenuity in the workforce as technology coordination became the industrial norm.[125] The training system must change to keep up with this otherwise the opportunity for production leadership would be lost.[126] And there may well be less jobs on the production side. The offset the report didn't quite state but implied was that in "making value" firms would have to create new kinds of blended jobs combining

[121] NAE (2015). Making Value for America, p. 1.
[122] NAE (2015). Making Value for America, p. 11.
[123] NAE (2015). Making Value for America, pp. 20–45.
[124] NAE (2015). Making Value for America, pp. 47–59.
[125] NAE (2015). Making Value for America, pp. 40–45.
[126] NAE (2015). Making Value for America, pp. 71–81, pp. 104–107.

a sophisticated mix of services, distribution and production — that's where the jobs were going to be. (And as this work has suggested in the previous section, looking at manufacturing as part of an hourglass of value chains means understanding that the real volume of jobs in manufacturing is not simply at the production moment but in the value chains that are dependent on it.)

The "making value" and "value chain" perspectives this report offered provided constructive additional ways of looking at advanced manufacturing – both what it could offer as a new role for production as well as new challenges it created.

2.7 Congressional manufacturing legislation

The final saga in this review of the major reports and efforts behind advanced manufacturing concerns Congressional legislation. For U.S. government action to be enduring, it must be authorized by Congress, and a foundation of regular and relatively stable appropriations must follow. When the executive branch is committed, the policy ship can be launched, but there is no real wind in the sails unless Congressional authorizations and appropriations follow; government commitments in the end follow law and corresponding funding not administrative fiat. If these steps don't evolve new programs often don't survive subsequent shifts in administrations. Of course, seeking Congressional approval can be high risk, particularly in a period of deep party divisions. You can never be sure what Congress might hand you.

Congress was afflicted particularly after 2010 with deep ideological divisions, including within the Congressional parties themselves, and a corresponding inability to move legislation. Despite this divide, Congress was able to pass significant manufacturing legislation on a highly bipartisan basis. This speaks to the political power of manufacturing, through the employment and relatively high wages it still commands, in regional American politics. Efforts by concerned companies led to support for the legislation from the National Association of Manufacturers and other industry groups; industry support was particularly important to building Republican support.

After introduction by bipartisan cosponsors in 2013,[127] and hearings in House and Senate Committees,[128] the bill had sufficient support in both parties in both Houses of Congress, and enough dedicated backing from its sponsors and Committee leaders that it was added to a monster annual Omnibus Appropriations bill to fund all the government agencies for the fiscal year — a "must pass" bill. As a "minibus" attached to the Omnibus, it passed the House on December 11th and the Senate on December 13, 2014.

The legislation authorized the establishment of a network of up to 15 regional manufacturing institutes across the country, each focused on a unique technology, material, or process relevant to advanced manufacturing.[129] This was to form a Network for Manufacturing Innovation. NIST was to be the lead agency in forming the network, but could collaborate with other federal agencies in selecting and awarding funding institutes, which must be cost shared by industry and state or local governments. It was required to develop and periodically update a strategic plan for the network of institutes. It was also required the institutes to link to the existing Manufacturing Extension Partnership (MEP) that offered efficiency and technology advice to small manufacturers in every state, and required institutes to take on education and training roles.

Of course, in the meantime a series of manufacturing institutes had already been stood up, led by the Defense Department's Manufacturing

[127] S.1468, 113th Congress 2nd Session, Available at: https://www.govtrack.us/congress/bills/113/s1468/text (the legislation was reported as amended by the Senate Commerce Committee chaired by Senator Jay Rockefeller (D-W.Va.) on August 26, 2014); HR 2996, Revitalize American Manufacturing and Innovation, 113th Congress, 2nd Session, Congress.gov, bill actions, Available at: https://www.congress.gov/bill/113th-congress/house-bill/2996/actions.

[128] Report of the House Committee on Science, Space and Technology, Report on HR 2996 to Revitalize American Manufacturing and Innovation, House Report 113-599, 113th Congress, 2nd Session, September 15, 2014, Part IV (Hearing Summary), Available at: https://www.congress.gov/congressional-report/113th-congress/house-report/599/1; Report of the Senate Committee on Commerce, Science and Transportation, on S. 1468 Revitalize American Manufacturing and Innovation Act, Senate Report 113–247, 113th Congress, 2nd Session, August 26, 2014, Legislative History section, Available at: https://www.congress.gov/congressional-report/113th-congress/senate-report/247/1.

[129] Report of the House Committee on Science, Space and Technology, Report on HR 2996, September 15, 2014, Section IV (Hearing Summary).

and Industrial Base office and its Mantech program, and sponsored by particular military services, and led by the Department of Energy through its Energy Efficiency and Renewable Energy office. The approach in the bill of NIST leadership for new institutes didn't really match the reality of what was already evolving. But the bill amounted to an important Congressional validation of the manufacturing institute model. It also called for a network of institutes, for development of an ongoing strategy and gave NIST important authority — which it did not have until this — to sponsor its own institutes when it could round up sufficient appropriations to do so. In the Budget Agreement in 2015, Congress provided NIST with the initial funding to launch one or more institutes, and a competition promptly got underway. A notoriously divided Congress had actually come together on a bipartisan basis to bless advanced manufacturing and a creative model of manufacturing innovation institutes to get there.

2.8 Summary

What can we make of all these pieces of a manufacturing puzzle that fell into place in the half decade between 2010 and 2015? It was a period of creative ferment for manufacturing. First, a series of articles and reports began to plow the ground for new policies to grow from. An ad campaign from General Electric touting its "onshoring" of appliance jobs around a "Made in the USA" theme helped. Next, the White House, with leadership from the President and his staff on the National Economic Council and the Office of Science and Technology Policy, coalesced around an innovation-based strategy to try to transform American manufacturing. Innovation policy was not new to government — most understood it had helped create the recent IT and biotech technology waves. But it was new for government to apply innovation policy to manufacturing. This was not the only fix needed, but it became central.

Meanwhile, the Production in the Innovation Economy (PIE) study was evolving at MIT, informing the policy actors of its findings as they were developed. PIE's in-depth look at manufacturing created a narrative about a thinned-out ecosystem of production that was jeopardizing not simply manufacturing but the innovation system itself, a crucial U.S. comparative advantage. It saw production as a key link in the innovation system — a weakened link. The AMP1.0 report's central contribution was to move the innovation narrative for manufacturing into policy by advocating the advanced manufacturing institute concept, which the Administration jumped on and began to implement well before the report was released in 2012.

The AMP2.0 report of 2014 fleshed out the innovation policy proposals, urging a public-private technology strategy around advanced manufacturing technologies and processes, R&D and new institutes organized around the strategy, a network of institutes for shared learning and best practices, and new workforce training models. AMP1.0 had suggested a number of these points but AMP2.0 fleshed these ideas out. The National Academy of Engineering's 2015 report added a larger frame — advanced manufacturing was going to be at the core of the future economy, merging services and production for new "value" models, and requiring broader education reforms to prepare the workforce to both bring it about and work productively within it. Finally, Congress' Revitalizing American Manufacturing and Innovation (RAMI) legislation added a Congressional blessing to the manufacturing institutes and, in effect, the whole project, creating a reasonable possibility that it could survive the political turmoil of the times.

3

The Advanced Manufacturing Innovation Institute Model

A key goal of the "Manufacturing Innovation Institutes" was to fill a gap in the U.S. innovation system for manufacturing: to create a space where advanced manufacturing could evolve through a collaboration between industry (both small and large firms), universities, and government. According to the director of NIST's Advanced Manufacturing Office and his government colleagues, the aim for the new National Network for Manufacturing Innovation (NNMI) was to,

> create an effective manufacturing research infrastructure for U.S. industry and academia to solve industry-relevant problems. The NNMI will consist of linked Institutes for Manufacturing Innovation (IMIs) with common goals, but unique concentrations. In an IMI, industry, academia, and government partners leverage existing resources, collaborate, and co-invest to nurture manufacturing innovation and accelerate commercialization. As sustainable manufacturing innovation hubs, IMIs will create, showcase, and deploy new capabilities, new products, and new processes that can impact commercial production. They will build workforce skills at all levels and enhance manufacturing capabilities in

> large and small companies. Institutes will draw together the best talents and capabilities from all the partners to build the proving grounds where innovations flourish and to help advance American domestic manufacturing.[130]

The federal award to each new institute over a 5-year period was to range from $70 to $120m, with the consortium of firms, universities, and local government backing each new Institute contributing at least a one-to-one match to leverage the federal government's investment.

3.1 The complex institute and network model

This was a very complex model for the new institutes. The government's role here wasn't to make a single research award to a "principal investigator" to undertake a science research project according a carefully delineated plan in the grant application — the usual government R&D role. Instead it had to relate to a large, complex mix of industrial firms that varied widely across numerous sectors and sizes, along with academic institutions that ranged from major research universities to regional universities to community colleges. And state governments were to be co-investors, with industry and the federal government, supporting particular related projects, so involved as well. With the exception of Sematech, the federal government had not tried anything like this before.

The participant mix for the Institutes was complex and so was their task list[131]:

1. "create" new production technologies, processes and "capabilities";
2. serve as "proving grounds" to test new technologies and related processes;

[130] Michael Molnar (NIST), Steve Linder (DOD), and Mark Shuart (DOE) (2016). Building a New Partnership — The National Network for Manufacturing Innovation, presentation to the National Council for Advanced Manufacturing (NACFAM), April 29, 7.

[131] See generally. Molnar, *et al.*, Building a New Partnership, 20 ("Acclelerating Discovery to Application to Production").

3. support efforts to "deploy" for new production innovations; and
4. "build workforce skills" to enhance production and processes for the emerging technologies.

The overall goal was to enable domestic manufacturing around the focused innovation area of each Institute to "flourish."

There was also to be a "network" of manufacturing institutes layered above the individual Institutes, to enable cross-collaborations and exchanges of best practices. As advanced manufacturing took hold, a small- or mid-sized manufacturer likely wouldn't just have just a 3D Printing problem, it would have a range of future production challenges across a number of new fields, from digital production technologies to using advanced materials. Production was also anchored in regions which tended to focus on particular production areas — cars in the Midwest, aerospace on the coasts, pharmaceuticals in the Northeast, and so on. While the institutes needed to have regional depth, they also had to translate their advances and know-how to manufacturers nationally. The institutes and their NNMI "network" had a major overarching assignment which was both regional and national.

The task for the new institutes and their network may not have been as complex as NASA's "Moonshot" but it was undoubtably highly ambitious. While the Apollo Moonshot was a government contract model — the government would simply pay to get there — the manufacturing Institutes to succeed had to be intensely collaborative across many actors, as well as jointly funded from a number of sources, with all the challenging technology advances stood up in an aging industrial sector that had been in steep decline. And somehow the new institutes were to be self-sustaining within 5 years without further federal support. This was a very complex organizational model.

3.2 The agencies step up to the plate

The Institutes did not pop up from on a highly organized, well-timed governmental assembly line. They were scraped together. As set out in the previous section, this was a period of deep ideological divide politically. Rather than wait for a divided Congress to authorize and fund a new program, which could mean waiting forever, the Obama Administration cajoled the agencies to get started on setting up institutes, using existing authority with funding scavenged from other areas. As a result, the agencies were in charge, and picked focus areas for manufacturing institutes that matched their missions. The AMP1.0 report had assumed that the institute focus areas would come from a bottom-up model, with industry playing the lead role in selecting focus areas. Instead, there was top-down — the agencies decided the focus areas based on their own missions, not an overall manufacturing mission. This wasn't all bad. Since the agencies selected and were in charge, they got focus areas they cared about that would serve their needs, potentially making this a more sustainable project over time, not a White House imposed mandate. Over time, this tended to sort itself out. The top areas that industry had identified as its priorities in the AMP1.0 and AMP2.0 reports turned out to mesh with agency missions. And the agency lead tended to enhance agency buy-in for the new program.

In the absence of a central, authorized program with coordinated, fixed funding, the executive branch agencies led; legislation didn't come until 2014, and the first institute was created in 2012. So the cross agency governance model immediately became complicated. Someone once defined federal cross agency collaboration as a contradiction in terms. This made the White House coordination role especially complicated, requiring a high degree of creativity, diplomacy and cooperativeness. Fortunately, the National Economic Council (NEC) leadership and staff were strong; there was support at the Cabinet level, and NEC could also deftly apply occasional Presidential intervention from a committed President.

The Department of Defense (DOD) had the most money so stood up the most institutes. It was not notorious for playing well with others; it tended historically to guard its priority national security mission and was not prone to compromising it with others. DOD long had a manufacturing technology mission, imbedded in its longstanding Defense Production Act[132] authority. Over the course of two World Wars it

[132] The Defense Production Act, 50 U.S.C.A. 2061, et seq., P.L. 81-774, dates from

had mobilized and reorganized much of the nation's economy to meet wartime needs, and many of those practices continued during the four plus decades of the Cold War. It had a rich history of "industrial policy" — that is, governmental economic interventions to assure technology and industrial outcomes — which no other agency dared politically to consider. DOD's "Mantech" program, based in the Office of the Secretary with branches in each of the military services, dated back decades, but had not been a significant defense program for many years. For example, for many years, a major Mantech mission had been to assure continued production of obsolete technologies used in over-aged equipment, for example, for vacuum tubes for aging radar sets.

Suddenly Mantech had a national mission, a "Presidential" in Defense parlance, directed by the President himself.[133] But it did not get a big new influx of funding because of the Congressional impasse over all new programs, so had to rely on an existing small staff and stretch existing budgets. Mantech's role was complicated by the reality that there were separate programs, with separate service priorities, reporting systems and needs, in the military services, not simply in the Secretary of Defense's office, which also had to be brought aboard.

One early development helped create interest in DOD for all this. When the proposals came in for the first manufacturing Institute on 3D Printing (or "Additive Manufacturing") — which all the services were very interested in — the match proposed by industry and states to Mantech funds was not modest, the institute proponents were ready to significantly "overmatch." This was eye-opening to Mantech staff — they could get major additional leverage on their investments. This opportunity for leverage, and to work on major new technology thrusts at a larger scale had not happened in Mantech in recent memory — suddenly they had a force multiplier.

The story at the Department of Energy (DOE) was different. The Department of Energy's Energy Efficiency and Renewable Energy (EERE) office worked on applied energy technologies with industry. It had a

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1950 as a Cold War and Korean War industrial mobilization tool.

[133] Aside from Mantech, DARPA Deputy Director Ken Gabriel was involved in the AMP1.0 effort, and DARPA Program Manager Mick Maher led a sizable portfolio of DARPA advanced manufacturing R&D and advised on the AMP reports.

long standing industrial efficiency program; industry had long been a major energy user and there were major clean energy gains, as well as potential savings to industry, from conservation and more efficient energy technologies. Importantly, in the absence of carbon pricing legislation in the U.S., new energy technologies would have to compete in price with established fossil technologies. Unless production costs could be brought down for these new technologies, they would never get to the marketplace. Advanced manufacturing therefore became an important EERE priority.

The story at the Commerce Department's NIST was different, too. Despite NISTs' strong involvement in AMP, and coordinating role among agencies, NIST was unable to shake loose Congressional funding until FY2016 to establish a manufacturing institute. When it did, it avoided at "top-down" agency selection of the institute focus area, seeking "bottom-up" focus area proposals from industry and university consortia. NIST also played a supportive role in obtaining Congressional approval of the 2014 advanced manufacturing legislation, which focused on NIST.

While NSF was the fourth major federal government actor, its basic research focus limited its ability to stand up manufacturing institutes. However, NSF's Engineering Division was very involved in the AMP reports and led NSF programs on advanced manufacturing research, including a number of Engineering Research Centers focused on manufacturing technologies. In addition, NSF's Advanced Technology Education (ATE) programs emphasized advanced manufacturing education and training in community colleges.

3.3 The program centerpiece: manufacturing institutes

The Obama Administration had pledged to form 15 manufacturing institutes by the end of the administration and had selected 14 by the time it left office, which are the centerpiece of the advanced manufacturing program. The group of institutes was originally labeled the National Network for Manufacturing Innovation (NNMI) but renamed Manufacturing USA in 2016. The range of their technical focus is of particular note; while Germany's Industrie 4.0 advanced manufacturing initiative emphasizes the internet of things, that is only one of the areas featured by the U.S. institutes. The institutes' wide technical embrace is suggestive of how far-reaching an advanced manufacturing revolution could be. This technical breadth may be what is most interesting about the U.S. approach, and deserves enumeration.

America Makes — National Additive Manufacturing Institute[134] — was the first manufacturing institute, announced in 2012, headquartered in Youngstown, Ohio, with a regional base in the Cleveland, Ohio to Pittsburg, Pennsylvania corridor, focused on 3D Printing technologies, also known as additive manufacturing. Additive manufacturing is a process of joining materials to make devices using three-dimensional computer model data, layer upon layer, compared to subtractive manufacturing which relies on traditional machine tools. It typically uses powder forms of metals or polymers, and even tissue. A competitive advantage of additive manufacturing is that parts can be fabricated as soon as the three-dimensional digital description of the part is entered into the printer, potentially creating a new market for on-demand, mass customized manufacturing. Importantly, these processes minimize material waste and tooling requirements, as well as potentially compressing the elements and stages in the supply chain. These enable entirely new components and structures that cannot be cost effectively produced from conventional manufacturing processes such as casting, molding, and forging.

Additive manufacturing could prove able to compete directly with mass production techniques if the speed of layering is significantly improved. Meanwhile, it will be employed to replace parts on site, to reduce the need for parts inventories, and to create much more complex and intricate components beyond the reach of current processes. It could be a key enabler of mass customization — the ability to create small lots of personally designed products at the cost of mass produced goods. This could localize production, enabling scale down of production for the first time despite the past history of production of ever greater scale up. It could be a breakthrough production technology for the twenty-first century.

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[134] Information in this section drawn from America Makes website, Available at: www.americamakes.us/about/overview

Selected after a highly competitive process, state and industry funds from the America Makes consortium matched a $50m federal award through the Air Force Mantech program for an approximately $100m program. America Makes' mission is to accelerate additive manufacturing and its widespread adoption by bridging the technology gap between research and technology development and deployment. It roster of participants includes 53 companies, both small and large, especially in the Midwest but stretching across the nation. These include firms organized around 3D printing technologies, like 3D Systems, major aerospace firms, like Boeing, Lockheed Martin, United Technologies and Northrup Grumman, where 3D printing may prove transformative, medical technology firms like Johnson and Johnson and a large number of small production firms. The 36 universities, range from major research universities to community colleges. There are over 20 other organizations participating, from state agencies to industry associations.

The consortia has developed a detailed technology roadmap organized around design, materials, process, and supply chain adoption. There is also an additive materials "genome" effort to enable step change improvements for the time and cost required to design, develop, and qualify new materials for additive manufacturing, using novel computational methods, such as physics-based and model-assisted material property prediction tools. The institute has worked to create an infrastructure for the sharing of additive manufacturing ideas and research, on development and evaluation of additive manufacturing technologies, on engaging with educational institutions and manufacturers for training in the new field, and linking small- and mid-sized firms with resources to enable them to use additive manufacturing. A major emphasis of American Makes has been on R&D and technology development projects, such as a joint university–industry effort between the University of Texas at El Paso with Lockheed Martin. Boeing, Honeywell, and Draper Lab in Cambridge to embed a suite of electronics manufacturing technologies into 3D printing processes, such as precision machining, thermoplastic extrusion, direct foil embedding, wire embedding, and wire management. There are over 30 other comparable joint university–industry development projects. While information and IP sharing among the highly competitive larger aerospace firms proved complex, which affected technology development, the institute has played a significant role in convening the new 3D printing community, helping them learn which researchers and firms were working on which advances. It also has been promoting a significantly faster and less costly process for DOD to approve new aerospace parts through simulation and modeling.

America Makes is the most mature institute, but the pattern of activities set by American Makes is comparable at other manufacturing institutes, with a total of eight institutes sponsored by DOD, five by DOE and one by NIST as of the beginning of 2017.[135] The thirteen other institutes are summarized in Table 3.1.

Table 3.1: The Manufacturing Institutes

Institution	Description
DMDII — Digital Manufacturing and Design Innovation Institute	Formed in 2014 with a hub location in Chicago. Digital manufacturing involves the use of integrated, computer-based systems, including simulation, three-dimensional visualization, analytics and collaboration tools, to create simultaneous product and manufacturing process definitions. Design innovation is the ability to apply these technologies, tools, and products to re-imagine the entire manufacturing process from end to end. DMDII has 201 members, including major firms from a wide range of sectors, numerous smaller firms and 11 universities in its first tier. Its $70 million in DOD Army Mantech funding matched with industry and state matching of $248 million. Its mission is digital manufacturing to lower product design costs by fostering deep connections between suppliers, to lower production costs and reduce capital requirements and reduce capital requirements through better linkages from end to end of the product lifecycle, to cut time to market through faster iterations, to develop and implement innovations in digital design digital factories, and digital supply chains, and to develop both new products and improve legacy products.

[135]Descriptions of the institutes drawn from their websites; descriptions of the manufacturing technologies they aim to advance are drawn from, National Science and Technology Council (NSTC), Subcommittee on Advanced Manufacturing (White House, Office of Science and Technology Policy, Washington, DC: April 2016), pp. 36–39.

Table 3.1: *Continued*

Institution	Description
Lift — Lightweight and Modern Metals	Founded in 2014 with its hub in Detroit, Michigan, extending regionally through the I-75 corridor, including locations in Michigan, Ohio, Indiana, Tennessee, and Kentucky. Lightweight and advanced metals offer major performance enhancements and greater energy efficiency that can improve the performance of many systems in defense, energy, transportation, and general engineered products. Lightweight metals have applications in wind turbines, medical technology, pressure vessels, and alternative energy sources. Lift has 78 members, from a wide range of firms, small and large, including metals and aerospace firms and automotive suppliers, and 17 universities, who matched $70 million in federal funds from the Navy Mantech program and the Office of Naval Research. Its mission is to innovate in lightweight high-performing metals production and enable the resulting new technologies to expand into industrial base application. It is working on projects in melting, thermo-mechanical processes, powder processing, agile low-cost tooling, coatings, and joining, with widespread applications in automotive, aerospace, ship building, railroads, fabrication, and other sectors.
Power America — Next Generation Power Electronics	Founded in 2015 to develop wide bandgap semiconductor technology. This could enable a major increase in the energy efficiency and reliability of power electronics through smaller, faster and more efficient semiconductor materials than silicon-based technologies. These are able to operate at higher temperatures, can block higher voltages, switch faster with less power loss, are potentially more reliable and carry substantial system- level benefits. These capabilities make it possible to reduce weight, volume, and life-cycle costs in a wide range of power applications. They will have a great array of applications including in industrial motor systems, consumer electronics and data centers, and in conversion of renewable energy sources (solar and wind). If widespread adoption of these technologies is accomplished in even a limited number of applications, then very significant of electrical power savings, including in industrial production, could be achieved annually. The higher cost of wide bandgap technologies is expected to decline as higher production levels are achieved. Power America was supported by a $70 million award from the Department of Energy's Energy Efficiency and Renewable Energy Advanced Manufacturing Office, which was matched by

Table 3.1: *Continued*

Institution	Description
	$70 million. It includes 17 industry partners, 5 universities, and 3 laboratories, and is based in Raleigh, North Carolina.
IACMI — Advanced Composites Manufacturing Innovation	Formed in 2015 to develop and demonstrate technologies that will make advanced fiber-reinforced polymer composites at 50% lower cost, using 75% less energy, with 95% or more reuse or recycling of the material within a decade. It is headquartered in Knoxville, Tennessee. Lightweight, high-strength, and high-stiffness composite materials have been identified as a key technology that can cut across sectors, with the potential to achieve an energy efficient transportation sector, enable efficient power generation, and increase renewable power production. The range of light weight, high-strength composite applications is vast, from autos, to aircraft, to wind blades. The challenges to accomplishing this include high costs, low production speeds (long cycle times), high manufacturing energy intensity for composite materials, recyclability, and a need to improve design, modeling and inspection tools and meet regulatory requirements. Technology acceleration and manufacturing research is needed to meet production cost and performance targets, from constituent materials production to final composite structure fabrication. IACMI's hub is in Knoxville, Tennessee and was supported by a $70 million award from the Department of Energy's Energy Efficiency and Renewable Energy Advanced Manufacturing Office, which was matched by $180 million. It includes 57 companies, 15 universities and laboratories, and 14 other kinds of entities.
AIM Photonics — American Institute for Manufacturing Integrated Photonics	Formed in 2015 with hub locations in Albany and Rochester, New York. Its goal is to foster ultra high-speed transmission of signals for communications, new high performance computing, and sensors and imaging enabling health sector advances. Integrated photonics requires the integration of multiple photonic and electronic devices (for example, lasers, detectors, waveguides and passive structures, modulators, electronic controls, and optical inter- connects) on a single substrate with nanoscale features. The benefits of integrating these components could be very significant: simplified system design, improved system performance, reduced component space and power consumption, and improved performance and reliability, which will enable important new capabilities and functionality with lower costs. The current photonics manufacturing sector is a collection of interrelated but largely independent

Table 3.1: *Continued*

Institution	Description
	businesses, organizations, and activities — it a potential ecosystem, but lacks the organization and aggregated market strength needed to efficiently innovate manufacturing technologies for cost-effective design, fabrication, testing, assembly, and packaging of integrated photonic devices. Aim Photonics is to focus on building an end to end photonics ecosystem including domestic foundries, integrated design tools, and production automated packaging, assembly and testing, as well work- force development. The federal award was matched by over $200 million in state and industry support.
NextFlex — Flexible Hybrid Electronics	Formed in 2015 with a hub in San Jose, California in Silicon Valley. Its goal is highly tailorable devices on flexible, stretchable substrates that combine thin CMOS components with new components added through printing processes. These represent flexible and hybrid features for circuits, communications, sensing, and power sources that are unlike current silicon processors. Flexible hybrid electronics would preserve the full operation of traditional electronic circuits, but in novel flexible architectures and forms that, allow for bending, stretching, or folding. These highly functional devices could be part of curved, irregular, and stretched objects. They could expand traditional electronic packaging to new forms, enabling new classes of commercial and defense technologies. Examples include medical devices and sensors, sensors to monitor structural or vehicle performance, sensors interoperating through the Internet or as sensor clusters to monitor physical positions, wearable performance or information devices, robotics, human–robotic interface devices, and lightweight human-portable electronic systems. This includes applications in wearable technologies, new information devices and sensors, medical prosthetics and sensors, and for unattended and mobile sensors. The DOD Mantech award was for $75 million, with an industry and state and local government cost share of $96 million. It includes 22 member companies ranging from semiconductor firms and their suppliers, to aerospace, to life science, 17 universities, and state and regional organizations.
AFFOA — Advanced Functional Fabrics of America	This institute was announced in April 2016 and is starting up. It is headquartered in Cambridge, Massachusetts, and plans a series of regional nodes. Scientific advances have enabled fibers and textiles with extraordinary properties including strength, flame resistance, and electrical conductivity – they could

Table 3.1: *Continued*

Institution	Description
	become electronic components. This new range of fibers and textiles are composed of specialty fabrics, industrial fabrics, electronic textiles, and other forms of advanced textiles. They could provide communication, lighting, cooling, health monitoring, battery storage, and many more new functions. These technical textiles are built upon a foundation of synthetic, natural fiber blends and multi-material fibers that have a wide range of applications, in commercial and defense sectors, which go far beyond traditional wearable fabrics. It joins $75 million in DOD Mantech funds with some $240 million in industry and state matching support. It aims to serve as a public–private partnership to support an end-to-end innovation ecosystem in the U.S. for revolutionary fibers and textiles manufacturing and leverage domestic manufacturing facilities to develop and scale-up manufacturing processes. It plans to provide rapid product realization opportunities, based on robust design and simulation tools, pilot production facilities, a collaborative infrastructure with suppliers, as well as workforce development opportunities. The institute wants to effect a revolution in fiber and textiles, incorporating IT advances and integrating intelligent devices with fibers.
Smart Manufacturing Innovation Institute	This institute was announced in June 2016* and is now beginning a start up phase and setting membership. It is headquartered in Los Angeles. Smart manufacturing can be characterized as the convergence of information and communications technologies with manufacturing processes, to allow a new level of real-time control of energy, productivity, and costs across factories and companies. It was identified by the AMP2.0 report as a high-priority manufacturing technology area in need of Federal investment. Tying advanced sensors, controls, information technology processes and platforms, and advanced energy and production management systems, smart manufacturing has the potential to drive energy efficiency and manufacturing capability in a wide range of industrial sectors. Of the $140 million Smart Manufacturing institute budget, $70 million over 5 years is already-appropriated federal funding from the Energy Department's Advanced Manufacturing Office and the remain- der is in matching funds. The Smart institute will focus on integrating information technology into the manufacturing process through devices like smart sensors that reduce energy use. For example, the institute plans to partner

Table 3.1: *Continued*

Institution	Description
	with DOE's Institute for Advanced Composites Manufacturing Innovation to test advanced sensors in the production of carbon fiber. The Smart institute expects to partner with more than 200 companies, universities, national labs, and nonprofits. Microsoft Corp., Alcoa Inc., Corning Inc., ExxonMobil, Google, the National Renewable Energy Laboratory, and numerous smaller firms are among the partners. The institute plans to launch five centers, focusing on technology development and transfer and workforce training, in regions around the country headed by universities and labs in California (UCLA), Texas (Texas A&M), North Carolina (N.C. State University) and New York (Rensselaer Polytechnic Institute), and the Washington (Pacific Northwest National Laboratory).
RAPID — Rapid Advancement in Process Intensification Deployment Institute	On December 9, 2016, the EERE office announced that a consortium led by the American Institute of Chemical Engineers would form the fourth institute sponsored by the Department of Energy, calling it a critical step in the Administration's effort to double U.S. energy productivity by 2030. Leveraging up to $70 million in federal funding with a higher level of private cost-share commitments from over 130 partners, RAPID will focus on developing breakthrough technologies to boost domestic energy productivity and energy efficiency by 20 percent in five years through manufacturing processes in industries such oil and gas, pulp and paper and various domestic chemical manufacturers. Traditional chemical manufacturing relies on large-scale, energy-intensive processing. The new institute will leverage approaches to modular chemical process intensification — including combining multiple, complex processes such as mixing, reaction, and separation into single steps — with the goal of improving energy productivity and efficiency, cutting operating costs, and reducing waste. Process breakthroughs can dramatically shrink the footprint of equipment needed on a factory floor or eliminate waste by using the raw input materials more efficiently. For example, by simplifying and shrinking the process, this approach could enable natural gas refining directly at the wellhead, saving up to half of the energy lost in the ethanol cracking process today. In the chemical industry alone, these technologies could save more than $9 billion annually in U.S. processing costs.

Table 3.1: *Continued*

Institution	Description
NIIMBL — National Institute for Innovation in Manufacturing Biopharmaceuticals	On December 16, 2016 the Secretary of Commerce announced an award of $70 million to the new NIIMBL institute. This is the first institute with a focus area proposed by industry and the first funded by the Department of Commerce. The agency developed an “open topic” approach, where a new institute could cover any area not currently targeted by an existing institute. NIST had launched an “Industry-proposed Institutes Competition” as a way to allow a bottom-up topic selection process to allow industry-led consortia to propose technology areas seen as critical by regional manufacturers. NIMBL was the result. NIIMBL will aim to transform the production process for biopharmaceutical products. Overall, it will seek to advance U.S. leadership in the biopharma industry, improve medical treatments and ensure a qualified workforce by developing new training programs matched to specific biopharma skill needs. The announcement was made at the University of Delaware, which will coordinate the institute in partnership with Commerce’s NIST. In addition to the federal funding, the new institute is matched by an initial private investment of $129 million from a consortium of 150 companies, educational institutions, research centers, coordinating bodies, non-profits and Manufacturing Extension Partnerships across the country.
ARMI — Advanced Regenerative Manufacturing Institute	On December 21, 2016, the Department of Defense announced ARMI with an $80 million, five-year award to establish the biomanufacturing consortium, which will be headquartered in the Manchester, New Hampshire. The institute — led by a coalition that includes DEKA R&D Corporation, the University of New Hampshire and Dartmouth-Hitchcock health care system — is tasked with developing and bio-manufacturing tissues and organs that can be transplanted into patients. It would pioneer next-generation manufacturing techniques for repairing and replacing cells and tissues. If successful, such technology could lead to the ability to manufacture new skin or life-saving organs for the many Americans stuck on transplant waiting lists. The institute will focus on solving the cross-cutting manufacturing challenges that stand in the way of producing new synthetic tissues and organs – such as improving the availability, reproducibility, accessibility, and standardization of manufacturing materials, technologies and processes. Collaborations are expected across

Table 3.1: *Continued*

Institution	Description
	multiple disciplines, from 3D bio-printing, cell science and process design, to automated pharmaceutical screening methods, to the supply chain expertise needed to rapidly produce and transport these live-saving materials.
REMADE — Reducing Embodied Energy and Decreasing Emissions in Materials Manufacturing	Formed by DOE, was selected on January 4, 2017, to be headquartered in Rochester, New York and led by the Sustainable Manufacturing Innovation Alliance. REMADE will leverage up to $70 million in federal funding, subject to appropriations, and will be matched by $70 million in private cost-share commitments from over 100 partners. REMADE will focus on driving down the cost of technologies needed to reuse, recycle and remanufacture materials such as metals, fibers, polymers and electronic waste and aims to achieve a 50 percent improvement in overall energy efficiency by 2027. These efficiency measures, DOE indicated, could save billions in energy costs and improve U.S. economic competitiveness through innovative new manufacturing techniques. It would aim to reduce the total lifetime energy use of manufactured materials via reuse and recycling. The institute will focus on reducing the total lifetime use of energy in manufactured materials by developing new cradle-to-cradle technologies for the reuse, recycling, and remanufacturing of manmade materials. U.S. manufacturing consumes nearly a third of the nation's total energy use annually, with much of that energy embodied in the physical products made in manufacturing. New technologies to better repurpose these materials could save U.S. manufacturers and the nation up to 1.6 quadrillion BTU of energy annually, equivalent to 280 million barrels of oil, or a month's worth of that nation's oil imports.
ARM — Advanced Robotics Manufacturing Institute	DOD proposed this new manufacturing institute to focus on building U.S. leadership in smart collaborative robotics, where advanced robots work alongside humans seamlessly, safely, and intuitively to do the heavy lifting on an assembly line or handle with precision, intricate or dangerous tasks. DOD indicated assistive robotics has the potential to change a broad swath of manufacturing sectors, from defense and space to automotive and health, enabling the reliable and efficient production of high-quality, customized products. ARM, the 14^{th} and last

Table 3.1: *Continued*

Institution	Description
	Manufacturing USA Institute to be announced by the Obama Administration was named on January 13, 2017. It will be headquartered in Pittsburgh, and the proposal group was convened by Carnegie Mellon University. The institute will bring together a very large team, including 84 industry partners, 35 universities and 40 other groups in 31 states. Federal funds plus industry and state cost sharing will total some $250 million; the federal commitment is for $80 million. Clemson University's Center for Workforce Development will lead the new institute's workforce training programs. DOD described in its announcement statement the need for the new institute: The use of robotics is already present in manufacturing environments, but today's robots are typically expensive, singularly purposed, challenging to reprogram, and require isolation from humans for safety. Robotics are increasingly necessary to achieve the level of precision required for defense and other industrial manufacturing needs, but the capital cost and complexity of use often limits small to mid-size manufacturers from utilizing the technology. The ARM Institute's mission therefore is to create and then deploy robotic technology by integrating the diverse collection of industry practices and institutional knowledge across many disciplines – sensor technologies, end-effector development, software and artificial intelligence, materials science, human and machine behavior modeling, and quality assurance – to realize the promises of a robust manufacturing innovation ecosystem. Technologies ripe for significant evolution within the ARM Institute include, but are not limited to, collaborative robotics, robot control (learning, adaptation, and repurposing), dexterous manipulation, autonomous navigation and mobility, perception and sensing, and testing, verification, and validation.** DOD characterized the current domestic capabilities in manufacturing robotics technology as "fragmented," citing a need for better organization and collaboration to better position the U.S. for the global competition in this sector. An additional Department of Commerce institute, bringing the total to fifteen, could be developed since NIST's topic selection process had been completed, but the final selection process was subject to the availability of FY2017 funds.

Table 3.1: *Continued*

*Source: White House, Office of the Press Secretary, Fact Sheet; President Obama Announces Winner of New Smart Manufacturing Innovation Institute, June 20, 2016, Available at: https://obamawhitehouse.archives.gov/the-press-office/2016/06/20/fact-sheet-president-obama-announces-winner-new-smart-manufacturing
**Source: Department of Defense, DOD Announces Award of New Advanced Robotics Manufacturing (ARM) Innovation Hub in Pittsburgh, Pennsylvania, Release No. NR-009-17, Jan. 13, 2016, https://www.defense.gov/News/News-Releases/News-Release-View/Article/1049127/dod-announces-award-of-new-advanced-robotics-manufacturing-arm-innovation-hub-i

Their technology focus areas include: digital production and design, lightweight metals, power electronics, photonics, flexible hybrid electronics, advanced composites, revolutionary fibers, new chemical processing, biomanufacturing, smart manufacturing, regenerative manufacturing, recycled and remade products, and assistive robotics.

The institutes have already been hard at work. The administration has proffered a series of examples on what the institutes have been accomplishing[136]:

- To help anchor production of new semiconductor technologies in the U.S. and accelerate the commercialization of advanced power electronics, in March, the Power America Manufacturing Innovation Institute successfully partnered with X-FAB in Lubbock, TX, to upgrade a $100 million foundry to produce cost-competitive, next-generation wide bandgap semiconductors, enabling new business opportunities to sustain hundreds of jobs.
- Using next-generation metals manufacturing techniques, Lightweight Innovations for Tomorrow (LIFT), the Detroit institute focused on lightweight metals, has successfully demonstrated how to reduce the weight of core metal parts found in cars and trucks by 40%, potentially improving fuel efficiency and saving consumers fuel costs.

[136] White House, Obama Announces Winner of New Smart Manufacturing Innovation Institute, June 20, 2016, p. 4.

- In addition, LIFT has experimented in a developing a series of strong workforce training models. For example, it introduced curriculum reaching workers in over 20 states to train on the use of lightweight metals. This past summer, 38 companies hosted students in paid manufacturing internships in partnership with LIFT.
- America Makes has attracted hundreds of millions of dollars in new manufacturing investment to its region, including helping to attract GE's new $32 million global 3D printing hub and spurring Alcoa to invest $60 million in its New Kensington, PA. facilities, both of which will benefit from proximity to America Makes and its expertise in 3D printing with metal powders.
- In addition, America Makes, with Deloitte and other partners, has created a free online course on the fundamentals of 3D printing for businesses. Over the last year, over 14,000 business leaders have taken this course to learn what 3D printing can do for their businesses.

Deloitte, commissioned by DOD Mantech, undertoom an independent assessment of the institute model in 2016. Its overall findings, released in a January 2017 report, are quite positive. It found that adoption of advanced manufacturing was critical for progress in the overall domestic economy to improve productivity growth and the trade imbalance, and for job creation. In this regard, it found that the public-private partnership model of the institutes can create collaborations to improve R&D investment in manufacturing, overcome problems of collective action in the sector, reduce barriers to innovation, enable better access to intellectual property, and cut risk and cost through shared asset access.[137] Concerning technology facilitation, it found that institutes can play a significant role in de-risking investments in manufacturing R&D, particularly given the pattern of uneven investment between firms of

[137] Deloitte, Manufacturing USA, A Third-Party Evaluation of Program Design and Progress (Washington, DC Deloitte, report Jan. 2917), 8–21, https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-mfg-manufacturing-USA-program-and-process.pdf

different size and in different sectors. Shared advanced equipment, R&D pooling, technology roadmapping and knowledge-sharing enabled by the institutes could create significant benefits from industry participants unachievable on their own.

Regarding workforce training, Deloitte found that the institute model could mitigate the talent gap industrial firms now face as they move into advanced manufacturing. Institute workforce programs included assessments of workforce supply and demand, employee credentialing and certification, and technology focused training and apprenticeship programs. It also found significant progress in creating improved ecosystems for production. The portfolio of institutes, both in the range of technology focus areas and geographical reach, was a strength of the system. Their high levels of membership from different sizes and types of firms was a signal of the initial success of the model. The institutes were also found to be playing a role in strengthening regional economic clusters key to regional growth. The Deloitte report also made a number of program recommendations, some of which complement the list of institute challenges that appears below in 3.5. However, the Deloitte review amounted to an early certification from an independent expert source that the institute model was on the right track.

3.4 Manufacturing institute case study

To get a better idea of what is evolving in the institutes, let's look at an institute in more depth.

IACMI, the Institute of Advanced Composites Manufacturing Innovation, is headquartered in Knoxville, T.[138] Its objective is to develop and demonstrate innovative technologies that will, within 10 years, make advanced fiber-reinforced polymer composites:

- At 50% lower cost
- Using 75% less energy
- And reuse or recycle more than 95% of the material.

[138]This section is draw from information prepared by NIST's Advanced Manufacturing National Program Office, slide presentation, July 2016.

Clear and Unique Institute Focus: Institutes including IACMI are designed to address a critical industry need with a clear and unique focus. The opportunity IACMI is attempting to meet is the development of lightweight composites that offer significant benefits to energy efficiency and renewable power generation compared to current materials. This will require deployment of advanced technologies to make composites at significantly lower cost, faster, using less energy, and can be readily recycled. Although there are numerous technical and institutional barriers, the field arguably offers significant opportunities for U.S. industry.

Consortium Approach: IACMI, like the other institutes, is based on a consortium across industry, universities, and government. It includes large firms, such as Dow, Ford, GE, Dupont, and Boeing, as well as smaller firms, totaling 57, that reach across chemical, automotive, and aerospace. University participants include the University of Tennessee, Penn State, University of Illinois, and Purdue — 15 universities, labs and colleges overall. It also includes states and economic development entities.

The Core Idea: The institute aims to provide access to major resources and a partnership across industry and universities to develop new low-cost, high-speed, and efficient manufacturing and recycling process technologies that will promote widespread use of advanced fiber-reinforced polymer composites. The institute seeks to link leading industrial manufacturers, material suppliers, software developers, and government and academic experts. The focus will be on dramatically lowering the overall manufacturing costs of advanced composites, cutting the energy required to form them and ensuring they are recyclable.

The Industry Value Proposition: IACMI intends to offer four basic services that will be of interest to its industry partners:

- *Access to Shared RD&D Resources*: provide access to equipment, from lab level to full-scale production level, to enable demonstration, testing and to reduce risk for industry investment.

- *Applied R&D*: leverage significant government R&D, plus cost sharing from industry, and academic investments, to create innovative solutions to challenges formed from member input.

- *A Composites Virtual Factory*: access to end-to-end commercial modeling and simulation software for composite designers and manufacturers through a web based platform.

- *Workforce Training*: provide specialized training to prepare the current and future workforce for the latest manufacturing methods and technologies for advanced composites.

Addressing Goals and Challenges: The institute has developed 5- and 10-year technical goals: to reach 25% then 50% lower carbon fiber-reinforced polymer (CFRP) cost; to reach 50% then 75% reduction in CFRP embodied energy requirements; and to reach 80% then 95% composite recyclability into useful products. Its impact goals, with a series of targets to be achieved over time, include enhanced energy productivity; reduced life cycle energy consumption; increased domestic production capacity; job growth, and economic development.

Roadmap and Strategic Investment Plans: IACMI will take a portfolio approach to projects. Its initial projects were identified in proposal to the Department of Energy. These include strengthening infrastructure capacity for materials and processing as well as modeling and simulation, and workforce development in strategic areas. The aim is national benefit, including in automotive, wind, and compressed gas storage sectors.

A second phase involves technology roadmapping, which is driven by IACMI's Chief Technology Officer, and an industry and technology advisory board. It will identify key hurdles to high-impact, large-scale advanced composites manufacturing and prioritize opportunities across the materials and manufacturing supply chain.

A third area requires development of a strategic investment plan, which will be driven by IACMI board and its technical advisory board. The aim will be to change the innovation cycle to enable rapid adoption and scale-up of advanced composites manufacturing. Ongoing open project calls for technology development projects will align with the strategic investment plan and technology roadmap, with an emphasis on projects with high near term impact.

Accelerating Discovery to Application to Production: this will be a general goal, and like other institutes, IACMI will seek to:

- establish a presence, at scale, in the "missing middle" of advanced manufacturing research (TRL 4-7);
- create an Industrial Commons, supporting future manufacturing hubs, with active partnering between stakeholders;
- emphasize and support longer-term investments by industry;
- combine R&D with workforce development and training.

An overarching objective will be new U.S. advanced manufacturing capabilities and industries in composites.

IACMI provides a good look at the structure and aims being adopted by many of the new manufacturing institutes. However, the institute model is flexible, depending on sector to be served, and can significantly vary.

3.5 Challenges faced by the manufacturing institutes

The manufacturing institute program was stood up very rapidly by the Obama Administration at the President's personal direction in response to a policy crisis — a major decline in the aftermath of the 2008–2009 recession in a major U.S. economic sector, manufacturing. Because of Congressional ideological deadlock, the administration was unable to start with a clean slate and design and stand up a completely new program. Instead it had to turn for funding and organization to existing agencies with their existing programs and funding, grafting new programs onto established organizations. So the large foot of a very innovative new program for manufacturing innovation had to be squeezed into a series of existing agency program shoes. Needless to say, it could not be a perfect fit. All said, standing up such a major, new, innovative program in such a short time was a remarkable political accomplishment, requiring dedication from many talented people from both public and private sectors.

Like any new program, some of the experimental pilots will fail and some succeed. Only a few of the new institutes have been around long enough to even start to evaluate their progress against their mission statements, the others are still infants. Transforming a massive economic sector like manufacturing through innovation is not a short term project. Clearly, there has been major progress in getting off the ground some important R&D and technology strategies in a range of important new technology areas that could dramatically affect the future of manufacturing. This is a significant accomplishment. In light of this progress in getting the institutes stood up, it is now appropriate time to "think big" about the overall model, and a new stage of features and improvements that can now be considered. We can now see a new set of challenges that have come up as the institutes have evolved and consider how to meet them, as set out below. Some institutes are already addressing many of these, but others may now want to as well. So this list, developed from discussions with institute leaders, federal agency officials and participating university experts, represents a number of early "lessons learned" that may have more general application. In effect, these can be viewed as potential enhancements to the institute model that could be considered across the network.

Orientation to Technology versus Production: Manufacturing institutes created to date are working in topic areas selected by the agencies in meeting their missions not by the manufacturing sector. They have tended to be more oriented to technology development than other tasks. This is not a surprise. As noted, thirteen of the institutes were created by and through mission R&D agencies and their focus therefore had to be on topics that fit the missions and needs of the agencies (DOD and DOE) under available authorizations and appropriation laws. And the agencies understand and focus primarily on mission R&D, which has carried through to the institutes. These agency missions did not include the future of U.S. manufacturing — at DOD the core mission is national security and at DOE it is new energy technology; the funding from these agencies has to fit and serve those missions. In only one case — the Commerce Department/NIST 2016 "open topic" competition — is industry itself proposing the topic, although the other agencies have invited comments from industry in the selection of focus topics. So, in effect, the advanced manufacturing effort to date has been to stand up interesting and significant new technology areas tied to agency missions, not solely to manufacturing innovation breakthroughs needed by manufacturing sectors. Fortunately, however, as noted below, in many cases these two pathways have converged.

The AMP2.0 report identified core criteria for selecting focus areas for advanced manufacturing institutes ("manufacturing technology areas" — MTAs) which, although not formally applied by the agencies, remain illuminating and relevant:

1. *Industry or market pull*: Does there exist a current "pull" or demand for this MTA by industry? If industry is not yet adopting this MTA, is there a strong perceived pull by the market or consumers?

2. *Cross-cutting*: Does this MTA cut across many sectors (automotive, aerospace, biotech, infrastructure), and across multiple sizes of manufacturers in the supply chain network?

3. *National or economic security*: Does failure to have U.S. competence or dominance in this MTA pose a threat to national security or to economic security? Does lack of U.S. competence severely disadvantage the U.S. competitiveness position of the supply network?

4. *Leveraging U.S. strengths*: Does this MTA leverage an already available workforce and education system, unique infrastructure, or policies?[139]

The application by the AMP2.0 workgroup of this logical set of selection criteria resulted in prioritization of three top technology areas for future institutes: advanced sensing, control, and platforms for manufacturing;

[139] President's Council of Advisors on Science and Technology (PCAST), Advanced Manufacturing Partnership, Report to the President on Accelerating U.S. Advanced Manufacturing), (Advanced Manufacturing Partnership AMP2.0 Report) (Washington, DC: PCAST Oct. 2014), pp. 22–25, 59–60.

visualization, informatics and digital manufacturing; and advanced materials manufacturing. In fact, agency-selected institute topics did result in institutes embracing these general technology areas being formed — the Smart Manufacturing Institute, the Digital Manufacturing and Design Innovation Institute, the Advanced Composites Manufacturing Innovation institute, and the Lightweight and Modern Metals institute. The detailed technology strategy that the AMP2.0 workgroup prepared for each topic proved particularly useful as guidance for the Digital Manufacturing and Design Innovation Institute as it started up. So there has been an effort to apply the results of the AMP2.0 criteria in topic selection. But generally speaking, the areas for institute focus have been more oriented toward new technologies the agencies are seeking for their missions than to overall manufacturing sector needs. Fortunately, as noted, there has been significant overlap, and other technology areas selected could create significant new production opportunities if not necessarily new production processes. If additional institutes are created in the future, agencies could be encouraged to more formally weigh the AMP2.0 criteria in their topic selection process.

Halt in Federal Support after Five Years: Starting with the announcement of the first manufacturing institute, America Makes, there has been a requirement that the institutes be self-sustaining without federal funding support after five years. The Revitalize American Manufacturing Act passed in 2014 likewise adopts a 5-year term for federal support to manufacturing institutes created by NIST.

This approach follows the Sematech model, where DARPA's funding for the Sematech semiconductor industry consortium ended after 5-years. This was a politically appealing idea — the federal government could pull out after 5-years, manufacturing would be revived and somehow the institutes would continue. In contrast, as discussed below, Germany's Fraunhofer Institutes face no such cut off after a relatively short, fixed term from their federal government support. The assumption that the institutes can go independent in 5-years is problematic. Reinvigorating manufacturing innovation is going to be a long-term not a short-term project and requires technology realism not technology magic.

For Sematech, a 5-year transition worked because, compared to a manufacturing institute, Sematech received massive funding ($100 million a year from DARPA which was matched by industry), because the improvements needed in semiconductor manufacturing processes were studied and understood quickly and could be implemented in a relatively short period, and because the industry itself began to rapidly expand with advances in new integrated circuits so had new resources to manage the improvements. Sematech stands as an important organizational and collaboration model for the manufacturing institutes given its significant role in helping U.S. firms retain semiconductor leadership. But there, the 5-year cut off could work because the Sematech effort, focused on the manufacturing process for evolving semiconductor equipment and technologies, was more straightforward compared to the complex and longer term tasks to develop entirely new technology areas faced by the manufacturing institutes.

The federal government historically has funded R&D because of what economists term a "market failure:" as critical as R&D is for innovation, in a highly competitive, globalized world firms are increasingly unable to take on the risk of research because the chances for returns from it are inherently speculative. In industry after industry major firms in recent decades have sharply curtailed or closed down their R&D labs — the demise of the famous Bell Labs is not an isolated example. The surviving industrial labs are increasingly focused on late stage development work directly tied to incremental product improvements. This trend likely is more apparent in the manufacturing sector than any other. And small- and mid-sized manufacturers rarely undertook significant research to begin with. While some of the technologies being pursued by the manufacturing institutes may be sufficiently advanced after 5 years of development that industry will be prepared to take the risk of further implementation, many won't. A major aim of the advanced manufacturing effort was to bring innovation into close reach of small- and mid-sized manufacturers in particular; picking up advanced technology R&D even after 5 years is simply not going to be an option for small- and mid-sized firms, and will be a problem for major firms facing steep competition, even if the collaborative, shared research model at an institute continues after the end of federal support. In other words, significant areas of economic market failure are enduring, they don't get fixed in 5 years, they continue.

Most of the technologies that new institutes are being organized around will require a longer term evolution than the 5-year term currently fixed for federal support before they are ready for implementation at scale. Technology development and implementation likely will still be incomplete after 5 years in such areas as lightweight and composite materials, the range of digital and additive manufacturing technologies, wide bandgap semiconductors, photonics, flexible electronics, smart fibers, and regenerative tissue engineering. We will not be close to technology maturity in any of these areas even if there is significant new progress through the institutes over the next 5 years. There are significant breakthroughs required in many of these areas as well as extensive follow-on development.

How could this 5-year federal termination clause be managed? This deadline is now creeping up on the first institute, which is facing a federal cutoff in 2017. First, we can hope that the collaborative, shared-risk R&D model for the institutes will encourage firms to stay engaged and cost share. Second, we can also hope that interest and support from state and regional governments will continue — their manufacturing sectors will likely remain important to their regional economic development, so their interest may continue. This continued state, regional and industry support could be a prerequisite for continued federal backing. Given this support, the most straightforward mechanism could take the form of an evaluation process as the initial five years comes to a close, with an opportunity for an institute to obtain a renewed term of federal funding if performance has been successful. Alternatively, the institutes will be eligible to apply for federal R&D funding from mission agencies. Although these agencies in the past have not had portfolios in manufacturing R&D, they have had related research in particular technology areas. AMP2.0 recommended that R&D strategies[140] be developed through the agencies for advanced manufacturing areas, with collaboration from industry and universities. That can still be undertaken, and help guide further federal R&D investments in research undertaken at manufacturing institutes. However, given the evolving

[140]PCAST (2014). Accelerating U.S. Advanced Manufacturing, AMP2.0 Report, pp. 4–5, 26–28, 64.

development of the institutes, some mechanism for continued federal cost sharing will likely be required for a significant additional period beyond the initial 5 years. The executive branch should begin work now on following funding support mechanisms.

To summarize, there is an underlying problem for the institutes because of their relatively short 5-year federal time horizon: the institutes have a longer term project model and too short a timeframe to meet it within. Reframing of the time horizon is necessary.

The Research Governance Model: The manufacturing institutes were formed by federal mission agencies, and these carried over their regulatory and organizational perspectives as they began this effort. Agencies have tended to treat and manage their institutes like the animals they are familiar with — as research recipients. So the agency governance model is an R&D supervisory model (through cooperative agreements or technology investment agreements), and agencies tend to see their role as research contract supervisors that encourage technical project execution and cost-sharing industry membership. The institutes are typically governed by independent non-profit organizations with a Board of Directors, on which the agency does not sit; that Board often seeks sustainable fiscal operations that satisfy agency requirements. A minimum of 1:1 cost match of the agency investment is required of the institute, and institutes must adopt an intellectual property plan that is attractive to industry and also solicits significant industry cost share derived typically from larger firms. Yet the role of the institutes is much broader than research contract supervision– building lasting collaborations with support systems across a wide range of firms in varying sectors, not only for research but also for testing, technology demonstration and feedback, product development, and workforce education and training.

This is a very complex and ambitious model, and requires a different governance and support model than much more straightforward research projects that involve small teams of scientists and "Principal Investigators" not massive collaborations. Despite the extensive cost sharing from industry and states, with frequent overmatching of federal funds, the federal agencies tend to apply their research oversight rules to govern the cost shared funding as well as their federal funding. This approach may not help move the institutes toward the independent operations that will be required within 5 years. To summarize, the governance system for federal research in some cases may not foster the kind of collaboration required for the non-research aspects of the institute's tasks, and may not help prepare the institutes to be self-sustaining and enduring after 5 years. Thought needs to be given to how the governance model is working, including administrative delays in standing up new institutes. Should, for example, the cost share funding from industry and states be controlled by the agency, or should the institutes set these parameters with the contributing stakeholders? Could the agencies shift from traditional research contract supervision and oversight to encourage a more collaborative model with growing state and local government and especially industry? How could this be undertaken?

Support from the Network: The AMP2.0 report recommended that the growing group of manufacturing institutes be joined together into a supporting network. The report proposed, "a governance structure that maintains autonomy for individual institute operations while creating a public–private network governing council that oversees the broader performance of the network and the sustainability of the individual institutes."[141] NIST has been working to implement this recommendation through the Advanced Manufacturing National Program Office, though this office does not yet administer any of the current institutes. The network, labeled Manufacturing USA in 2016, can serve, as NIST understands well, a range of needs. As each new institute is stood up, it should not have to "reinvent the wheel." There have been many lessons learned about how to constitute governing boards and legal structures, how to manage intellectual property, how workforce education programs can be assembled, how to set up tiers of participants, how to organize regional outreach efforts, and so forth. A strong network organization could help ensure that common problems are shared by the institutes and tackled in common, and that best practices and lessons learned by

[141] PCAST (2014). Accelerating U.S. Advanced Manufacturing, AMP2.0 Report, pp. 6, 30.

individual institutes are studied and shared across the network. Standup for new institutes has been taking a year. Considering the complexity of the model this is not unreasonable, but could the network help significantly speed up that process by standardizing and packaging solutions for common issues? Again, NIST's Advanced Manufacturing National Program Office, acting with the other agencies plus the institute directors are taking this task on. A self-governing institute network could provide a powerful boost to an efficient, sustainable, sharing system of institutes.

Emphasis on R&D verses Implementation: The manufacturing institutes' primary role so far has been as R&D shops — not surprising given the goal of developing new manufacturing technologies and the R&D missions of the agencies that created them. Considering the shortage in the U.S. innovation system of manufacturing research, this fills an important gap and is an early and critical mission. The Institutes tend to look more like mini-NSFs, more focused on the technology development than the technology implementation side of their mission. For example, one of the strengths of China's manufacturing sector is its ability to rapidly scale up new production prototypes through such rapid prototyping centers as Shenzhen, which abounds in small prototyping shops. The primacy of the technology development role is logical for institutes — but technology implementation needs to be within their scope, as well, as they realize.

The AMP1.0 report envisioned institutes organized at Technology Readiness Levels 4–7 (technology development to technology demonstration to system and subsystem development).[142] NIST later articulated this focus as Manufacturing Readiness Levels 4–7 (prototype to pilot scale production), seeking to focus efforts on de-risking of manufacturing technologies rather than on discovery science or on product innovation. Since the institutes have tended to organize around new technologies still some distance from industry implementation, they therefore may well require additional development to move into the range of industry users. This may be inevitable considering the gap in the U.S. in R&D directly on manufacturing research, so unless corrected, over time this

[142] AMP 1.0 Report.

will create an implementation gap in the role of the institutes. Yet the institutes must focus more on process technologies, demonstration, testing, and feedback systems, to serve their small- and mid-sized manufacturing firm members. If sought-after technologies are not ready for these later stages, where the smaller firms could pick them up, the institutes face a problem.

There is a related technology development issue. It can be difficult for institutes to foster technology and IP sharing between larger firms that are in competition with each other. This in turn affects their ability to collaborate with smaller firms. Best practices in resolving this need to be shared across the network.

In summary, the institute technology development role is clearly important and central, but the institutes must also focus on the tasks required for TRL 4–7 further down the innovation pipeline so the evolving technologies can be implemented, especially by smaller and mid-sized firms. Coordination between the R&D agencies and the institutes is needed, linking TRL 4 with TRL 5–7.

Supply Chain Involvement: Institutes often focused initially on project calls for technology development R&D that typically involve university and major firm researchers; smaller firms are usually not included because they have limited R&D capability. Yet the new technologies won't be adopted unless smaller firms understand and use them; for this to occur, the institutes will need to embrace more of a full supply chain approach, with supply chains engaged in technology demonstration, testing, and training. Backing from smaller manufacturers in these supply chains will also be key to political support at the state level for ongoing efforts to support advanced manufacturing. So for the sustainability of the institutes it will be important for small firms to be involved, and engaging through their participation in supply chains is a good mechanism. Since, as noted below, manufacturing ecosystems tend to be regional, a supply chain approach will also be important in establishing a regional as well as national base for the institutes.

Making Education and Workforce Training a Priority: There is a similar potential challenge for the role of the manufacturing institutes in workforce training and engineering education. Without engineering teams and workforces fluent and skilled in the new technologies in small as well as large firms, the evolving advanced manufacturing technologies simply cannot be implemented. Given the traditional role of states in providing education and training, particularly through their community college systems, this is a good way for institutes to link to states. While some institutes have seen that workforce training can be an early "win" for the institutes in serving their industrial sectors, and building their networks of contacts with firms, states, and community colleges, others are behind on this. Agency contract and program officers for the institutes tend to be technology-oriented, not education experts, so many focus on the R&D side of the institute role. So the prioritization of this workforce training goal is not always signaled clearly by the partnered federal agency. And the institute directors themselves come from the engineering and industry sides, with limited background generally in workforce education.

However, institutes should not be "either/or," they need to master both sets of tasks — technology implementation and workforce development — to fully serve their industry sectors. The agencies should ensure a workforce education focus across the institutes and work to get best practices to all. A few institutes, led by LIFT, are well ahead in forming new education approaches and these could benefit and serve other institutes. Online and blended learning approaches and platforms, in particular, could serve the whole system. The evolving Manufacturing USA network should play a constructive role in bringing best education training, and credentialing practices across the institutes. This was indeed a topic at the August 2016 institute directors meeting. These efforts may include a stronger role for industry internships and apprenticeships, experienced leadership of this workforce component within each institute, clear budgeting expectations that signal priority of this goal, engagement by states in programs and training facilities as part of cost share, and inclusion of education and workforce development within the sustainability plan of each institute. It is worth noting that the AMP reports clearly envisioned strong workforce and training programs. The role of the Fraunhofer Academy, which offers an advanced skills training system alongside the Fraunhofer Institutes, has proved to be a critical technology dissemination program for these institutes — training is the key to technology implementation.

The Role of the States: From the outset participants in the AMP1.0 and 2.0 process, including government, industry, and university participants, saw a critical balance challenge for the institutes. All manufacturing, in the end, is local, embedded in production and innovation ecosystems that are very regional. So the manufacturing institutes must keep one leg in regional manufacturing economies; that's where their industry and university constituencies are. Yet the technologies the institutes are developing are also going to be needed nationally, and won't just evolve in one region — they must translate into the national economy. 3D printing won't be just needed in northeast Ohio, it will be needed nationally in many regional economies in many industrial sectors. Keeping one leg in regional economies and the other leg in the national economy creates a complicated, bifurcated model for the institutes.

One issue some of the institutes are facing is that with a strong emphasis on R&D projects as their initial focus, they may be too tilted to a national approach and need more balance. If the federal role ends after a 5 year term, the regional, local role the institutes can play becomes vital — support from states could be key to institute survival. If the institutes are not closely tied early on to regional economies, the support from states will simply not develop in the depth necessary. For example, if the America Makes 3D printing institute is not actively helping the economy of Youngstown, its headquarters, then continuing support, as it understands well, from the state of Ohio will be harder to mobilize. A national focus must also translate into a local focus and local gains.

The state governors were not at the table when the AMP reports and plans were being developed — they were not participants.[143] Part of that was due to the ideological divide that grew in the last decade between the historic political parties; it became harder for the administration to invite both sides to the table, even at the state level. And

[143]The AMP study groups, however, did consult extensively with the National Governors' Association in preparing their reports.

advanced manufacturing technology development to support a regional manufacturing ecosystem was a new idea — it was never a part of the economic development toolset applied by the states, which all too often is a zero sum game approach with states subsidizing major firms to leave one state and move to another.

Could this traditional approach change? NIST, working with the National Governor's Association, creatively formed a "Policy Academy" for states offering workshops and competitive planning grants to interested states to enable them to develop state manufacturing strategies to strengthen their manufacturing base.[144] This proved to be a very good tool for helping states to understand their production sectors and consider technology and workforce roles. Of the eight states that developed state manufacturing strategies, all became active participants in manufacturing institutes and four became institute headquarters. State policymakers care deeply about their manufacturing sectors because they are often central to their state economies and job creation. Programs like NIST's Policy Academy can play a key role in nurturing sophisticated state manufacturing programs and strong regional manufacturing institutes. The Economic Development Administration in the Commerce Department has had a program, Investing in Manufacturing Communities Partnership (IMCP) that continued aspects of this approach, although at a regional not a state level.[145]

In summary, building state support by tying to regional economies will be a key pillar for institute survival. One of the reasons NIST's Manufacturing Extension Program (MEP) has endured is because it is anchored in the states — every state has one. The program is popular with small manufacturers, an important constituency for governors, and running a sound MEP program has proved a good way for governors to connect politically with this constituency. MEP, therefore, provides an

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[144]National Governors Association, Making our Future — What States are Doing to Encourage Growth of Manufacturing through Innovation, Entrepreneurship and Investment, An NGA Policy Academy Report, Jan. 28, 2013, Available at: http://www.nga.org/cms/home/nga-center-for-best-practices/center-publications/page-ehsw-publications/col2-content/main-content-list/making-our-future.html.

[145]See, Economic Development Administration, Investing in Manufacturing Communities (IMCP), Available at: https://www.eda.gov/challenges/imcp/.

example for the institutes. For new governmental programs to survive and thrive they not only need a strong substantive policy design, but also must have a sound political support design that will sustain them. The political design is not easy — it must not distort the substantive policy design to serve political ends, it must support the substantive policy design and keep it strong, but still build support to sustain it.[146] The institutes need to find the right mix of political design with substantive design; developing a strong regional economic focus is important not only for the substantive model of a strong institute but also to a political design that will assure future support.

While the state role in the U.S. system is not R&D, states do play a significant role with small businesses and, as noted earlier, in workforce training and education. Engaging small manufacturers that are part of regional industrial supply chains in the manufacturing institutes is also a key way to engage state support. Secondly, the workforce training role of the institutes, which is inherently regional, provides another means to engage the states. Importantly, too, the distributed nature of the manufacturing supply chains and workforce implies that multiple states must coordinate efforts within a single institute.

Measuring Progress: As the institutes and their supporting federal agencies understand, if they are to be sustainable, they will need to demonstrate the progress they are making on technology development and workforce education. Developing performance metrics, then, is a key step. Working with the institutes, NIST's Advanced Manufacturing National Program Office, which supports the network, has issued an initial guidance for this process[147] agreed to by the institute directors. It calls for institutes to collect data on institute participants including the number of small and mid-sized manufacturers actively involved, on active R&D projects and their progress on meeting key technical

[146]William B. Bonvillian (2011). "The Problem of Political Design in Federal Innovation Organization," Chapter 15 in Kaye Husbands Fealing, Julia Lane, John Marburger and Stephanie Shipp, eds., *The Science of Science Policy*. Stanford University Press, pp. 302–326.

[147]National Institute of Standards and Technology (NIST), Advanced Manufacturing National Program Office, Guidance on Institute Performance Metrics: National Network for Manufacturing Innovation, Aug. 2015, https://www.manufacturing.gov/files/2016/03/nnmi_draft_performance.pdf

stages, on levels cost-sharing support by source, on numbers of students reached in workforce training efforts, and on workforce trainers trained. This is a constructive step. Further work is needed on tracking progress against the technology roadmaps institutes are developing. The Deloitte report has also recommended looking at the stages of evolution the institutes must go through, from startup to R&D execution to longer-term outcomes, and developing benchmarks for progress at each stage.

An Underlying Problem: Federal R&D for Advanced Manufacturing Technologies: A significant issue that affects the ability to meet a number of challenges discussed earlier is the lack of past focus by the federal R&D agencies on research on manufacturing. As noted, the U.S. long assumed its manufacturing leadership, and did not feel the need to make it a focus. That is part of the reason that a number of manufacturing institutes, focused on TRL 4–7, still tend to have a need for somewhat earlier stage Technology Readiness Level support than proposed in the Advanced Manufacturing Partnership report — foundational research work in manufacturing technologies still needs work. If ongoing federal mission agency R&D can focus more on enabling manufacturing technologies, that could be an important complement to the manufacturing institutes, helping create new manufacturing paradigms. As noted, this was recommended in both AMP reports. To be clear, many of the discoveries needed for this shift are well underway; ongoing federal research has supported major advances in such areas as digital and sensor technology, advanced materials, photonics, robotics, flexible electronics, and composites — the potential manufacturing paradigms are in sight, which is a major part of what makes them so interesting.

There has been an initial step down this pathway of translating research toward the institutes. In April 2016, the Subcommittee on Advanced Manufacturing (SAM) of the National Science and Technology Council (an arm of OSTP used for interagency collaborations) released a report, "Advanced Manufacturing: A Snapshot of Priority Technology Areas Across the Federal Government."[148] It cataloged ongoing federal

[148] National Science and Technology Council, Subcommittee on Advanced Manufacturing (2016).

R&D efforts in emerging technologies that can be manufacturing priorities: advanced materials manufacturing, biomanufacturing to support bioengineering, regenerative medicine and other advanced bioproducts, and continuous manufacturing of pharmaceuticals. It also looked at research directly relevant to the technologies focused on by first nine manufacturing institutes.

Many of these agency efforts are significant. One highlighted example concerned the Energy Materials Network, a $40 million Department of Energy project, which included integration of computational capabilities into experimental materials research, development of new multiscale computation, informatics and data management tools, and new technologies for modeling and validating new materials manufacturing processes, for a new "materials genome" for optimal advanced materials. These and other research assets, if linked to institute needs, could be significant. The report lays the groundwork for what needs to be the next logical step — developing technology strategies around the emerging manufacturing paradigms, bringing together R&D agencies and their leading researchers with the institute experts and researchers. The strategies could help guide work by both groups. As previously noted, technology strategies were a specific recommendation in the AMP2.0 report. However, unless the R&D side is better linked to institutes, which focus on applied work, they could become stranded, losing overtime their ability to bring on new manufacturing technology advances.

Federal Procurement for Advanced Manufacturing Technologies: There is an additional dimension as well to the federal role. Federal agencies, particularly its largest procurement agency, DOD, could play a significant role in creating initial markets for new manufacturing technologies. 3D printing is not only a potentially very important new manufacturing process, it enables production of a series of new technologies and components, some of which, particularly in the aerospace and tissue fabrication area, may be of major interest to DOD. Using procurement to advance the technologies it needs is a traditional role for DOD. For example, after integrated circuits were developed in 1959 by Robert Noyce and Jack Kilby, the initial market for some 4 years belonged solely to DOD and NASA. As the technology was perfected for military and space markets, civilian markets gradually opened up, and, of course, became dominant.

DOD could play a comparable and critical initial market creation role for new products from new generation of manufacturing technologies, but its procurement system has to become aligned with the results being developed by the institutes and their participating firms. This should be achievable. The General Accountability Office (GAO) has studied, for example, the potential of 3D Printing technologies emerging from America Makes, and identified an extensive series of military needs these could be matched to.[149] GAO recommended that the Office of the Secretary of Defense develop and implement an approach "for systematically tracking department-wide activities and resources, and results of these [3D Printing] activities; and for disseminating these results to facilitate adoption of the technology across the department." Just as the federal R&D system needs to be tied to the manufacturing institutes around technology strategies to optimize idea and research inputs to assist the institutes, so government procurement needs, particularly at DOD, could be aligned with the results — the output — coming from the institutes to help create initial markets to disseminate their advances.

3.6 Summary

The advanced manufacturing institute effort is off to a rapid and promising start in the U.S. addressing what has become a critical gap in the U.S. innovation system for manufacturing innovation. This has been accomplished through dedicated work by a group of federal officials working across agency lines, with effective top executive branch leadership, as well a unique industry–university work group, the Advanced Manufacturing Partnership, which developed two major action-oriented reports.

Now that the basic framework is in place with a group of 14 institutes, this is a good opportunity to consider enhancements to the model. The

[149] Government Accountability Office, (Oct. 2015) Defense Additive Manufacturing — DOD Needs to Systematically Track Department-wide 3D Printing Efforts, GAO 16–56.

institutes face a series of challenges that could be met:

- improving the current research agency governance model;
- continued federal government support after the initial 5-year commitment;
- creating a strong network of institutes where best practices and research advances can be shared;
- an emphasis within the institutes on technology implementation at later Technology Readiness Levels as well as technology development;
- ensuring institute emphasis on workforce training and education; and
- ensuring linkage between institutes and regional economies, in addition to serving manufacturing technology development at the national level.

In addition, federal R&D at mission agencies in advanced manufacturing technologies should be better connected and contribute to the institutes. This would help the institutes include in their agendas more technology implementation efforts with participating firms. Federal procurement, another traditional tool for technology advance, could be applied to create initial markets for new technologies emerging from the institutes.

Finally, there are important lessons from Germany's Fraunhofer organization and institutes, which served as the model for the U.S. institutes. As noted earlier, there are 60 of these, operating in every region fostering collaborations between the mittelstand, larger firms and engineers from academic institutions to foster technology and process advances. Although the Fraunhofer institutes have significant autonomy, the overall organization allows participatory governance, as well as sharing of practices and research. The U.S. institutes could benefit from a strong institute network, providing both access to best practices and a shared governance model. The continuing central government support of Fraunhofer institutes, which is not term-restricted as in the U.S. has been critical for their sustainability and strength, which the U.S. should consider.

With 14 institutes in place by the beginning of 2017, this may be a good time for a new administration to hit a pause button before creating more. Institute directors have been noting that there is a certain amount of "donor fatigue." Major companies that cost share the institutes are often participating in a number of them, and are reluctant to spread themselves too thin. There are also limits to how much more cost share funding they are prepared to commit to. States are starting to have the same problem — there are practical limits to the number of institutes a strong manufacturing state can effectively contribute to and participate in. Given the reality that the sustainability of the institute model is still an open question, early 2017 may be a good time to look hard at both additional missions the institutes may want and need to address and ways to make the institute model sustainable.

4

Startup Scaleup: Addressing the Manufacturing Challenge for Start Ups

4.1 The innovation gap for technology development

Lewis Branscomb and Phillip Auerswald in 2002 wrote a classic in innovation literature, "Between Invention and Innovation"[151] putting flesh on what was then a skeletal idea of a "Valley of Death"[152] located at early stage technology development, lying between proof of concept/invention and product development stages. As is well understood, they noted that technological innovation was critical for long term economic growth; although established firms typically undertake incremental advances, radical technological advance introducing truly new products and services was required for new industries and markets

[151] Lewis M. Branscomb and Philip E. Auerswald (2002). *Between Invention and Innovation, NIST Report GCR 02-841*. Gaithersburg, MD: National Institute of Standards and Technology. See also, Branscomb and Auerswald (2001). *Taking Technical Risks: How Innovators, Executives and Investors Manage High Tech Risks*. MIT Press. The author thanks Peter L. Singer of the MIT Washington Office for his major contributions to this section.

[152] Branscomb and Auerswald preferred the term "Darwinian Sea" to "Valley of Death" arguing that the concept of valley suggested a linear model of innovation, which was instead inherently a more complex system. Branscomb and Auerswald (2002). *Between Invention and Innovation*, pp. 35–37.

and for corresponding major steps in growth.[153] They cited economist Martin Weitzman's statement, "the ultimate limits to growth may lie not as much in our ability to generate new ideas, so much as our ability to process an abundance of potentially new seed ideas into usable forms",[154] arguing that a gap in support for early stage technology development was thwarting that transition.

Their study found that although there was major federal support for research, little funding extended to early stage technology development. They found that venture capital funding was available for potentially high growth ventures, but only materialized when the new technology was close to production after the firm had worked through its technology development. While angel investors were more active at this early stage, their total funding was modest; little corporate funding was available for other than incremental advances that complemented the established firm's existing technologies.[155] Thus markets for support of early stage technology development were highly inefficient, they found, resulting in a significant gap in the U.S. innovation system.

4.2 An innovation gap where high potential startups stagnate

Could this technology development gap be yielding a startup decline? Economist Robert Litan noted in the wake of the 2008 recession, "America's great challenge is to ... bring about a substantial increase in the numbers of highly successful new companies .... Nothing less than the future welfare of America and its citizens is at stake."[156] So the nurturing of startups has policy significance. The Kauffman Foundation has long compiled an entrepreneurship index to indicate the growth or decline in numbers of U.S. startup companies. That index showed a steep decline in total startups between 2009 and 2013, hitting a 20-year low in 2012, before an uptick began in 2014, which by 2016 began to

[153] Branscomb and Auerswald (2002). *Between Invention and Innovation*, p. 1.

[154] Martin Weitzman (May 1998). "Recombinant growth," *Quarterly Journal of Economics* 113(2), p. 333.

[155] Branscomb and Auerswald (2002). Between Invention and Innovation, pp. 4–5.

[156] Robert E. Litan (2010). Inventive Billion Dollar Firms: A Faster Way to Grow, SSRN Working Paper No. 1721608.

again approach pre-2008 recession levels if not prior historical levels.[157] A number of economists, including Litan, noting that startups had become key to the U.S. innovation-based growth model, looked beyond the 2009–2013 decline. Noting that firm exits were passing firm entry, they expressed concern about a long term decline from 1978 to 2011 in net firm formation, which led to concern about the declining pace of job creation which they linked to this business dynamism decline.[158] If the U.S. depended on new firm creation for its growth rate and jobs, it was not a pretty longer term picture.

But treating all entrepreneurs alike can lead to the anomalous grouping of new "Mom and Pop" corner stores with biotech startups. Within the last few years this analysis has started to reflect this, as academics have begun creating new indices to focus more explicitly on innovative, technology-based firms, which have much greater potential to scaleup and grow than, say, a neighborhood dry cleaner. The Kauffman Foundation starting in 2016 added "growth entrepreneurship" to its annual index. This new Kauffman index incorporates the rate of startup growth, the share of "scaleups" in the startup mix (i.e. the percent of firms that have grown to employ more than 50 people in the first 10 years), and high-growth company density, to better measure trends in *growth* entrepreneurship in the U.S..

This new growth entrepreneurship index shows a deep decline from 2009 to 2013, clearly affected by the Great Recession, but it has now returned towards the pre-financial crisis numbers.[159] However, the individual components of the index present a less positive picture. The rate of startup growth hit a 20 year low in 2012, before ticking slightly up-

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[157] Arnobio Morelix, E.J. Reedy and Joshua Russell (2016). *Kauffman Index of Growth Entrepreneurship, National Trends*. Kansas City, MO: Kauffman Foundation, p. 14, Available at: http://www.kauffman.org/~/media/kauffman_org/microsites/kauffman_index/growth/kauffman_index_national_growth_entrepreneurship_2016_report.pdf.

[158] Ian Hathaway and Robert Litan (2014). *Declining Business Dynamism in the United States: A Look at States and Metros*. Washington, DC: *Brookings Institute Economic Studies*, pp. 1–3, Available at: https://www.brookings.edu/research/declining-business-dynamism-in-the-united-states-a-look-at-states-and-metros/

[159] Arnobio Morelix, E.J. Reedy, and Joshua Russell (May 2016) "Growth Entrepreneurship: National Trends," *The Kauffman Index 2016*, p. 14.

ward, which is similar to the trend for the share of scaleup startups.[160] But of these higher growth firms, over 47% fall into five industries: Software, Health, IT Services, Advertising & Marketing, and Business Products & Services.[161] The positive uptick in the index of growth entrepreneurs, while a welcome improvement, seems somewhat confined to relatively few sectors of economy.

Economists Jorge Guzman and Scott Stern worked on another way to dive into the overall data and look at the kinds of firms that were particularly important for growth — firms that were based on science and technology innovations.[162] These firms — sometimes called gazelles — have a much higher potential growth rate because such innovation can scale better and faster than more commonplace "mom and pop" firms like restaurants. Such firms appear particularly critical to growth. How was the U.S. doing in creating these technology-based innovative firms? Looking at firms in 15 states that contributed more than half of U.S. GDP, they developed characteristics they could track for such high potential firms, such as IP held, name, legal structure and other factors.[163] These characteristics were in turn tested against signals of higher growth outcomes (using data on firms obtaining IPOs or entering high value acquisitions). They found that these kinds of high potential firms went into decline after the dot-com bubble in the early 2000s, but that in 2010, a rise began and by 2014 the U.S. had reached the third highest level in a quarter century of entrepreneurship growth for such quality firms.[164]

Although the number of high potential startups appears back on the rise and returning to sound levels, the study found that the ability of these startups to scaleup may still be stagnating. Using a new methodology, these researchers found that a high potential startup begun in 1996

[160] Morelix, *et al.*, *Growth Entrepreneurship*, pp. 15, 17.

[161] Morelix, *et al.*, *Growth Entrepreneurship*, p. 20.

[162] Jorge Guzman and Scott Stern (March 2016). The State of American Entrepreneurship: New Estimates of the Quantity and Quality of Entrepreneurship for 15 U.S. States, 1998-2014, NBER Working Paper 22095, Available at: http://jorgeg.scripts.mit.edu/homepage/wp-content/uploads/2016/03/Guzman-Stern-State-of-American-Entrepreneurship-FINAL.pdf.

[163] Guzman and Stern (2016). *The State of American Entrepreneurship*, p. 6.

[164] Guzman and Stern (2017). *The State of American Entrepreneurship*, pp. 7–8.

was four times as likely to experience a growth event — that is, an IPO or high value merger — within 6 years, than a startup begun in 2005 and measured for a growth event through 2011.[165] Of course, the 1996 startup experienced the dot-com bubble, and the 2005 startup followed the dot-com bust, but even so, the size of the differential suggests a problem in scaling up startups. There are also significant regional variations in scaleup — where you start matters. While there has been some overall recovery in scaleup rates for startups that began in 2009–2011, the recovery is still quite weak. As a companion study concluded,

> While the supply of new high-potential-growth startups appears to be growing, the ability of U.S. high-growth-potential startups to commercialize and scale seems to be facing continuing stagnation. Policy interventions to enhance the process of scale-up may be more impactful than those that simply aim to increase shots on goal.[166]

4.3 The innovation gap for manufacturing startup scaleup

So far we have reviewed an innovation gap in support for technology development, and another for high potential startups overall in achieving scaleup. There is an additional and compounding innovation gap problem affecting startups that need to manufacture their products. While the advanced manufacturing institute model detailed in the previous chapter addresses innovation at large and at mid-sized and small manufacturing firms, to date it has largely focused on existing firms and not encompassed new entrepreneurial startups. These startup firms face not only an early stage technology development gap, as Branscomb and Auerswald have described, but a production scaleup gap. Startup scaleup is a problem in general, and for manufacturing startups a problem in particular.

[165] Guzman and Stern (2016). *The State of American Entrepreneurship*, pp. 32–33.

[166] Catherine Fazio, Jorge Guzman, Fiona Murray, and Scott Stern. *A New View of the Skew: A Quantitative Assessment of the Quality of American Entrepreneurship*, MIT Laboratory for Innovation Science and Policy, February 15, Available at: http://innovation.mit.edu/assets/A-New-View_Final-Report_5.4.16.pdf.

This third category of firms, then, comprises the startup and entrepreneurial firms that manufacture products based on their own new innovative technologies, typically emerging from university research centers. As summarized earlier, Elizabeth Reynolds, Hiram Semel, and Joyce Lawrence of the MIT Production in the Innovation Economy (PIE) project studied a group of such highly innovative startup firms in the Boston area and found that these have this additional problem in scaling up production.[167] While the innovations from this group were often able to command initial venture capital funding, their venture firms lacked the financing capacity to stand up significant production. They found that venture firms are typically organized around a timetable that is well suited to the IT — and increasingly software — firms that have historically led the venture sector, in which the technology becomes a marketable product within 5–7 years. But the firms in the study group aimed to produce manufactured goods in sectors that had a development cycle that could last a decade or more. The MIT study found that many of the venture firms did not abandon their startup firms after more than 5–7 years, but if their technology remained promising, the VCs instead put them into what could be termed "income maintenance." This means that the firm would be sustained at a basic funding level but when such firms were well along the path of product design and they asked their venture firm for financing for scale-up to actual production, they were usually told that no, the venture firm lacked the depth and resources to finance the capital requirements required for investment in local production, and they were typically referred to contract manufacturers in Asia.

This has important implications. The initial stage of production of a new technology involves significant engineering advances and original design, and frequently requires redoing the underlying science and the innovation itself. It is a highly creative stage and part of the innovation process not divorced from it, as previously discussed. The U.S. firm's innovation team, if relying on a contract manufacturer,

[167] Elizabeth Reynolds, Hiram Semel, and Joyce Lawrence (2014). "Learning by Building: Complementary Assets and Migration of Capabilities in U.S. Innovative Firms," Chapter 4 in *Production in the Innovation Economy*, Richard Locke and Rachel Wellhausen, (eds.) Cambridge, MA: MIT Press, pp. 81–108.

often spent significant time abroad with that manufacturer; much of the innovation is transferred in that process, and the capability for follow-on incremental advances tends to shift overseas. So while the start-up may have its technology produced and enter into markets, important aspects of its “know-how” move offshore; this means that when production capability shifts offshore, significant aspects of innovation capability shift with it. These advanced technology start-up firms represent the next generation of U.S. technology and manufacturing firms; this gap in scale-up financing means that important in-depth innovation features may be transferred abroad, and may become the basis for future major innovations in both processes and products there.

4.4 The venture capital availability problem and financing alternatives

Data on venture capital availability further substantiates this story. Ben Gaddy, Virun Sivaram, and colleagues have studied venture capital funding in the clean energy sector.[168] They found that venture capital investments in new energy technologies between 2006 and 2014 reached a high point in 2008, and have been in substantial decline since then. Although VC investment in new energy technologies increased between 2004 and 2008 from $1 billion to near $5 billion, at an annual growth rate of close to 50%, after 2008 this level (A-round deals) fell back to the 2004 level.[169] Less than half the $25 billion invested in clean energy was returned to investors in the 2006-11 period. Over 90% (on average) of clean energy investments failed to return 1x invested capital in 2008–2011, and in 2008, 2009, and 2011, 0% of clean energy investments returned 2× invested capital.[170] The failure rate in software firms in these periods was considerably lower. Following the financial crisis in 2008, the major decline in the price of oil, the failure of Congress to

[168] Benjamin Gaddy, Sivaram Varan, Timothy Jones, and Libby Wayman, Venture Capital and Cleantech: The Wrong Model for Energy Innovation, paper, June 2, 2016. See also, Gaddy, Benajmin, Varun Sivaram and Francis O’Sullivan (July 2016). “Venture Capital and Cleantech,” MIT Energy Initiative Working Paper, http://energy.mit.edu/wp-content/uploads/2016/07/MITEI-WP-2016-06.pdf.

[169] Gaddy, *et al.* (2016). *Venture Capital and Cleantech*, p. 1.

[170] Gaddy, *et al.* (2016). *Venture Capital and Cleantech*, p. 7.

pass carbon pricing climate legislation, and the collapse of a number of solar companies because of solar panel overproduction in China, VC clean energy investment dipped substantially.

In addition, investments in energy technology firms require large capital commitments; the average VC investment in all types of firms in 2016 was approximately $12.5 million, and energy firms often required many times that level to scaleup. In contrast the average 2016 investment in a software firm was only $6.37 million. For venture firms, a low initial investment translates into lower risk per firm and a higher equity stake. Another reason venture funding has been pulling out of clean energy is that the energy technology timetable does not fit the timetable VCs seek to apply. Typically, VC's will make 5 years of progressive investments and over the next 5 years expect to see returning profits. However, the timeframe for clean energy firms can be twice that for the firm to mature. A third issue concerns exit strategy, where established firms will acquire the startup. The exit rate for software firms is 11.9% while only 3.8% of clean energy firms were acquired in the same 2006–2011 period. Venture firms have limited interest in funding firms, such as in the energy technology space, that have little chance of being acquired because this affects the ability of their investors to obtain a prompt return.

Because of its lower risk, lower capital requirements, shorter term timetable, and stronger exit strategy, software is a much better bet for VCs than longer term, capital intensive sectors like energy technology. Software needs little infrastructure and does not require manufacturing; VC can get in and out of software quickly — they either succeed or fail fast. A snapshot of a representative period, the first quarter of 2016, for early stage and seed venture funding in all economic sectors, nationwide, bears this out.[171] In that period there were a total of 468 venture deals. Of those, there were 197 deals in software and IT services; biotechnology placed second with 76 deals. These two categories combined captured $2.55 billion of the total deal volume of $4.62 billion. No other sector was close. Biotech is very different than software — with much larger capital

[171] Historical Trend Data, PWC MoneyTree (with the National Venture Capital Association), (2016) Available at: https://www.pwcmoneytree.com/HistoricTrends/CustomQueryHistoricTrend.

requirements and a longer term technology development timetable. Why do VCs support that sector, too? The answer is that biotechnology firms, although requiring a far longer term commitment than software or IT services firms, continue to attract venture funding support, (1) because patents tend to be more powerful in the life science sector than physical science-based sectors in assuring longer term monopoly rents, (2) because the Food and Drug Administration's three levels of clinical trial stages allow firms to evaluate and better manage investment risks at each phase and (3) because FDA's final safety certification for a new drug virtually guarantees a significant market for drugs that serve sizable disease markets. The combination, then, of FDA's three approval stages, which allow benchmarking of investor risk, and its final certification, which virtually guarantees a market, and which is protected for the rest of a product's patent term, helps VC's manage investor risk; no other economic sector has such a system for risk management.

In contrast to biotech and software, the entire "industrial/energy" category had only 13 deals worth $32.6 million, and medical devices, another capital intensive example, had 23 deals worth $206 million. Looking at A-round investments in 2004–2014 in "hard" technologies — new materials, chemicals, processes, and hardware integration firms — VC investors lost nearly $1.25 billion while software returned 3.7× what was invested.[172]

The pie chart shown in Figure 4.1 bears all this out — it illustrates how U.S. industrial and services sectors fared in total venture capital investment (totaling just below $60 billion) in 2015, based on National Venture Capital Association data.[173] The pie sizes show the dominance of software which amounted to 40% of the 2015 venture total. Biotechnology accounted for 13% of the total. Various services sectors (including "Media and Entertainment" and "IT Services") had a 31%

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[172] Gaddy, *et al.* (2016). *Venture Capital and Cleantech*, pp. 10–12.

[173] See, Historical Trend Data, PWCMoneyTree, Available at: https://www.pwcmoneytree.com/HistoricTrends/CustomQueryHistoricTrend. For definitions of the technologies and services included in the various industry categories, see, https://www.pwcmoneytree.com/Definitions/Definitions. In 2016 PWCMoneyTree revised its categories and spending levels, but the sectoral trends identified here continue.

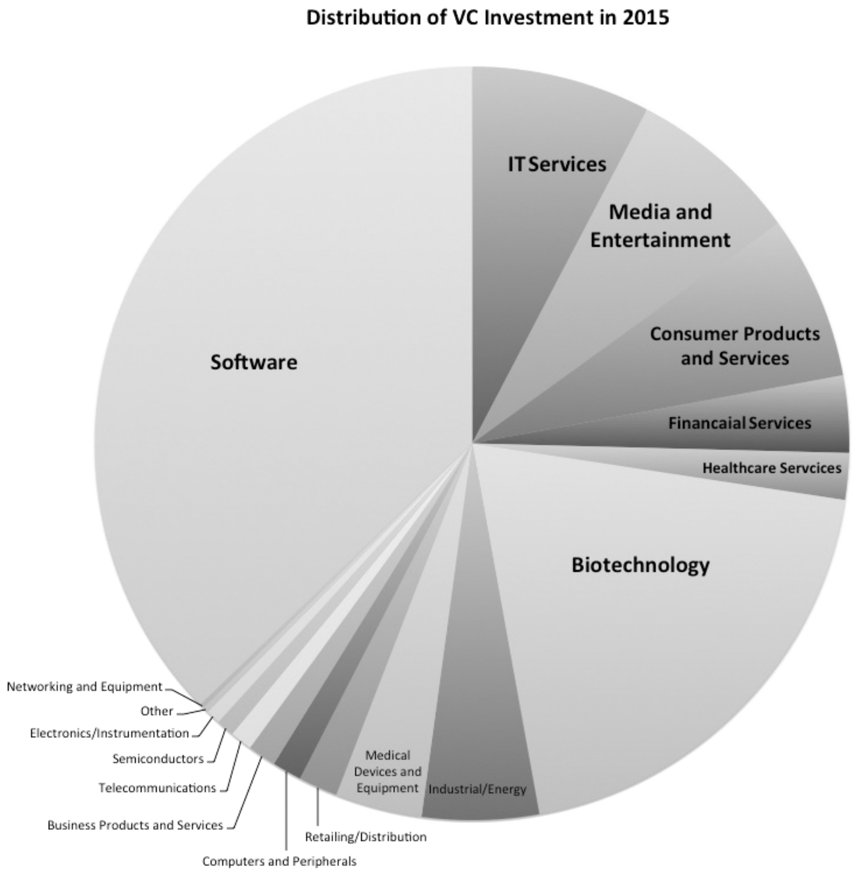

Figure 4.1: Distribution of VC investment in 2015.
Source: NVCA and PWC/MoneyTree data, July 2016.

share in 2015 venture investment. The entire category of "industrial and energy" funding is small in comparison, a 5% share.

In other words, although VCs were the great engine, starting in the 1980s, for scaling up the IT revolution and then the biotech revolution, VCs are not providing significant support to many of the other sectors that tend to be the more job creating and capital intensive sectors of the economy. If VCs weren't going to play a role in scaling up technology firms that plan to manufacture, where could substitute financing come from?

Are there other means to scale up startups that plan to manufacture? *Initial Public Offerings (IPOs)*, once a frequent means to raise scaleup capital, have been in sharp decline. Between 1995 and 2015, U.S. IPOs per year decreased from 578 to 183, although for venture capital-backed firms this decline was only 183–77.[174] The sector to see the largest increase in number of IPOs was biotechnology, which increased from 16 in 1995 to 41 in 2015, making up 61% of all venture backed firms to go public in 2015.[175]

Mergers and acquisitions (M&As) can be another scaleup device, potentially enabling innovative startups to partner with larger firms with deeper pockets for scaleup. M&As, unlike IPOs, have not been in decline.[176] It is hard to break out from overall merger totals those between innovative startups and larger firms aiming to further the technology. But M&As are a standard exit route for VCs and that data is available. As with the underlying venture funding, two sectors dominate. The software sector makes up the greatest share of annual M&A's for venture-backed firms, with just over 50% in 2015. However, even though over seven times as many software firms were acquired or merged in 2015 than biotech companies, the total value of the biotech deals was 23% higher.[177] As biotech companies move their products closer to market their value increases rapidly and is indicative of the more monopolistic markets (based on the power of patents in the health sector) that biotech firms operate in compared to many software companies.

Crowdfunding, a new source of financing where large numbers of investors contribute small sums online, was authorized by the JOBS Act of 2012.[178] By 2013 it raised $5.1 billion for new firms. However,

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[174] National Venture Capital Association (NVCA), Yearbook 2015, p. 63.

[175] NVCA Yearbook 2015, p. 66.

[176] David Braun (2016). Mergers and Acquisitions: 2015 A Record Breaking Year, Jan. 22, 2016, Available at: http://successfulacquisitions.net/mergers-and-acquisitions-2015-a-record-breaking-year/

[177] NVCA Yearbook 2015, pp. 70–71.

[178] Jumpstart Our Business Startups (JOBS) Act, HR 3606, 112th Cong., 2nd Sess., signed into law on April 5, 2012. See, Securities and Exchange Commission, JOBS Act, https://www.sec.gov/spotlight/jobs-act.shtml. See generally, Chance Barnett, Crowdfunding Sites in 2014, *Forbes*, Aug. 29, 2014; Stuart Dredge, Kickstarter's biggest hits — why crowdfunding now sets the trends, *The Guardian*, Apr. 17, 2014.

crowdfunding to date tends to favor services or products that can be readily understood by consumers and promptly brought to market, not production of complex technologies that require long term development. The JOBS Act also authorized *mini-IPOs*. Because of delays in Securities and Exchange Commission regulations and issues with state auditors, only a small number of firms have been able to use this mechanism to date.[179] *Traditional bank lending* has always been hard for startups to obtain because they lack an income stream and collateral. In economist Hyman Minsky's panoply of debt, they fall into the riskiest category: there is no cashflow and the firm is betting its underlying (its new technology) asset will appreciate enough to cover liabilities.

A number of new approaches have been tried in recent years to help startups in addition to making more capital available. These can include elements such as the creation of a support community and familiarity with local opportunities, or family offices where well-to-do families are sometimes prepared to undertake higher risk, perhaps if societal benefits are involved. These could potentially reduce some uncertainty and help firms outside of software and biotech. However, the data shows that venture funding (which is in turn often tied to follow-on IPO or M&A exit strategies) remains by far the largest pool of funding for innovation-based startups — close to $60 billion in 2015 — and that it is dominated by software and biotech startups, as well as services-oriented firms.

The second Advanced Manufacturing Partnership (AMP2.0) project picked up on a growing awareness of VC financing problems for startups and the findings from the PIE report noted earlier. It identified the gap in financing for production scaleup, which limited the ability of non-IT products to be designed, produced and enter markets, as a major problem in the U.S. manufacturing system, and studied possible solutions.[180] The AMP2.0 workgroup on "Scale-up Policy" held a series of multi-city workshops looking at financing mechanisms that could

[179] Ruth Simon, Few Businesses Take Advantage of Mini-IPOs, *The Wall Street Journal*, July 6, 2016.

[180] President's Council of Advisors on Science and Technology (PCAST), Advanced Manufacturing Partnership, Report to the President on Accelerating U.S. Advanced Manufacturing, Advanced Manufacturing Partnership AMP2.0 Report. Washington, DC: PCAST, Oct. 2014, pp. 38–43, 77–87.

make investment in the scaleup to production more attractive to capital markets. The workshops included experts from a wide array of banking, venture capital, private equity, and corporate venture firms evaluating ways to move capital-intensive technologies into commercial production. It also looked at existing federal financing mechanisms.[181] To increase this capital access, which the workgroup found affected small- and mid-sized manufacturers with innovative ideas as well as entrepreneurial startups, the AMP2.0 report recommended:

> *Launch a Public–Private Scale-Up Investment Fund for First At-Scale Production Facilities.* By offering low-cost loans to private-sector investors in "first-of-a-kind" production facilities a public–private Scale-Up Fund could incentivize additional investment in first of a kind production facilities, ensuring that technologies invented in the United States can be made in the United States. The fund would award loans to investment funds or investor consortia in an equivalent amount to half the cost of the project being financed, and support investments of at least $40 million, to address investments at the scale where access to finance becomes truly challenging.

These were clearly ambitious proposals. Although the White House was supportive, Congress, in a period of scarce resources, was simply unwilling to consider the new financial tools recommended.

None of the various and emerging financing mechanisms discussed earlier, then, is either positioned or at the scale needed to offset the inability of venture firms to undertake the higher risk of scaling up complex, science-based, innovative technologies that require manufacturing. Venture capital, by far the largest source of support for startups, for very understandable market return and risk management reasons, has focused on two sectors, software and biotechnology. These are important sectors and certainly deserve support. However, the data shows that

[181] For a summary of potential federal financing mechanisms for startups or smaller firms for production scaleup, see, Peter Singer, MIT Washington Office, Manufacturing Scale-Up: Summary of 14 Relevant Federal Financing Programs, report, May 27, 2014, Available at: http://dc.mit.edu/resources/policy-resources.

there is indeed a gap in the innovation system for scaling up innovative startups outside of the software and biotech sectors as well as services.

4.5 Societal implications

If technological and related innovation is the dominant causative factor behind historical U.S. economic growth, expanding the scope of the economic sectors that innovative startups can reach into could be important to broader economic growth. The reason to support entrepreneurship and startups is to increase societal levels of innovation to improve growth; if we wall off the access of entrepreneurship largely to two sectors and leave much innovation to die on the vine, the consequences for the economy and society will be serious.

There may be an underlying rule here: we get the innovation we pay for. If we invest in certain kinds of innovation, that is the kind of innovation we will get. If we want, for societal as well as economic reasons, to broaden the kinds of innovation entering the economy and society — for example, new energy technologies — we will need to find ways to broaden our innovation support mechanisms.

There is another reason to attempt to fill this innovation system gap. Manufacturing is well known for its ability to serve as the economy's largest job multiplier.[182] Complex, capital intensive, science-based technology goods require manufacturing. As noted earlier, manufacturing tends to create value chains of firms and accompanying jobs that reach, on the input side, from resources to R&D to suppliers and component makers, then to the production stage itself, and then on the post-production output side, from distribution to retail to repair to product life cycle.[183] The employment at the production stage itself is only a part of the employment that stems from the larger system. Software does not require manufacturing and biotechnologies generally

[182] See discussion and sources cited in, William B. Bonvillian and Charles Weiss (2015). *Technological Innovation in Legacy Sectors*. Cambridge, MA: MIT Press 2015, p. 44.

[183] William B. Bonvillian (2016). Donald Trump's Voters and the Decline of American Manufacturing, *Issues in Science and Technology*, Summer, 37–38, See generally, Bonvillian and Weiss, *Legacy Sectors*, 37–54, 87–95, 215–239.

require less. Software especially does not require and therefore does not create comparable value chains and corresponding employment. If we are curtailing startups that make hard technologies, we are therefore affecting our employment rate. Both software and biotechnology are vital, for different reasons. But they are not enough.

Since in recent years the U.S. has been facing the consequences of what has been called a "jobless recovery" (a very slow job recovery rate) following the Great Recession, of growing income disparity, and of a 20% decline between 1990 and 2013 in median income for men without high school diplomas, and a 13% decline for men with high school diplomas or some college, this quality jobs creation issue is a significant societal challenge.[184] Leading economists are arguing that the economy has fallen into a state of "secular stagnation" with insufficient demand and resulting slow growth, low inflation and low interest rates.[185] U.S. per-person GDP growth averaged 2.4% for the 40 years starting in 1961, but for the past 15 years averaged only 0.9%.[186] A McKinsey study showed 81% of the U.S. population in income brackets with flat or declining income over the past decade.[187] While 2016 unemployment rates fell to 4.9% this counts only those actively looking for work; there are some 5 million fewer workers in the workforce than projected in 2005, about half from an aging population, but half not fully accounted for.[188] While the steep declines of the Great Recession affected these numbers, the subsequent recovery has not been robust — for example, per capita GDP growth since 2010 has still been well below 2%. There is also a

[184] Bonvillian, Decline of American Manufacturing.

[185] Lawrence Summers, Speech to IMF Economic Forum, Nov. 8, 2013, Available at: https://www.youtube.com/watch?v$=$KYpVzBbQIX0.

[186] World Bank, GDP Growth Per Capita (annual percentage) — United States, 1960–2015, Available at: http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations$=$US.

[187] McKinsey Global Institute (July 2016). Poorer than their Parents? A New Perspective on Income Inequality, Available at: http://www.mckinsey.com/global-themes/employment-and-growth/poorer-than-their-parents-a-new-perspective-on-income-inequality.

[188] Jason Furman, Chairman, Council of Economic Advisors Trends in Labor Force Participation, presentation, National Press Club, August 6, 2015, Available at: https://www.whitehouse.gov/sites/default/files/docs/20150806_labor_force_participation_retirement_research_consortium.pdf.

growing anxiety about what has been termed "jobless innovation"[189] — a growing host of innovations that that enter economic sectors that create fewer jobs or that replace jobs.[190] If such problems are to be overcome, part of the answer may be expanding the access of innovative startups to a broader spectrum of the economy, including in higher job-creating sectors that require manufacturing.

An important part of the answer, then, may be to look at the organization of the innovation system itself. Despite problems neoclassical economists have in tracking the complex innovation system and viewing as it as endogenous not exogenous to the economics,[191] it is widely acknowledged by economists to be at the heart of economic growth. This system is not locked-in on some kind of "invisible hand" economic autopilot. It is a flexible, dynamic system that responds to a range of inputs and organizational approaches. If the U.S. limits investment in innovation to the fruits of software, biotech, and services sectors because of the financing challenges discussed earlier, then it will get innovation in those sectors, not others. Inputs affect outputs. If the U.S. wants to address challenges of "jobless recovery" and "jobless innovation," one step is to adjust the innovation system to expand the entry of innovation into a wider range of economic sectors.

4.6 "Innovation orchards:" substituting space for capital

In a May 2015 *Washington Post* op ed titled, "A better way to deliver innovation to the world," MIT President Rafael Reif proposed an alternative.[192] He argued that the current U.S. innovation system based

[189]Bonvillian and Weiss, *Legacy Sectors*, ix, 2–5, 7, 197, 253.

[190]Erik Brynjolfsson and Andrew McAfee (2014). *The Second Machine Age*. New York: WW Norton and Company 2014; Eric Brynjolfsson and Donald McAfee. *Race Against the Machine*. Lexington, MA: Digital Frontier Press. Compare, David Autor (2015). "Why Are There Still So Many Jobs? The History and Future of Workplace Automation," *Journal of Economic Perspectives*, 29(3), Summer, 3–30.

[191]This debate stems from Paul Romer (1990). Endogenous Technological Change, *Journal of Political Economy*, 98(5), Available at: http://pages.stern.nyu.edu/~promer/Endogenous.pdf.

[192]L. Rafael Reif (2015). "A Better Way to Deliver Innovation to the World," op ed, *Washington Post*, May 28, 2015, Available at: https://www.washingtonpost.com/opinions/a-better-way-to-deliver-innovation-to-the-world/2015/05/22/35023680-fe28-11e4-8b6c-0dcce21e223d_story.html.

on venture support for startups was not suited "to support complex, slower-growing concepts that could end up being hugely significant." This included disruptive new technologies emerging from basic science advances in non-"digital" areas that were not "market-ready." He wrote that if new technologies have,

> a good shot of producing returns within five years, they are magnets for talent and venture capital — and eventually for big companies that often buy startups whole. But this system leaves a category of innovation stranded: new ideas based on new science... [These] may take 10 years, which is longer than most venture capitalists can wait. The result? As a nation, we leave a lot of innovation ketchup in the bottle.

He proposed an interesting potential solution to close this gap and accelerate the process from "idea to investment": create spaces for startups that would be rich in technology, advanced equipment and know-how to enable the startup to undertake advanced prototyping, demonstration, testing, and pilot production. In effect, he proposed substituting space for capital. This technology-rich space could bridge over the missing venture funding support for what Reif called "tangibles" — complex, more capital intensive, longer-term, hard technologies, which could also be "tangible-digital hybrids" — since those steps in the product design and development process would be what venture capital, if it was available, would have funded. He proposed establishing coalitions of "funders from the public, for-profit, and not for-profit sectors" to support these new spaces and the startups that would populate them. He believed that regional firms would increasingly need to follow emerging innovations and some could also be persuaded to support this new model, which he called "innovation orchards." These new support communities would support innovators with the resources, facilities and mentorship as well as bridge funding, they need to successfully de-risk and commercialize their technology. If the emerging startup technology was de-risked, demonstrated, and proven, it could potentially move within range of more traditional financing, such as partnerships with existing firms, corporate venture, and venture capital funding.

He also proposed that there may be "ways to shorten the full span from idea to impact, reducing it from, say, 10 years to 5." He suggested it, "may be possible to reproduce the process of rapid, relatively low-cost refinement and interaction that is so powerful in advancing purely digital concepts." The "innovation orchards" model may be able to help with that step, as well, such as by creating parallel development paths for both ongoing research and production design and testing.

4.7 Models relevant to "innovation orchards:" Cyclotron Road and TechBridge

The proposed "orchards" would be anchored in existing innovation clusters, taking advantage of the mixes of firms, small and large, and capabilities typically present in these. It would add a new institutional element building on "cluster theory."[193] The orchards could also build on existing mechanisms to help startups: regional technology incubators that generally serve startups in their early stages, the SBIR (Small Business Innovation and Research) program, the Bayh Dole Act system of licensing new technologies from university research, NSF's new Innovation Corps program to train university researchers in initiating startups, and various state and university programs for technology commercialization.[194] But the "orchards" model would fill an important gap in the existing mechanisms, around startup scaleup.

There are some specific working models that are comparable to the "innovation orchard" concept Rafael Reif has proposed; two are

[193]Cluster theory began with economist Alfred Marshall who noted the importance of specialized industry sectors in particular regions, which he called "industrial districts." Alfred Marshall (1890). *Principles of Economics*. London: Macmillan. See for example, Michael Porter (1990). *Competitive Advantage of Nations*. New York: Free Press; Adrian T.H. Kuah (2002). "Cluster Theory and Practice: Advantages for the Small Business Locating in a Vibrant Cluster," *Journal of Research in Marketing and Entrepreneurship*, 4(3), 206–228 (sources on cluster theory).

[194]The range of available programs is summarized in Joseff Kolman, MIT Washington Office, Summary of Federal State University and Private Programs for Supporting Emerging Technology, July 10, 2015, Available at: http://dc.mit.edu/resources/policy-resources. See also, William B. Bonvillian (2014). "The New Model Innovation Agencies: An Overview," *Science and Public Policy*, 42(4), 28–29 (programs from the 1980s to bridge the technology "valley of death").

discussed here and each offers different insights on how this approach might work.[195]

Cyclotron Road: Lawrence Berkeley National Laboratory, a Department of Energy lab managed by the University of California — Berkeley, formed Cyclotron Road (CR) in July 2014 as an early stage clean energy technology incubator. The project was supported by the Advanced Manufacturing Office in DOE's Energy Efficiency and Renewable Energy office and founded by Ilan Gur, previously a program director at DOE's ARPA-E where he worked on energy storage, solar and advanced materials. CR describes itself as "a home for top entrepreneurial researchers to advance technologies until they can succeed beyond the research lab."[196]

Lawrence Berkeley Lab is an $820 million a year energy lab with 4,200 employees and 6 major national user facilities adjacent to the UC Berkeley campus. CR aims to link the lab, with its technology, equipment, and knowledge base, with a group of competitively selected, early stage, energy technology startups. As of 2016, there were 16 such startups located in a facility next to the lab with access to it and its resources. Each of the startups receives DOE seed funding and salaries for 2 years to pursue technologies tied to DOE's mission of nurturing new energy technologies. CR, with the lab, provides supporting mentorship and expertise and help in pursuing manufacturing and technoeconomic feasibility for the startups' technologies. The startups are not "home alone": in addition to access to advanced equipment and technologies to perfect their technologies they gain access to strong supporting "know-how" networks in the lab and at UC Berkeley, and through connections, to nearby Silicon Valley, and to potential industry partners. An aim is validation of business and technology models to enable the technology to scale.

CR follows a five-element approach to find and develop promising energy technologies[197]: this is not a linear set of steps, they can proceed

[195] This section draws on Nathalie Bockelt, MIT Washington Office, Bridging the Innovation Gap in the U.S. Energy System, February 2016, Available at: http://dc.mit.edu/resources-links.

[196] Cyclotron Road website, Available at: http://www.cyclotronroad.org/home.

[197] Cyclotron Road, 2015 Report — A New Pathway for Hard Technology: Supporting Energy Innovators at Cyclotron Road, 2015, p. 10, Available at: http://static1.

in parallel and in different sequences.

1. *Recruit outstanding innovators.* CR states that, "Top-notch innovation can't occur without top-notch people. We look for outstanding talent willing to go "all-in" to drive their energy technology from lab to market." They aim at early-stage startups at the pre-financing stage, and now have their second cohort in place, totaling 16 selected from pools of more than 100 applicants each. So CR is talent oriented, looking for capable entrepreneurs with sound and exciting technology ideas, capturing these at an early stage.

2. *Select projects focused on commercial and scalable technical solutions to maximize energy market impact.* CR is focused on commercial energy breakthroughs that have realistic potential for impact at scale. It attempts to assist innovators in identifying first product markets to demonstrate potential customer reach and technical feasibility as early as possible. The process of evaluating technical and economic feasibility and making potential technologies manufacturable at competitive cost are important parts of this process.

3. *Leverage existing R&D assets through the partnership with Lawrence Berkeley Lab.* For startups working in hard technologies, the cost and time needed to set up a research lab, procure advanced equipment, obtain equipment training, and set up safety protocols are significant barriers. But having this set up is key to developing and testing advanced prototypes. CR resolves this through its partnership with Lawrence Berkeley Lab. Startup leaders work directly with Berkeley Lab experts using cutting edge equipment almost from the time they join the program. This immediate access to R&D facilities dramatically reduces the startup costs for hard technology projects, while providing innovators the opportunity to fail and pivot efficiently based on early results—substantially de-risking technologies while continuing to revise their business

squarespace.com/static/543fdfece4b0faf7175a91ec/t/55efcf96e4b0fe570119a737/1441779606809/Cyclotron_Road_A_New_Pathway_final.pdf.

model. This rich access to technology is a key distinction between CR and most technology incubators.

4. *Support innovators with seed funding, mentors, and networks.* CR provides salaries and seed funding to enable its innovators to focus full time on their projects and also helps enable federal R&D funding by meeting any cost-sharing requirements. It links its hard-tech entrepreneurs, R&D executives, investors, and government researchers as mentors for it startups, helping them with the technical and business advice necessary to take their projects to the next level. Networking with other entrepreneurs and industry and at technology events is also built into the model.

5. *Connect innovators commercial partners.* CR argues that, "There is no one-size-fits-all business model for hard tech. Our goal is to maintain the viability of multiple pathways technologies to scale." CR aims to help its startups find the optimal commercialization path and funding sources, considering a range of partners, including:

    - *Corporations* — firms can partner with entrepreneurs in joint development projects, minority equity investment, or outright acquisition.
    - *Venture Firms* — **v**enture financing is limited for early-stage hard technologies, but as the technology is derisked, it may be available for some firms at later stages. Venture can also provide leverage for non- dilutive grants and help innovators scale when the technology is proven and the market opportunity sufficiently clear.
    - *Family Offices* — family offices are increasingly interested and creative in their ability to extend equity and debt financing to clean tech entrepreneurs.
    - *Non-profits* — some innovations can be effectively brought to scale through non-profit or open source development models.

The first cohort of startups illustrates the kinds of technologies that could emerge from CR — it includes:

- *Mosaic Materials*, which is working on new metal-organic adsorbents to reduce the cost and emissions impact of chemical separations that required in the production of a wide range of commodity chemicals.
- *Visolis*, which focuses on the bio-based production of carbon-negative, high-performance polymers which could be much more efficient and less expensive than petroleum-based processes and cut greenhouse gas emssions.
- *Spark Thermionics*, which is working on directly converting heat to electricity using compact, microfabricated thermionic energy converters that could replace conventional heat engines.
- *CalWave*, which aims to convert ocean waves into electricity for both baseload power and for freshwater through desalination.
- *PolySpectra*, which works to print functional materials with tailored forms and functions in a single step — called "functional lithography" — for example, for paintable photonic crystals for energy efficient windows.
- *OPUS 12*, which aims to recycle carbon dioxide into chemicals and fuels using an electrochemical process.

Interestingly, CR may represent a new approach to tech transition for DOE. The department has been working for decades to improve the transition of technologies from its labs into commercial products. However, well-paid lab scientists with assured employment and interesting scientific work have only a limited incentive to leave their labs and create new high-risk companies around their technologies. While established companies can license technologies from the labs, their interest in technology licensing tends to be limited to incremental advances that fit their existing technologies and business plans. But locating energy technology startups just outside DOE lab gates with access to lab technologies and know-how may be a more effective new way to transition technologies. DOE has been very interested in the CR model — Argonne National Lab near Chicago has just created a similar model called Chain Reaction Innovations to "help entrepreneurs bridge the commercialization valley of death," Oakridge Lab has created "Innovation Crossroads," and others may evolve.[198]

TechBridge: This energy technology program was started in 2013 through the Boston Fraunhofer Center, a non-profit R&D center and a branch of the German Fraunhofer network. It was founded by Johanna Wolfson, a physical chemist PhD from MIT who has now shifted, as Director of Tech-to-Market, to work on comparable models at DOE, and is currently led by Jacqueline Ashmore, an applied math PhD with experience in scientific analysis and innovation partnerships. It follows a different approach from Cyclotron Road: it identifies potential industry partners for startups based on technologies the larger firm is interested in, links the two, then performs a detailed technology evaluation and validation of the startup's technology to help set the pathway for its scaleup.

TechBridge has developed its own four-step "method" that defines its role and how it attempts to pave the way for innovative new energy firms to attract partners, funding and customer[199]:

1. *Define*: Techbridge works with program sponsors — typically larger companies — to determine the scope and goals of each project, typically focusing on innovation in a particular a topic of strategic interest to the sponsor, or in a particular region (often using a collaborating government sponsor). This is key for the TechBridge approach — working on a concrete innovation of strong interest to the sponsor, then tying this interest to a developing technology.

[198] Argonne National Laboratory, Argonne Launches First Tech Incubator, May 20, 2016, Available at: http://www.anl.gov/articles/argonne-launches-first-tech-incubator. See also, Chain Reaction Innovations Website, Available at: http://chainreaction.anl.gov. Oakridge National Lab, Innovation Crossroads website. Available at: http://innovationcrossroads.org/program/about/.

[199] Fraunhofer Center for Sustainable Energy Sytems, TechBridge website, Available at: http://www.cse.fraunhofer.org/techbridge/method.

2. *Identify*: with a sponsor, the need, and the technology is pinned down: TechBridge then executes a comprehensive search and selection process for a startup that can meet the technology need. The startup must integrate strong technical and business expertise.

3. *Design*: Fraunhofer domain experts design a customized technology validation or demonstration project that integrates the goals of the sponsor with those of the selected startup. Fraunhofer is noted for its skill and expertise in the tech validation process — will the startup's emerging technology work, can it be efficiently produced and how, and is it in financial range to solve the challenge? Here, TechBridge tries to design a practical implementation process that fits the best optimal development of the technology given the sponsor's timetable and financial limits.

4. *Execute*: The technical projects are executed at Fraunhofer research facilities[200] and in real-world settings. Projects include optimizing and testing prototypes; conducting field demonstrations in real-world conditions; performing system integration work; end evaluating manufacturability. Practical problems such as maintenance, and ease of technology operations are considered. Fraunhofer plays the role of third-party independent evaluator for both sponsor and startup, preparing the startup for the partnership and the scaleup of its technology in practical settings.

The technology validation process through the highly respected Fraunhofer labs — an independent third party — is unique and particularly valuable, for both the startup and the supporting company. The startup is aided by a thorough evaluation of its technology and detailed recommendations for production design. It can demonstrate that the proposed technology can work and can be produced. The larger firm in turn can be reassured by the validation step that it is getting a sound and manufacturable solution to its challenge from the startup. It lowers risk for both sides.

[200] Fraunhofer CSE Research Facilities, Available at: http://www.cse.fraunhofer.org/about-fraunhofer-cse/labs-and-facilities.

As Nathalie Bockelt has noted,

> While CR tends to work bottom-up, focusing on entrepreneurial researchers with ideas, providing them access to technology, then linking them to possible funding support, TechBridge tends to work the other way around, top-down. It finds significant supporters (typically larger firms) in need of innovations, then seeks to link them to startups with the capability to purse these innovation challenges, while providing technical support and validation.[201]

Both Cyclotron Road and TechBridge provide instructional models for ways to scaleup startups in preparation for the production process. MIT in October 2016 started its own version of an "Innovation Orchard," The Engine, to work with startups in the Kendall Square area. But what about help with the production process itself?

4.8 Linking startups to small manufacturers: Greentown Lab and MassMEP

Most technology-based, innovative startups now come from university research benches through researchers, post-docs, and grad students. These startups know their research, but not manufacturing. The Greentown Lab–MassMEP partnership[202] between startups and small manufacturers has attempted to get the startups past this innovation gap; it offers an additional feature to the Innovation Orchards approach.

Greentown Labs is an energy technology startup incubator located in Somerville, adjacent to Cambridge, MA and MassMEP is the Massachusetts branch of the NIST-sponsored Manufacturing Extension Partnership. The MEP program dates from the 1980s manufacturing competition with Japan and works in every state to bring the leading

[201] Bockelt (2016). Bridging the Innovation Gap, p. 16, Available at: http://dc.mit.edu/resources-links.

[202] Section draws on, Katherine W. Nazemi (July 2016). "From Startup to Scale-Up: How Connecting Startups with Local Manufacturers Can Help Move New Technologies from Prototype to Production," MIT Washington Office Paper, Available at: http://dc.mit.edu/sites/default/files/doc/Connecting%20Startups%20to%20Small%20Manufacturers%20Nazemi%20July%202016.docx.

manufacturing technologies and processes to small American manufacturers. The 250,000 small manufacturers employing less than 500 produce the majority of U.S. goods; they are the suppliers and component makers for the OEMs (original equipment manufacturers) — the larger manufacturers. But MEP has been a program for existing small manufacturers; helping startups manufacture has not been part of the MEP equation.

In November 2014, Greentown and MassMEP partnered on a 1-year pilot program called the Greentown Labs–MassMEP Manufacturing Initiative, to link startups to local manufacturers to help them get their new technologies production-ready. The program was created and run by Micaelah Morrill, a program director at Greentown Labs, and Peter Russo, the growth and innovation program director at MassMEP.

Morrill at Greentown Labs saw that even startups with initial funding and an initial prototype still had trouble moving to the production stage. During their one-year pilot, Morrill and Russo at MassMEP identified the barriers that prevent startups and established small- and mid-sized manufacturers from working together and developed a system to address them. Their initiative developed a way for startups moving toward production to connect to manufacturer partners and move their prototype to production-ready design.

Barriers between the Two Sides: An initial Greentown survey found not only that startups and manufacturers didn't know each other or how to find each other, but that there were cultural and communications barriers. They were speaking in different languages from different worlds.

Startups often thought they had to manufacturer in Asia; if they were fortunate enough to have venture support, their VC often told them to do this.[203] They were often unaware how much manufacturing capacity remained nearby — after all, the U.S. is still the second largest manufacturing nation by output. They also had little sense of the advantages of working in close proximity to collaboratively resolve ongoing design problems. While the startups did thorough research they generally had little to no experience with production processes. The small manufacturers were the other side of the coin — they conducted

[203] Reynolds, *et al.* Learning by Building.

no R&D but knew intimately production processes and technologies. While startups typically made connections online, small manufacturers interested in teaming with startups made connections by word of mouth, by telephone and through face-to-face relationships.

When it came to design for manufacturing, startups were often out of their depth: they were uncertain of their own production needs and of what questions to ask. Communication style, timeframes, and incentives were simply different between the two sides. Finally, the startups did not understand the levels of overhead and cost for developing an advanced, manufacturable prototype, and how this required most small manufacturers to be assured of a longer production run to recoup a profit. Small lot production often won't work for most innovative, complex products.

Yet the two sides needed each other. The startups had to understand and succeed at production and needed expert allies to get there. The small manufacturers didn't undertake R&D but were interested in the possibility of growing past their current supplier networks by producing innovative goods to scale their production. A number also wanted to help their communities by helping the startups, and to inspire their employees by working with startups.

The Pilot Program: To get across these barriers, Greentown Labs and MassMEP developed a multi-part program to educate and organize startups on production issues and enable connections with area manufacturers. Because of the barriers between the two sides, the program had to be intensely face-to-face — an online computer matching service was not going to work. The program included surveys, a series of "office hours" meetings and workshops and face-to-face sessions in which startups received one-on-one advice and guidance for effective communication with manufacturers along with general design for manufacturing information.

1. *Survey*: Two required surveys, one to startups and one to interested manufacturers, helped each to focus and develop expectations for the other.

2. *"Office Hours"*: Office hours were available to Greentown Labs startups, along with other hard tech startups in the area, hosted

by Peter Russo from MassMEP, an experienced manufacturer, along with other manufacturing experts and Greentown Lab's staff. The process helped startups determine the types of manufacturing capabilities they needed, to understand production processes, and to consider their production design. When he found the startups were not yet ready to begin manufacturing, Russo would review their plans and help with the design, in a 30 to 40 minute work session. After incorporating Russo's feedback, the startups would come back for a second, shorter meeting. Once their design was closer to readiness, Russo and Morrill would help connect them to a manufacturer.

3. *Workshops*: To educate startups about manufacturing processes, Greentown Labs hosted workshops and "lunch and learns" for groups of Greentown and other startups. These brought manufacturers to Greentown for half-day informational panels, then startups could meet one-on-one with the manufacturing representatives and start to build relationships. Workshops focused, for example, on production processes, such as extrusion and injection molding, or on types of materials.

Greentown's involvement formally ended after the first connection was made; the process of negotiating and signing a contract was left to the manufacturer and the startup. No subsidies were provided — the startup had to find its own funding for the deal, which gave both sides a major stake in the outcome. But Morrill and Russo continued to provide mentorship and advice to both startups and manufacturers as they progressed in their relationships.

Results: In the one-year pilot, 32 startups were interested in participating in the program and 83 manufacturers were interested in working with startups. The program facilitated some 140 connections between startups and manufacturers and resulted in 19 signed contracts. Working with local manufacturers meant a close and prompt collaborative process for production design that solved many design problems and challenges. Both Greentown and MassMEP have continued to followup on their pilot, fostering connections.

The Greentown Labs-MassMEP initiative to link startups and small manufacturers is a complementary feature for the "Innovation Orchards" model. One is pursing the full scope of the innovation process through technology scaleup, the other enables startups to link to the initial production stage of the innovation process. But this initial production stage is clearly part of the innovation process; missing it amounts to an innovation system gap. The combination of approaches can integrate the manufacturing process into the startup innovations, helping to ensure that their prototypes can become be commercially viable.

4.9 Summary

Startups represent the next generation of technology. If startups offshore their production, this affects the strength of the overall innovation system because production, particularly initial production of new technologies, is an important part of that innovation system. Ultimately, it means that a core innovation capability has shifted with the production shift. So enabling innovative startups that require manufacturing fills a gap in the innovation system.

However, these kinds of innovative, hard technology startups are running into increasing difficulty in scaling up to the manufacturing stage. Venture capital financing has been key to the entrepreneurial startup system pioneered by the U.S. since it supported the computing, semiconductor, and then biotechnology advances in the 1980s. However, venture capital is increasingly focused on software, biotech, and services sectors, where investor risks can be reduced, and away from longer term, higher risk, hard technologies. While there may be other startup financing options, these are not at a scale or positioned to provide significant help to most hard technology startups.

Despite the importance of innovation to economic growth, the U.S. is narrowing its innovation to several sectors, therefore affecting its potential growth rate. We will get the innovation we pay for; if we are unable to invest in a broad range of technologies, we simply won't get them. In addition, the U.S. is not supporting innovation in significant job-creating sectors. Startups that manufacture and can't are particularly worth noting because of the role of manufacturing as the sector with the highest job multiplier effects. So problems of “jobless recovery,” of “secular stagnation” and “jobless innovation” are in part tied to this increasing gap in the innovation system.

Are there ways to get hard tech startups that manufacture out of this box and on the road to scaling up? The concept of “Innovation Orchards” proposed by MIT President Rafael Reif offers a promising approach, where university–industry–government partnerships can offer technology, equipment and know-how rich spaces for promising startups to scale up, in effect, substituting space for capital. Initial models for this approach include Cyclotron Road, based at DOE’s Lawrence Berkeley Lab, and TechBridge, housed in the Boston Fraunhofer Institute. MIT has recently launched its own “Orchard” model, The Engine, started in October 2016. A complementary feature for this “Orchard” model has been developed by Greentown Lab and MassMEP in the Boston area, where startups ready to undertake advanced prototypes, product design, and pilot production can be linked to small manufacturers who can help them scale into manufacturing.

5

Conclusion

The current U.S. innovation system really dates to Second World War — this period saw the creation of a major federal R&D role for the first time, including the creation of the federally funded research university. In the period immediately after the war the system regrouped, with a major emphasis on basic research and the research university role expanded. As the Cold War settled in, technology development to meet defense needs was added back into the mix. By then, nearly all of the current mix of decentralized, mission-based R&D agencies was fixed in place.

In this period there was no focus on R&D and technology development for the manufacturing sector. The U.S. had invented the mass production model and came out of the war with the world's strongest manufacturing sector by far. The U.S. was the manufacturing king; it could focus its innovation system on technology development on a wide range of defense, health, and other needs, not on manufacturing. Other countries couldn't do this. Germany and Japan, rebuilding their industrial bases after the war had to focus on innovation systems that were "manufacturing-led."[204] Emerging economies like Taiwan and Korea like-

[204] Bonvillian and Weiss, *Legacy Sectors*, 9–10, 25, 184–185.

wise created manufacturing-led innovation systems as they moved to the technological frontier, and China is the latest to follow that path. The U.S. left “manufacturing-led” innovation out of its innovation equation.

After a steep decline in its manufacturing sector in the decade of the 2000s, the U.S. is now playing manufacturing catchup. As detailed earlier the decline was characterized by a steep loss of 5.8 million manufacturing jobs, declining capital investment, declining output and lower productivity gains in the manufacturing sector. It was also characterized by significant social disruption. As delineated earlier, the country faces growing income disparity and a 20% decline between 1990 and 2013 in median income for men without high school diplomas, and a 13% decline for men with high school diplomas or some college. U.S. per-person GDP growth averaged 2.4% for the 40 years starting in 1961, but for the past 15 years averaged only 0.9%. A leading study showed 81% of the U.S. population in income brackets with flat or declining income over the past decade. Leading economists are arguing that the economy has fallen into a state of “secular stagnation” with insufficient demand and resulting slow growth. This stew of social problems is behind much of the voter anger that thoroughly disrupted the political system in the 2016 Presidential election. The decline in manufacturing is a leading culprit.

The implications of manufacturing decline for the U.S. innovation system are even more problematic longer term. While the U.S. built its rich economy on an approach of innovate here/produce here, where it realized the gains of innovation at every stage from R&D through production and use, it has increasingly been offshoring production and shifting to innovate here/produce there. By distributing production, it is starting to forego the full spectrum of gains from its innovation system. The issue is that manufacturing, particularly initial production of new technologies, is a crucial and creative stage in the innovation process, the step where ideas are implemented. If production shifts abroad, there is a risk that significant parts of the innovation system shift along with it. The U.S., then, has been moving toward an approach of produce there/innovate there. The jewel of the American economy, its historically strong innovation system, key to its economic growth, is at stake.

Enter Advanced Manufacturing: If the U.S. is to compete with low wage, low cost competitors abroad, arguably it must raise its production efficiency and productivity. This means it must have an innovation strategy to get there. There are no real policy substitutes; tax, trade, and macro-economic policy can adjust competition numbers at the margins but cannot significantly raise productivity and efficiency; innovation in production technologies and processes, with accompanying business models to implement them, appears to be the best, real option.

The Policy Design: The Obama Administration began to focus on an innovation initiative approach for manufacturing in an initial 2011 report. MIT's Production in the Innovation Economy (PIE) study was meanwhile evolving, telling a story of a thinned-out ecosystem of production that was jeopardizing not simply manufacturing but the innovation system itself, a crucial U.S. comparative advantage. It saw production as a key link in the innovation system which had become a weakened link. In response to such concerns, the President commissioned the Advanced Manufacturing Partnership, an intense collaboration of industry, university, and government agency leaders. The initial report, AMP1.0 advocated the advanced manufacturing institute concept, which the Administration jumped on and began to implement well before the report was released in 2012.

The second report, AMP2.0, released in 2014, fleshed out additional innovation policy proposals, supporting a public–private technology strategy around key advanced manufacturing technologies and processes, new R&D, and new institutes organized around the strategy, networking the institutes for shared learning and new workforce training models. Finally, Congress passed advanced manufacturing legislation which added a Congressional blessing to the manufacturing institutes and the whole project, creating a reasonable possibility that it could survive the disruptive politics of the time.

Institutes: The effort to stand up 15 advanced manufacturing institutes got off to a promising start starting in 2012, attempting to address a critical gap in the U.S. innovation system for manufacturing innovation. It was a complex and challenging organizational model, requiring large groups of firms, small and large and university researchers to collaborate and cost share, under guidance from federal R&D agencies not used to managing such large teams.

However, now that the basic structure is getting into place, focused initially on manufacturing technology development projects, there is an opportunity to consider a second stage of enhancements to the model. The institutes face a series of challenges, as described earlier, that can now be focused on as they continue to mature:

- improving the current research agency governance model;
- continued federal government support after the initial 5-year commitment;
- creating a strong network of institutes where best practices and research advances can be shared;
- an emphasis within the institutes on technology implementation at later Technology Readiness Levels as well as technology development;
- ensuring institute emphasis and collaboration on optimal workforce training and education approaches; and
- ensuring linkage between institutes and regional economies, in addition to serving manufacturing technology development at the national level.

In addition, federal R&D at mission agencies in advanced manufacturing technologies could be better connected to contribute to the institutes, flowing in on a continuing basis so that the technologies at the institutes don't get stranded but keep improving. Of course, the U.S., if it wants to stay in the game, now has few options other than pursuing and upping its game in advanced manufacturing, since its leading competitors are now pursing somewhat similar strategies.[205]

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[205] See, for example, Forschungsunion and Acatech (National Academy of Science and Engineering), Securing the future of German manufacturing industry, Recommendations for implementing the strategic initiative Industrie 4.0, Final report of the Industrie 4.0 Working Group, April 2013, Available

Startups: Finally, startups represent the next generation of technology manufacturing and the U.S. has developed a system where startups are key to bringing innovative new technologies into the economy. However, "hard" technology startups that manufacture are running into major difficulty in scaling up to production. Venture capital financing has been the central support mechanism for startup scaleup since the 1980s. However, venture capital is increasing focused on software, biotech, and services sectors, where risks can be reduced, and away from longer term, higher risk, hard technologies.

Are there ways to move hard tech startups that make products into scaleup? The concept of "Innovation Orchards" proposed by MIT President Reif offers a promising approach, where university–industry–government partnerships can offer technology, equipment and know-how rich spaces, with some bridge funding, for promising startups to scale up. This, in effect, substitutes space for VC capital. Initial models for this, as discussed, include Cyclotron Road, based at DOE's Lawrence Berkeley Lab, and TechBridge, housed in the Boston Fraunhofer Institute. MIT has now offered its own entrant, The Engine, to support startup scale up in the Boston area.

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The manufacturing decline in the U.S. in the decade of the 2000s led to a new strategy for manufacturing based on innovation known as advanced manufacturing. This was recognized as one among a series of needed approaches — from tax, trade, and macro-economic policy to new training approaches. But this new innovation approach was unlike anything that had been tried before by the U.S. in its manufacturing sector. It required a complex and challenging innovation organization model, joining industries small and large, university research and government agencies in common pursuit of new production technologies and processes. It sought a new competitive formula by raising production efficiency and productivity. It was an attempt to apply an historic U.S. economic strength — its innovation system — to an entirely new set of problems. Although advanced manufacturing is now well underway, many challenges lie ahead. But as Henry Ford once reminded, "Obstacles are those frightful things we see when we take our eyes off our goal."

Author Biography

William B. Bonvillian served as Director of the Massachusetts Institute of Technology's Washington, D.C. Office from 2006 to 2017, supporting MIT's long-standing role on national science and technology policy. He currently teaches as a Lecturer at MIT. He has been writing about advanced manufacturing since 2012, was an advisor to MIT's Production in the Innovation Economy study issued in 2013, and participated for MIT in the President's Advanced Manufacturing Partnership and its reports of 2011 and 2014. Prior to MIT, he served for over fifteen years as a senior policy advisor in the U.S. Senate working on innovation issues.

His 2015 book *Technological Innovation in Legacy Sectors*, with Charles Weiss of Georgetown, was published by Oxford University Press and takes up the challenge of bringing innovation to complex, established "legacy" economic sectors that constitute most of the economy. Their book *Structuring an Energy Technology Revolution,* published by MIT Press in 2009, proposed new models for energy technology innovation. He has written extensively on science and technology policy issues in numerous journals, including *Science*, *Issues in Science and Technology*, *Nature*, *Science and Public Policy*, *Innovations*, *Environment*, and *American Interest*, and has chapters in books published by Brookings, Stanford Univ. Press, the National Academies and Edinburgh Univ. Press.

He has lectured and given speeches before numerous organizations on science, technology and innovation questions, has been on the adjunct faculty at Georgetown and Johns Hopkins teaching in those areas, and teaches policy courses at MIT on science and innovation. He is on the National Academies' standing committee for the Science Policy Forum, served for seven years on its Board on Science Education, and on four other Academies' committees. He has served on the AAAS Committee on Science Engineering and Public Policy, on the Board of the Information Technology and Innovation Foundation, and on APLU's Commission on the Science and Math Teaching Imperative. He was the recipient of the IEEE Distinguished Public Service Award in 2007 and was elected a Fellow by the AAAS in 2011.

Earlier in his career, he served as a Deputy Assistant Secretary at the U.S. Department of Transportation, working on major transportation deregulation legislation, and was a partner at a large national law firm. He received a B.A. from Columbia University with honors, an M.A.R. from Yale Divinity School; and a J.D. from Columbia Law School, where he also served on the *Columbia Law Review*. Following law school, he served as a law clerk to a noted Federal Judge in New York.