Musings on Manufacturing

Volume 1 - H2 2026

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Figure 1 - This image was AI generated with the prompt: "Generate me an image of a man excitedly pointing at an operating CNC machine with the largest $#!t-eating grin possible." It gave me an image with the machine cover open, so I asked it to appropriately decorate the operator with coolant. What you see is the result of that 3 seconds of work.

Contents

A note from the person responsible

For those who don’t know me already, I’ve been working in the CAD/CAM/CAE software industry for almost thirty years now, and specifically with manufacturing software for over a decade. Recently, I changed jobs, and I needed to refamiliarize myself with where things are in the world of manufacturing. So, being Gen-X, I did research, which means I read... a lot. As I read, I took notes... with a pen... on paper... trying to synthesize what I was reading into some ideas about the state of manufacturing. Along the way I ran into some interesting side questions that I thought were worth thinking about.

This report is the result of that exercise. You’ll notice that I haven’t tarted this up with pretty formatting and barely relevant images (title page excluded) and I didn’t ask for anything from you to get access. Let’s be honest... if you feel like you need pictures to stay interested, then this probably isn’t the place for you, and I don’t know if this is all worth anything anyway. However, if you want to spend some quality time thinking about manufacturing, and you feel that the written word triggers your brain in a way that a 2-minute video on a 6-inch screen could never do, then you’re my kind of person. Welcome. I highly suggest you print this out on some dead trees and make handwritten notes about my stupidity in the margins... preferably with a pour of bourbon and some jazz on the stereo. That’s what I would do.

Some of the essays below are more straight-up research while some are more random ponderings or opinion. I’ve focused on some subjects that I thought were worth discussion as I did my research. The conclusions, conjectures, and cogitation in this report are all mine. If this is useful to anyone, I’d be surprised, but I’ll also be happy to update it on occasion as I learn more and as the manufacturing landscape shifts. Give me your requests for other manufacturing subjects or perspectives to analyze. You can find me on LinkedIn, and there will be a post pointing to this report when it drops. The comments there will be a great place to tell me I’m an idiot, call me “Captain Obvious”, or point out my undeniably questionable conclusions. The reality is that I did this exercise for myself, and I’m just hoping that someone else will find it useful, so if nine hundred people think it’s utter trash and one person finds it enlightening, then I’ll be happy. Either way, I hope it’s at least worth the price you paid for it. YMMV.

Whatever,

Ashley

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Manufacturing might be thriving, but where and why?

Depending on what article you read and where it was written, you may hear that manufacturing is dead, that it's declining, that it's re-emergent, or thriving, and everything in between. So, what's the real story?

The simple answer is that the story is complicated. (Shocker, I know.) Manufacturing improvements are made in fits and starts, and they don't happen uniformly across industries or geographies. This means we need to take a more nuanced look than what most headline captions give us.

The Geography of Manufacturing Modernization

First off, it's worth establishing that manufacturing modernization is not happening uniformly across the world, and the gap between countries that have done the work to build the systematic support infrastructure for smaller manufacturers and those that haven't is widening. Understanding where different countries stand, and why, is good context for further analysis of where technologies like Industrial AI and advanced manufacturing will take hold first and fastest.

The single biggest differentiator in how well smaller manufacturers in a given country are modernizing seems to be not the technology itself, which is increasingly available globally, but the support infrastructure surrounding manufacturing technology. Countries where government, industry associations, and applied research institutions have built coherent frameworks for technology and knowledge transfer to smaller manufacturers are pulling their entire manufacturing base forward. Countries where modernization support exists only at the large enterprise level are seeing an accelerating gap between their most sophisticated manufacturers and their smaller ones. The gist of it is that policy matters.

Let's look at some individual countries and see if we can pull some insights from where they are, how they work, and where they might be headed.

Germany: The Mittelstand model

Germany represents a good example of successful manufacturing modernization across company sizes, and the structural reasons for this are worth looking at carefully because they point to what might be replicated elsewhere.

German Mittelstand companies, typically family-owned businesses in the €10 million to €1 billion revenue range, invest in manufacturing technology at rates that look unusual compared to equivalent-sized firms in the U.S. or UK. Several structural factors drive this. For example, long-term family ownership creates an investment perspective that is fundamentally different from a private-equity-backed operation optimizing for a five-to-seven-year exit. A third-generation German manufacturer investing in automation is working to hand something viable to the fourth generation, which makes capital expenditure with a decade-long payback period far easier to justify.

Another factor is Germany's dual education apprenticeship system, which produces workers who arrive on the shop floor already comfortable with industrial equipment and control systems. This reduces the training burden of technology adoption and creates a workforce that is younger and less resistant to modernization.[1]

The Fraunhofer Institute network is one of the most important and least-discussed elements of the German model. These applied research institutes specifically bridge academic research and industrial application for mid-size manufacturers, giving Mittelstand companies access to cutting-edge manufacturing research and implementation support that has no real American peer. The closest equivalents we might have in the U.S. are internal R&D labs at enterprise-level companies, but those are dwindling, and they do little to support mid-sized or small operations. The Manufacturing USA institutes are partially comparable, but they operate at smaller scale and with less integration into the overall industrial structure.

Finally, German trade associations like the VDMA[2] and ZVEI[3] function as technology transfer and standards bodies while similar U.S. entities often seem to act more as lobbying organizations. They disseminate best practices, run benchmarking programs, and create shared frameworks that help smaller companies understand where they stand and how to compete more effectively.

That said, Germany is not uniformly ahead and has its own challenges. Its deep dependence on the automotive sector has created significant exposure during the EV transition, and several Mittelstand suppliers embedded in combustion engine supply chains are under serious pressure.[4] Germany has also been slower than expected at adopting software advances in general and AI specifically. The cultural tendency toward engineering rigor creates friction with AI tools that involve probabilistic outputs and black-box decision-making. As a final data point, the energy cost shock since 2022 has consumed capital and management attention that might otherwise have gone toward modernization.

Japan: Old-skool precision

Japan presents a bit of a dichotomy when we think about manufacturing modernization. Japanese manufacturing has extraordinary precision capability and a culture of continuous improvement, embodied in kaizen and the Toyota Production System, that has no real equivalent elsewhere. As you probably know already, Japan invented many of the lean manufacturing principles that underpin much of modern smart factory thinking.

However, Japan has been surprisingly slow to adopt digital manufacturing tools relative to its overall manufacturing sophistication. An aging workforce resistant to workflow disruption, a cultural preference for incremental improvement over disruptive technology adoption, and deep institutional loyalty to established processes have all contributed to slower digital transformation than the country's engineering reputation would suggest.

The result is a country being outpaced in digital manufacturing implementation by South Korea and increasingly by China, despite having a deeper foundational manufacturing capability than either. It is a reminder that technological sophistication does not automatically translate to modernization.

South Korea: Top-down technology transfer

South Korea has driven sophisticated manufacturing technology adoption through a model that is structurally different from Germany's but has produced comparable results at the national level. The chaebol conglomerates (Samsung, Hyundai, LG, and others) have driven advanced manufacturing capability at the large enterprise level, and the South Korean government has been aggressive about pushing that capability down into the supplier base through programs that create meaningful technology transfer.

South Korea's manufacturing sector is more uniformly modernized than its company size distribution would suggest because the technology diffusion mechanism has been deliberately engineered rather than left to market forces alone. Again, policy makes the difference.

China: Subsidized modernization and technology transfer

China's manufacturing modernization is the most important development in the global competitive landscape, and it requires honest analysis, so I have tried to separate documented facts from political characterization. I’m not going to pull punches here, but I also want to give credit where credit is due.

The modernization of Chinese manufacturing has been driven by two different mechanisms operating simultaneously. There has been genuine domestic investment and capability development, but there was also artificial acceleration through access to foreign technology via both licit and illicit channels.

On the licit side, China's joint venture requirements for foreign companies seeking market access created a systematic technology transfer mechanism that operated in plain sight for decades. Every major Western and Japanese manufacturer that entered the Chinese market through one of these required joint ventures transferred technology, manufacturing processes, supplier relationships, and institutional knowledge as the price of admission. This was not a secret and Western companies made this trade deliberately, calculating that short-term market access and profits outweighed long-term competitive risk. That calculation proved badly wrong, but it was a business strategy failure as much as a geopolitical one. Considering the West’s myopic focus on short-term profits, the bargain was easy to make and the downsides somewhat irrelevant to people making short-term decisions who were likely to be floating on their golden parachute when the bills came due.

On the illicit side, the U.S. Trade Representative's Section 301 investigation documented systematic Chinese government-directed technology acquisition through cyber intrusion and forced licensing restrictions.[5] FBI and CISA advisories have repeatedly named Chinese state-sponsored actors targeting advanced manufacturing, aerospace, and industrial control systems. The IP Commission Report estimated the annual cost of IP theft to the U.S. economy, with China identified as the leading source, at between $225 billion and $600 billion.[6]

The result of this is a Chinese manufacturing base that reached competitive capability significantly faster than market dynamics alone would have enabled. The starting point was artificially accelerated, but it would be inaccurate to dismiss what has been built on that foundation. China has made genuine, original, domestic advances in battery technology, drone manufacturing, EV architecture, and certain precision manufacturing processes. Regardless of the beginnings, the Chinese manufacturing industry is legitimate, growing competition for the West.

Dismiss the competition at your peril

The most obvious example of the joint venture dynamic is the automotive industry, which offers a complete arc from market entry to competitive displacement that other sectors would be wise to treat as a preview rather than an isolated historical event.

Foreign automakers entered the Chinese market through required 50/50 joint ventures beginning in the 1980s, transferring technology and manufacturing process knowledge as the price of access to what would become the world's largest car market. The joint venture profits were substantial and funded Western automakers' global operations for two decades. The Chinese government used that same period to build domestic manufacturing capability, develop a domestic supplier ecosystem, and make a strategic decision to lead the EV transition rather than compete on internal combustion where the technology gap would have been very difficult to close.

The EV transition was the accelerant that turned gradual competitive erosion into rapid displacement. By subsidizing domestic EV adoption, mandating EV quotas, investing heavily in battery manufacturing through CATL and BYD, and building charging infrastructure at a pace Western governments haven't matched, China created a new competitive arena where the accumulated advantages of Western automakers in combustion engine technology were largely irrelevant.

Foreign automakers held the dominant position in Chinese passenger car sales as recently as 2020. However, Chinese domestic brands now hold the majority of their home market for the first time since the joint venture era began, and that share continues to grow.[7] The joint venture profits that looked so attractive in the 1990s funded the development of the competitors that are now displacing the companies that generated them.

Who would have seen that coming? Uh... Anyone who is a student of history.

The automotive case unfortunately followed a pattern that had already played out visibly with Japanese manufacturing in the 1970s and 1980s, and the failure to learn from that earlier experience is perhaps the largest failure of Western manufacturers. American automotive and electronics industries in that era dismissed Japanese competition as capable copiers but not innovators, terms later applied to China.

The lesson about dismissing Japanese manufacturing was documented and visible with quite a bit of analysis done in the 1980s and early 1990s warning American industry about what Japanese manufacturing discipline meant competitively.[8] The Western institutional response was slow and came only after significant market share loss.

Now it's China's turn to be dismissed, and the same script is playing out again with remarkably little apparent learning, resulting in the same contempt, the same short-term market access calculation, and the same eventual recognition arriving too late to prevent serious damage. The underlying driver in both cases was the myopic focus on quarterly earnings that made short-term profits difficult for public company management to refuse, even though the long-term strategic risk was predictable. The arrogance was the sin that made it easy to rationalize those short-term decisions as strategically sound, when history told a different story.

For any manufacturer today that dismisses Chinese, Eastern European, or Indian competition as incapable of matching their quality or complexity, the historical record offers a consistent and unambiguous warning. Not to put too fine a point on it, but if you think they can't eat your lunch, you're "gray matter challenged".

India, Eastern Europe, Mexico, and the emerging competitive landscape

Speaking of India, Eastern Europe, and Mexico, those countries should be discussed in any survey of the global manufacturing landscape, either as current competitors or as emerging ones. I've done a bit of research into these, but the story is more evolving than settled, so take all of this with a grain of salt.

India has significant manufacturing ambitions, a large and young workforce, and government initiatives attracting foreign investment into electronics and pharmaceutical manufacturing. The challenge in India is infrastructure variability, but putting that aside, India is genuinely positioned as an alternative to China for some manufacturing categories. It is a country to watch rather than a current benchmark as it could be the next big thing, or structural problems around logistics, infrastructure, and regulations may prevent it from achieving its potential.

Eastern European manufacturing, particularly in Poland, the Czech Republic, and Romania, probably deserves more attention than it typically receives, especially in American-centric manufacturing discussions. These countries have been modernizing steadily, operate within EU regulatory frameworks that make them attractive to European OEMs, have lower labor costs than Western Europe, and are increasingly well-capitalized. For smaller British or German manufacturers, this competitive pressure may be more immediate than that from China.

Mexico is relevant specifically in the nearshoring context, as manufacturing investment that might previously have gone to China flows toward proximity to the U.S. market and USMCA trade advantages. The modernization level in Mexican manufacturing is mixed and largely driven by foreign-owned facilities rather than domestic companies, but the trajectory is relevant to any North American manufacturer's competitive analysis.

The tariff limitation

Considering the newfound love of tariffs by President Trump, we should have a short discussion about them.

Tariffs and trade barriers address price competitiveness on specific traded goods at specific moments. However, they absolutely do not correct for actual capability gaps. A manufacturer that cannot quote a complex part accurately, cannot turn around a first article quickly, and cannot provide documentation of an unbroken digital thread alongside a finished part is losing on capability, not price. Tariffs cannot fix those kinds of structural problems in a manufacturing industry.

The tariffs applied to EVs from China in the U.S. may be reducing the urgency U.S. automakers feel to accelerate their own EV development. Protection can preserve market position temporarily while simultaneously reducing the competitive pressure that drives modernization.

That is a risk that extends beyond the automotive industry to any manufacturing sector currently operating behind tariff walls. Manufacturers who are relying upon tariffs to “level the playing field” should be afraid... very afraid... of what happens when those tariffs expire or are revoked. It’s quite possible that protectionism is making companies artificially comfortable and silently increasing their eventual risk. To mitigate this, companies protected by tariffs should actively prepare for the tariffs being lifted or reduced by investing in modernization, hardware, and personnel to close the gap.

The manufacturers most exposed are those treating current trade protection as a permanent condition rather than a temporary buffer. The historical record suggests that political and trade environments shift, and that the capability gap that accumulates during a period of protection turns into a competitive liability that gets exposed when that protection dissipates.

Key takeaway

Manufacturing is thriving to different degrees, but the depth of success is somewhat dependent on geography and the associated support structures. Good policy can definitely aid manufacturing while short-term thinking tends to do the opposite. Tariffs don’t correct for capability gaps in an industry. Only investment can fix those issues.

1 - https://doi.org/10.1007/978-94-017-8902-8_16

2 - https://vdma.eu/en/home?lang=en&index=1

3 - https://www.zvei.org/en/

4 - https://www.vda.de/en/press/press-releases/2026/260617_PM_Mittelstandstag_2026_EN

5 - http://ustr.gov/sites/default/files/Section_301_FINAL.PDF

6 - http://nbr.org/wp-content/uploads/pdfs/publications/IP_Commission_Report_Update.pdf

7 - https://eu.36kr.com/en/p/3916077131623811

8 - https://hbr.org/2007/07/managing-our-way-to-economic-decline

Does AI mean we're now in Industry 5.0?

I've been thinking a lot about where the manufacturing industry is today, and one question keeps coming to mind. Are we at the beginning of Industry 5.0? I think there is a good case to be made here, and the next few decades will either prove or disprove my analysis of this. But before we get to my definition of Industry 5.0, it makes sense to rewind just a bit and talk about how we got here.

The "Industry 4.0" designation and the history behind it

We should start by being honest that the whole "Industry X.0" definition stems from a marketing exercise. The term "Industry 4.0" was invented by the German government around 2011 as part of a strategic initiative to digitize manufacturing. This is one reason why you hear the term so frequently in industrial and policy contexts. It's less an actual historical demarcation and more a deliberate marketing buzzword that did its job and caught on globally.

Talking about Industry 4.0, however, brings to mind the question of what the other three generations of industry were all about, so let's briefly describe those.

Industry 1.0 was the First Industrial Revolution, from approximately 1760 to 1840. Steam power and mechanization transformed what had been entirely hand-based craft production (theoretically "Industry 0.0"). Textile mills, coal mining, and iron foundries replaced cottage industries. The key shift was moving work from homes and small workshops into factories.

Industry 2.0 coincides with the Second Industrial Revolution from about 1870 to 1914. Here, electricity and mass production arrived. Henry Ford's assembly line is the iconic symbol of this era where standardized parts, division of labor, and the ability to produce at massive scale became common. Steel production, new chemicals, and railroads expanded global trade bringing manufactured products to much of the world.

Many of us lived through Industry 3.0 which is commonly known as the "Digital Revolution" occurring from the 1970s through the 2000s. It goes without saying, but in this era electronics, computers, and automation took over repetitive tasks from human workers. Programmable logic controllers (PLCs) allowed machines to be reprogrammed rather than physically rebuilt and this era brought IT into manufacturing with databases, ERP systems, and robotics. It's worth noting that historians and economists begrudgingly use the term "Digital Revolution", and it's used way more in the popular press and in everyday conversation than it is as a proper historical construct.

The Industry 4.0 promise and reality

That brings us to Industry 4.0 which some people call the "Fourth Industrial Revolution", starting from around 2011 until now. This is the era characterized by cyber-physical systems with machines that communicate with each other in real time, generate feedback, and can be optimized. The core technologies are IoT (Internet of Things), networking, cloud computing, big data analytics, inexpensive sensors, and digital twins (virtual replicas of physical systems). A factory in Industry 4.0 can be adapted dynamically to demand, failures can be predicted before they happen, and it all integrates seamlessly with supply chains worldwide.

Industry 4.0 was fashioned around connectivity with IoT, digital systems, and digital twins. However, there is an argument to be made that this is more evolutionary than revolutionary. These systems made existing processes faster, more quantifiable, and easier to optimize, but they didn't change the fundamental human role of driving the factory, interpreting the data, and implementing the optimizations.

It's also worth noting that at the end of the day, Industry 4.0's adoption was not evenly distributed between enterprise-level organizations with the proper resources to implement these expensive technologies, and smaller "Mom-and-Pop" shops that have been left out of a lot of the data collection and optimization afforded by these technologies.

Therefore, Industry 4.0 is less a completed transformation than it is a partially realized optimistic vision. Many factories worldwide are still on 2.0 or 3.0 infrastructure and where a company is on the continuum depends on what industry they are participating in, the amount of resources they have, and even where in the world they operate.

The AI inflection point

Those of you with a good handle on manufacturing history will rightfully tell me that AI has been around for a while in one form or another, and you wouldn't be wrong. "Expert systems" were touted as early as the 1980s. The foundation there was PLCs and early machine vision, but these systems were all rule-based. Humans coded the logic and machines executed it. This is a vastly different proposition than what we are faced with today. (Though I'll admit that I have debates with myself about whether intelligence in general is just a rule-based state machine of sufficient complexity, but that is a discussion for some other time/article/publication.)

The AI systems of today, and specifically the way models go through a training phase instead of being hard-coded, are what make this particular generation of technologies unique. These new models can be retrained with new datasets and can deal with novel situations they weren't specifically programmed to handle. Furthermore, these models can take *intent* as an input, whereas previous generations of automation only took *instruction* as input with humans still controlling the strings of the marionette. This is the inflection point that I believe justifies the label of a new industrial era.

What are we talking about in concrete terms here? One example to consider is the emergence of cobots that utilize AI to adjust their behavior in real time to operate alongside the humans working around them. BMW has actively piloted this technology with a humanoid cobot, powered by AI, that worked alongside human operators in the body shop of its Spartanburg, South Carolina car plant. According to BMW, within ten months of its introduction, this cobot had supported the production of more than 30,000 BMW X3s where it operated Monday to Friday in ten-hour shifts. The task it was given was to precisely remove and position sheet metal parts for welding. This is a task well suited to the precision of a machine because it requires millimeter accuracy combined with efficiency. Over approximately 1,250 operating hours, that cobot moved more than 90,000 components and took around 1.2 million steps, all while working beside human operators.[1,2]

The final point worth considering concerns AI-enabled design and manufacturing programming. Software companies are beginning to embed real AI into complex software processes like CNC programming. The steps taken in this area are nascent, to be sure, but concrete, nonetheless. Within a few years, the expectation is that users of CNC programming software will be able to call upon AI not just for simple suggestions for how to machine a feature, but for generation of entire CNC programs.[3]

All of this being said, it's worth noting that the European Commission defined "Industry 5.0" in 2021 as a new human-centric, sustainable, and resilient industry.[4] This definition is inconsistent because it describes social constructs based on values and doesn't relate to technology that has a direct impact on manufacturing. The assembly line and the PLC changed *how* industry worked. Being human-centric, sustainable, and resilient is all about *why* manufacturing does what it does. The European Commission used the label for a different purpose than the Industry 4.0 label, which was created to describe a technological shift. Besides, we already see people using the Industry 5.0 moniker in a manner that is closer to what I describe here.[5] So, in the words of Adam Savage, "I reject your reality and substitute my own!"

The Counterarguments against Industry 5.0

One counterargument against the present coinciding with the emergence of Industry 5.0 is that we haven't yet finished the adoption of Industry 4.0. As I mentioned before, the adoption of Industry 4.0 practices and technologies is not uniform across industry. However, it can be said that boundaries between eras are never a hard line, and progress happens unevenly across geographies and industries. The boundary between Industry 3.0 and 4.0 was blurry, and the boundary between 4.0 and 5.0 will not be distinct either. For example, if earlier boundaries are an indicator, we can expect enterprise-level companies to adopt the technologies of Industry 5.0 faster than smaller shops with associated smaller budgets. This didn't stop us from declaring the emergence of Industry 4.0 in 2011, and I don't think it should stop us from declaring the emergence of Industry 5.0.

Another counterargument worth considering is that AI could be considered just an extension or evolution of the existing automation movement that started with Industry 3.0. This is a viable argument, and as I mentioned before, I have a similar feeling about Industry 4.0, so negating Industry 5.0 on this reasoning would also negate the "Industry 4.0" framing from the 2010s. This brings us back to the idea of a continuum where we call out approximate inflection points as an exercise in building common language and understanding around where we are in the long arc of history.

After all, "Industry 4.0" is a marketing slogan more than a specific era defined by historians, so the whole "Industry X.0" enterprise is a bit suspect from that perspective, but I feel it is valuable to make such demarcations in certain contexts.

The boundary has already been crossed

So, History is a continuum, and the boundaries we are discussing here are human constructs to help us understand our place in time. In my opinion, Industry 5.0 began when machines could take a goal and propose how to reach it, instead of only executing or reporting on steps a human predefined.

So, if we agree that Industry 4.0 began with sensors, feedback loops, and optimization, then it makes sense to say that the boundary from Industry 4.0 to Industry 5.0 has now been crossed with the application of AI systems that propose solutions to given manufacturing problems.

These technologies are already used in pockets, which will continue to expand, so the question in my mind is not whether the Industry 5.0 threshold has been crossed, but rather how fast the rest of the manufacturing world will catch up.

Key takeaway

We are at the forefront of true Industrial Artificial Intelligence applied to manufacturing. This portends a shift into a new era of industrialization (Industry 5.0) characterized by systems that can adapt to changing circumstances, can co-work with humans, and can use intent as input. Adoption of such technologies is never uniform and full-scale usage will take decades to accomplish with enterprise level companies acting first and smaller companies following.

1 - https://www.bmwgroup.com/en/news/general/2024/humanoid-robots.html

2 - https://www.bmwgroup.com/en/news/general/2026/humanoid-robot-in-leipzig.html

3 - https://engineering.com/make-machining-suggestion-now-in-siemens-nx-x-manufacturing/ (Full disclosure. I currently work for Siemens, so this link was a known proof-point.)

4 - https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50_en

5 - https://www.startus-insights.com/?p=50781

What's up with sustainability?

As I did my research, one subject that kept coming up, but which I found confusing, was sustainability. I kept getting this weird feeling that sustainability was a bigger deal in the press than it was at the individual level because I kept seeing articles about sustainability in industry and manufacturing, yet I hardly ever heard it mentioned as a driver when I talked with individuals actually doing the manufacturing. There seemed to be a real disconnect and I was having trouble understanding where the reality lay.

Who really cares about sustainability?

In the United States, where I'm based, it's hard to understand if sustainability is something that companies are taking seriously or if it's just a buzzword. Part of the problem is the ever-changing regulatory environment in the U.S. When one party is in power, the regulations are strengthened only to be undone when the other party is in power. This regulatory ping-pong means that it's hard to understand the reality of what is happening within U.S. industry with regard to sustainability. Do people in the U.S. actually care like people in other countries seem to?

The answer is, yes, to an extent, but the U.S. lags other regions such as Europe in this regard and the regulatory differences exist and are widening. In March 2025, the SEC ended its legal defense of its climate disclosure rules, no longer requiring companies to report on climate risks and greenhouse gas emissions.[1] At the federal level, the current administration has actively pulled back from ESG (environmental, social, and governance) disclosure requirements. In 2025 we saw a series of investigations by coalitions of state attorneys general and presidential executive orders pushing back on corporate ESG and sustainability strategies.[2]

Does the political rhetoric reflect reality?

It's interesting to note that the federal political rhetoric in the U.S. and the actual corporate behavior are running in different directions. Sustainability reports were issued by 99% of S&P 500 companies and 94% of Russell 1000 companies in 2025, both record highs, and for the first time more than half of reporting companies got external assurance on their sustainability data.[3]

Although domestic energy policy under the Trump administration shifts like the desert sand, a good number of manufacturing industry experts agree that manufacturers' long-term sustainability plans won't be affected much by the current administration. Manufacturers look at longer timelines than afforded a single administration in the United States.[4]

A United States values vacuum

In the United States, sustainability initiatives follow a predictable trend where economics is the driver, as seen in other areas where largemagnitude change is required. For better or worse, sustainability is not a large concern for the general public in the United States. Therefore, the values-based support for sustainability and environmentalism initiatives doesn't exist to a level that would allow for success at companies that work in the U.S. domestic market.

However, waste reduction and lean manufacturing have always had an alternative economic justification. U.S. manufacturers have pursued waste reduction and lean manufacturing for decades under efficiency and cost rationales rather than for sustainability. Large-scale efforts, like sustainability, in the U.S. are therefore driven by economics, not values.

I guess this shouldn't be a surprise when you consider that the U.S. may be the world's most pure capitalist society, and nothing of any scale happens here unless there are dollars to be won or lost.

The EU sets the regulatory tone

Supply chain sustainability, Scope 3 reporting, circular economy initiatives, and product lifecycle emissions are where the economics do not yet close the gap in the context of the U.S. domestic market. European manufacturers pursue these goals because their customers, regulators, and investors require auditable data, reflecting the values of their societies around sustainability.[5] A U.S. manufacturer selling only into domestic markets faces little of that pressure today, and the investment required to instrument and report on those metrics does not generate a return that justifies the cost without the societal pressure.

So, the U.S. does not have the regulatory architecture that makes sustainability a compliance requirement for most manufacturers, and the current federal posture is actively rolling back what existed. European manufacturers, on the other hand, face binding rules, standardized reporting methodologies, and carbon pricing that the U.S. does not have.

However, what complicates the picture is that large U.S. manufacturers are continuing sustainability work through a combination of international supply chain pressure (EU customers pulling Scope 3 data through their supply chains), economic efficiency arguments that do not require an environmental framing, state-level regulation in major markets, and investor expectations that have not retreated nearly as much as the political rhetoric suggests.[6,7] For small to mid-size U.S. shops with domestic-only customers and no large OEM customers with European exposure, the effective sustainability pressure is close to zero right now. For anyone in a global or OEM supply chain, the EU is effectively setting the standard regardless of what Washington does.

Manufacturers of today, especially at the enterprise level, often work within a connected world where domestic regulations matter less than international ones. In a connected world, we should keep our eyes open for more examples where the most restrictive policy becomes the de facto world standard as companies are required to "comply to play" in desirable markets, regardless of their domestic regulatory situation.

Key takeaway

Sustainability is real both in the U.S. and other nations, but the reasons for the emphasis on it vary. In the U.S. implementation is mostly an economics play. In other parts of the world, it is more a values play. Regardless, global players are required to abide by the desires of the most restrictive market in which they wish to operate, and the EU is driving many sustainability initiatives in industry.

1 - https://www.sec.gov/newsroom/press-releases/2025-58

2 - https://www.clarkhill.com/news-events/news/esg-sustainability-in-2026-twists-turns-and-trends/

3 - https://blog.thinkparallax.com/corporate-sustainability-reporting-2026

4 - https://www.supplychaindive.com/news/2025-sustainability-outlook-manufacturing-industry-emissions/740106/

5 - https://www.carbonchain.com/cbam

6 - https://www.aem.org/safety-product-leadership/eu-carbon-border-adjustment-mechanism-cbam

7 - https://www.integrumesg.com/insights/california-climate-disclosure-laws-sb-253-and-sb-261-explained

What happened to additive manufacturing? - Hype and the interrupted investment cycle

There was a period around 2018 when additive manufacturing (AM) was king of the world. The potential of the technology seemed limitless and so did the investment in it. Companies across the industrial landscape were either getting in on the game, or were looking to adopt additive with large, planned investments. Now it's 2026 and a technology that was on everyone's lips 8 years ago is hardly mentioned in the press anymore. What happened? How could the hype around additive manufacturing die so quickly, and what did that do to the technology itself?

Having spent a recent portion of my career working on software in the additive manufacturing area, I have some thoughts on this.

The role of hype in emerging technology

The Gartner Hype Cycle is a description of the lifecycle of technology, conceived by Jackie Fenn at Gartner[1]. For those not familiar, the cycle moves from the initial innovation trigger to a period called the "Peak of inflated expectations", otherwise known as "Hype". The hype is then replaced by a "Trough of disillusionment" where the projections fall short and people realize the technology will not achieve all the lofty expectations. This is followed by the "Slope of enlightenment" where the technology is gradually improved through a grinding process of slow investment and application. Finally, the technology achieves a "Plateau of productivity" where the technology is stable and used reliably in whatever context it has proven useful and profitable.

If I cared enough and thought I wouldn't get my pants sued off,
I'd put a picture of the Gartner Hype Cycle here,
but you've probably seen it already anyway.

The "hype" portion of that cycle is typically discussed with cautionary tones, a warning about how inflated expectations and the inevitable disillusionment that follows must be endured to reach the "Plateau of productivity". However, more attention should be paid to the functional role hype plays in an emerging technology's development. For capital-intensive industrial technologies with long development timelines, hype is not merely a market distortion to be wary of but has a reverse side that must be considered. In my analysis, hype is not a region of the cycle to be pushed through as quickly as possible but is a necessary funding mechanism that sets the technology on a trajectory to achieve the “Plateau of productivity”.

Additive manufacturing feels like a clear example of this. The sustained narrative excitement around 3D printing through the 2010s attracted venture capital, private equity, and corporate R&D budgets that funded real advances in machine reliability, material science, and software integration. That investment didn't evaporate when the hype peaked but rather compounded into the technology base that serious industrial AM users rely on today. Without the hype cycle pulling capital into the space, the development timeline for viable industrial additive processes would have been extended, possibly by decades.

This means that it’s valuable to look at the Gartner model in a different way. The “Peak of inflated expectations” isn't a bubble to be survived. It's a capital accumulation phase that funds the hard engineering work required to reach the “Plateau of productivity”. Technologies that miss or truncate their hype window may be starved of the investment needed to cross the development threshold at all.

COVID as investment interruption

Being deep into the additive manufacturing industry, I saw first-hand how additive manufacturing's hype trajectory was disrupted by COVID-19 in ways that were specific to how that particular emergent technology generated narrative momentum. Unlike software or consumer hardware, additive manufacturing depends heavily on physical demonstration. The texture, weight, and geometric complexity of a well-made, printed metal part communicate something that a photograph or video cannot. Trade shows, facility tours, and hands-on customer evaluations are the primary channels through which that demonstration happens for additive. All those channels collapsed simultaneously in 2020.

There was a brief counter-narrative early in the pandemic, as additive manufacturers stepped forward to produce PPE components and ventilator parts as stopgap solutions to supply chain failures. That story faded quickly, however, when it became clear that the additive industry of the day could not meet industrial supply chain demands at the volumes necessary in the short term. The result was a burst of attention followed by a sharper-than-usual deflation, potentially accelerating the “Trough of disillusionment” rather than sustaining the momentum needed to fund continued development.

The SPAC (Special Purpose Acquisition Company) era of 2020-2021, which brought companies like Desktop Metal and Markforged to public markets, complicates this picture. Capital was still flowing into additive aggressively even during the early pandemic period, suggesting the disruption was uneven across the sector. However, the post-SPAC performance of those companies points to a broader correction that may have been partly a natural “Trough of disillusionment” and partly a consequence of the demonstration channel collapse reducing the pipeline of new enterprise adopters.

The net effect was a stunting of investment momentum at a critical stage, before additive had accumulated sufficient capital to continue bending its cost curves independently of narrative-driven funding.

The scalability argument against additive

When discussing the disillusionment around additive manufacturing, a persistent criticism is that additive "doesn't scale." However, this argument conflates two distinct problems and is worth examining in more depth because that particular framing isn't correct, in my opinion.

Technically, there is nothing inherent to additive manufacturing that prevents parallel deployment at industrial scale. When Apple wanted to produce five million machined aluminum iPhone enclosures, the solution was straightforward. They deployed tens of thousands of CNC machines across acres of manufacturing facilities in China. The same approach is theoretically available to additive manufacturing. In general, the physics of the process doesn't break down at volume, though I do discuss a counterargument that should be considered below.

What does break down at volume is the unit economics. Additive manufacturing doesn't scale at its current price point for most high-volume applications. That is a different problem from the technology itself not scaling, because price points are not fixed. Price is a function of investment, manufacturing volume of the machines themselves, materials research, and process refinement. Every one of those inputs responds to sustained capital deployment over time.

The historical parallel is CNC machining itself. In the 1970s, CNC equipment was extraordinarily expensive, slow, and operator-intensive. The cost curve bent over subsequent decades because sustained investment made it bend, driven in part by the narrative excitement around computer-controlled manufacturing attracting capital and talent into the space. Additive manufacturing currently sits earlier on an analogous curve.

The corollary is important because the price point problem and the investment interruption problem are directly linked. If the COVID disruption and subsequent market correction slowed investment into additive manufacturing, it also slowed the rate at which machine costs, material costs, and post-processing costs compress. A technology that "doesn't scale at the current price point" needs investment to move the price point. Interrupting that investment doesn't only delay adoption, it delays the conditions that make adoption economically rational. This is one aspect of what happened to additive manufacturing.

Industrial AM quietly became real

While much of the popular press concentrates on FDM/FFF style printing for home users and small shops printing consumer-oriented parts, there is an industrial counterpart that gets much less press outside of niche industry publications.

The Aerospace and Defense industry has found metal additive manufacturing in particular to be a viable technology for production of real-world parts. This is in some part due to the nature of the industry (low-volume production, higher price tolerance), but also due to the unique value proposition of additive manufacturing. Specifically, the ability to produce very complex geometry that is difficult if not impossible to produce using other means is of great value in aerospace.

Fluid flow, aerodynamics, and thermodynamics are all areas of immense importance to aerospace applications, and the ability to design parts that maximize or minimize certain characteristics in these areas changes the cost-per-part equation, making the use of additive manufacturing feasible. Aerospace manufacturers tend to operate in a largely price-inelastic procurement environment, where material certification, traceability requirements, and performance specifications influence part design and manufacturing far more than unit cost. This has brought about an environment where the drawbacks of additive (its price point, for example) are less relevant. Future investment may bring additive into a price point where that same situation exists for other industries.

The counterargument

It's worth noting that the additive hype/adoption story is definitely not as simple as I have articulated here. There are a thousand variables that feed into whether a given technology is successful or not. For example, there are counter claims about additive manufacturing’s complexity being a real impediment to adoption that are grounded in reality. When you set up 5 identical CNC machines in a row and machine the same parts you will get 5 identical parts, which leads to the ability to scale. This is not always true in the case of additive manufacturing, and this is a real problem. Repeatability is a base requirement of any manufacturing technology, and some additive processes have real issues achieving this.

However, the case could also be made for this being an investment problem. It’s possible that with enough investment and refinement over time, many if not all additive processes could be normalized as knowledge about the fundamental physics in each technology is gathered, applied, and refined.

Along those lines, it's also worth remembering that early CNC systems were also not especially consistent by today’s standards. Early systems used discrete transistors with servo control that had backlash, drift, and thermal instability issues. Their parts weren’t machined to today’s tolerances so mechanical wear tended to introduce positioning errors over time. Furthermore, G-code itself didn’t stabilize until the 1960s or 70s, so machine consistency also depended on a specific controller’s implementation. Those problems were eventually overcome with continued innovation and investment, so one could realistically expect additive manufacturing to follow a similar trajectory.

We should also be cognizant that hype can encourage bad bets. The decline of companies like Desktop Metal and Velo3D and the wreckage left by the SPAC era in the additive industry suggest that a good amount of capital was misallocated.[2,3,4] It could certainly be argued that this deepened the disillusionment surrounding the technology as a whole.

The overall picture

In the end, the COVID-19 disruption in the additive industry affected different additive technologies unevenly. DMLS and SLS in aerospace and medical applications continued their adoption trajectories relatively undisturbed, because those customer relationships involve long sales cycles and committed program budgets that a two-year disruption doesn't easily reset. The prosumer and industrial crossover market, centered on FDM and accessible metal printing, was likely hit harder, as that segment depends more on the demonstration and trade show channels that went dark.

Additive manufacturing aside, it's worth thinking about the Gartner Hype Cycle in a slightly different way than we have in the past. Specifically, we need to think about the "Peak of inflated expectations" section of the curve not just as a negative stage in which expectations for the technology are created that will never be met. We should also be thinking of hype as one of the main generators of investment and the foundation on which the rest of Gartner's cycle stages are built. If we get rid of or abbreviate the hype portion of the cycle, the technology itself may either not achieve its potential or may at least take longer to achieve that potential than it would have.

There are many reasons why the adoption of additive manufacturing declined over the past decade. Claiming that COVID-19 is the sole, or even the main reason, would be disingenuous and flat-out false. Therefore, I want to be clear that I'm not making that claim. However, I do believe the argument can be made that the disruption caused by COVID-19 at the height of the additive hype/investment cycle may have had a larger retarding effect on the technology's adoption and lifecycle than most people realize.

The result for additive manufacturing is a technology sector that is further along than its current adoption numbers suggest, with a cost curve that has more room to compress than its critics acknowledge, but which lost meaningful time and capital during a period when sustained investment would have mattered most. Whether that interruption proves to be a temporary delay, or a more lasting setback, depends significantly on whether the investment community re-engages with additive's long-term trajectory rather than its short-term post-SPAC expectation dip.

Key takeaway

The Gartner Hype Cycle is a visualization of the progression new technologies take in their lifecycle. Normally, some areas of the cycle, especially the "Peak of inflated expectations", are seen as areas to endure rather than embrace. However, we should reframe those areas of the lifecycle as *necessary* to reach the "Plateau of productivity". The hype portion of the curve directly relates to investment, so interrupting the hype for a technology can also stunt its progression towards productivity.

The interruption of additive’s progression through its hype period by COVID negatively impacted the investment in additive manufacturing during a crucial stage of its evolution.

1 - https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

2 - https://www.metal-am.com/velo3d-to-become-public-company-valued-at-1-6-billion/

3 - https://ir.velo3d.com/sec-filings/all-sec-filings/content/0000950170-24-105603/0000950170-24-105603.pdf

4 - https://www.metal-am.com/desktop-metal-files-for-chapter-11-bankruptcy-plans-asset-sale-to-anzu/

Dodgy conclusions

So where are we at? Manufacturing is OK depending on where you are, we're in Industry 5.0 and that also means AI in manufacturing is legit (or vice versa), a lot of people care about money more than sustainability, and we might think about renaming the "Peak of Inflated Expectations" as the "Peak of Concentrated Investment".

I think that about wraps this up.

I guess I'll restate what I said at the outset. I have no idea if this was of value to anyone or not, but I hope it was at least worth the price of admission. If you got this far, you either really enjoy thinking about this stuff, or you're some sort of masochist... or both. Either way, I hope this was useful for someone, somewhere, and that at a minimum it made you think.

Along those lines, I would genuinely love your opinion about my Gartner Hype Cycle analysis, whether you agree that we're in Industry 5.0, or anything else bad or good about what I've written here. I'd put a link here to my LinkedIn post where I link to this report, but watching a lot of movies with questionable science leads me to the conclusion that this would create a dangerous time circularity, so I'll just encourage you to find my post on LinkedIn manually.

https://www.linkedin.com/in/ashleyeckhoff

Once there, leave a comment, propose your own theories, ask some good questions, and poke as many holes in what I've written as you can. If anything sparks my interest, maybe I'll punish everyone with a Volume 2. Time will tell.

Thanks for reading all this. Now go out and make stuff!

Sincerely,

Ashley

A quick note on AI – I did use AI as an underpaid research assistant and barely qualified editor when compiling this report. However, the dodgy conclusions, bad analogies, questionable life decisions, spelling and grammar mistakes, and poor phrasing are all mine. This was the work of a multitude of hours over many evenings and a lot of bourbon, so please don't think I phoned it in with some AI slop. No matter how bad it turned out to be, I'm the one who's responsible for you wanting to gouge out your eyeballs. Don't blame our poor AI overlords for this.