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# INSIGHTS

# GenAI: The Path Forward
# Part 3 – Physical AI

## EXECUTIVE SUMMARY

The objective of this white paper series is to contemplate the path forward for generative artificial intelligence. Part 1 reviewed scaling laws, a critical factor that drives AI infrastructure investment. To-date, scaling laws remain firmly intact driven largely by test-time scaling—the foundation for the newly popular reasoning models—and AI infrastructure investment has not abated. Part 2 examined the return on investment ("ROAI") from GenAI. GenAI applications will only be broadly adopted if their cost can be justified by the returns. Indeed, the adoption of GenAI is growing as consumers and businesses learn how to wring productivity benefits from these tools. This paper, Part 3, explores the potential for GenAI to be leveraged in the physical world. Intelligence-infused machines—broadly referred to as embodied or physical AI—can perceive, reason and act by leveraging advanced hardware—sensors, cameras, batteries and actuators—in combination with sophisticated software—digital simulators and Vision Language Models. The rise of AI-enabled machines marks a profound transformation for the global economy, with significant implications for corporate strategy, the labor market and investors.

## GENAI: FROM BITS TO ATOMS

Generative AI has been mostly confined to the digital realm for two primary reasons. First, large language models (LLMs) are trained using a process called tokenization, which breaks text into discrete units that can be processed by neural networks. Tokenization is much more easily applied to the highly structured world of bits—with semantic structure like text—than those of atoms. Additionally, the world is awash in an abundance of internet data upon which LLMs can be trained, while physical AI lacks a comparable corpus. Physical AI systems must build their domain-specific datasets from scratch. This is costly and complex relative to LLMs that have access to publicly available internet-scale datasets.

Two key factors have unlocked the potential for physical AI systems in recent years. The recent progress of Vision Language Models (VLMs) has made it possible for AI models to distill more than just text. Unlike LLMs, which are optimized for human language, VLMs are multimodal with the ability to train on text, images and videos. Meanwhile, ambitious companies have found ways to overcome the lack of training data. Tesla's car cameras have accumulated billions of real-world "miles driven" to train its Full Self Driving (FSD) system. Alphabet's Waymo uses a combination of radar, LiDAR (light detection and ranging), cameras and other sensors to create detailed 3D maps within the geofenced cities it operates. Deere's autonomous tractors have been trained on hundreds of millions of farm images and even collect data on soil quality and composition. Amazon's warehouse robots track every interaction within the fulfillment center to improve their efficiency. Boston Dynamics trains its humanoid robots using a variety of techniques, including Reinforcement Learning and data from human motion capture—individuals in "mo-cap" suits which generate real world movement data.

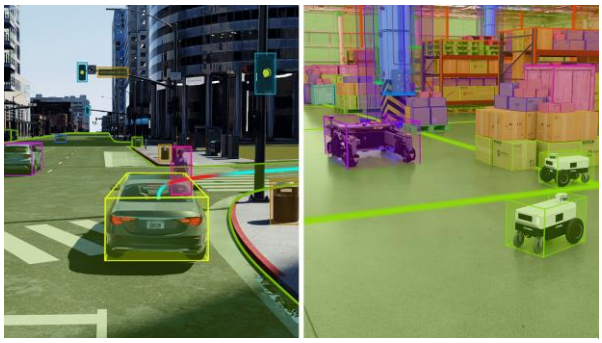
## TOKENIZATION OF ATOMS

Recent progress in the tokenization of real-world experiences is allowing leading technology firms to leverage AI on physical-world data sets. In January 2025, NVIDIA announced its Cosmos World Foundation Model, a multimodal platform.

> "What we need to do is we need to create effectively the world model, as opposed to GPT, which is a language model. And this world model has to understand the language of the world. It has to understand physical dynamics. Things like gravity and friction and inertia. It has to understand geometric and spatial relationships. It has to understand cause and effect. If you drop something and it falls to the ground, if you poke at it, it tips over. It has to understand

> object permanence. All of these types of intuitive understanding… most models today have a very hard time with. And so we would like to create a world foundation model." – Jensen Huang, CEO NVIDIA, CES 2025

NVIDIA Cosmos was trained on 20 million hours of video with the goal of helping developers create better training data for physical AI systems. NVIDIA Omniverse is pioneering the space of digital twins, virtual representations of real-world environments that are used to simulate, monitor and optimize their real-world counterparts in real time. Real world foundation models, like Cosmos, work in coordination with digital twins, like Omniverse, to generate synthetic data that can be used to train models for physical AI use cases.



*NVIDIA Omniverse (pictured) and Cosmos can accelerate AI development of autonomous vehicles, robots and Humanoids.*

Many companies are already incorporating transformer-based architectures into their physical AI machines. Tesla, Deere and Amazon are all utilizing VLMs to train their autonomous cars, tractors and warehouse robots, respectively. Robotics companies are using multimodal tokenization to convert vision, proprioception and motor actions into discrete representations that can be processed by neural networks.

## USE CASES

Factory automation tools (e.g., industrial robotic arms) have existed for decades but have historically been constrained to structured environments—manufacturing assembly lines, warehouses—with highly defined, preset instructions. The greatest constraint in enabling robots to function in less rigid environments has been software. Programming a general-purpose robot has proven to be a difficult engineering challenge, but breakthroughs in VLMs are unlocking new use cases. Similar to AI software, one of the strongest business cases for adopting physical AI lies in productivity benefits—time savings, increased throughput and error reduction. In an era that is defined by labor shortages and aging demographics, increasing productivity through automation will be critical to drive noninflationary economic growth.

**Logistics.** Logistics is one of the most commercially mature sectors for physical AI deployment. Amazon has deployed more than 1 million robots across its operations network since its acquisition of Kiva Systems in 2012. Robots contribute in some way to approximately 75% of Amazon's deliveries. These machines automate tasks such as picking, packing and sorting, leading to an estimated 25% reduction in fulfillment costs. Amazon's new Vulcan robot is the first of its kind that maintains a sense of touch, using sensors to determine pressure and torque. Amazon's implementation of AI-driven systems led to a 15% reduction in recordable incident rates and 18% decrease in lost-time incident rates in 2022. Morgan Stanley estimates that Amazon could achieve efficiency gains of up to $10 billion annually as it continues to automate its fulfillment network. Positive Sum Research estimates that 95% of warehouse space is yet to be addressed by robots—a $50 billion market opportunity.

*A RWC4 robotic arm in an Amazon warehouse.*

*Source: Automated Warehouse*

*An Aurora Innovation truck cab consists of a suite of sensors, including LiDAR, radar and cameras.*

*Source: Aurora Innovation*

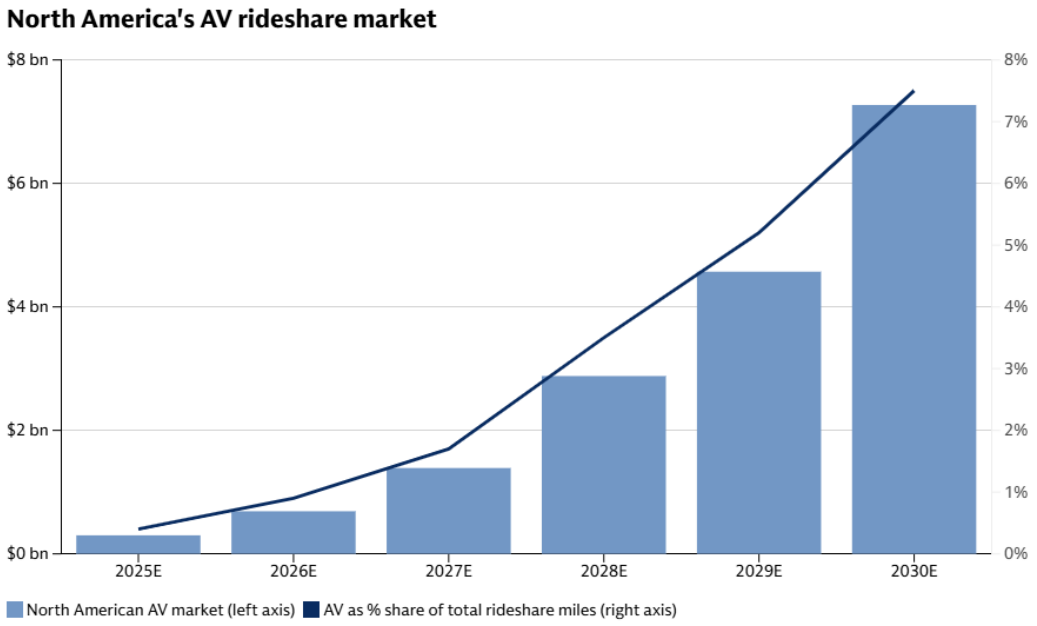
**Autonomous Vehicles.** Autonomous vehicles encompass a wide spectrum of devices. Physical AI is being used to improve speed and reduce costs of at-home delivery. Companies like Serve Robotics are powering Uber Eats autonomous food delivery on city sidewalks and college campuses. Amazon has launched Prime Air, delivering packages via drone in 60 minutes or less in certain areas of Texas and Arizona. Zipline and Wing are applying drone delivery to both food and package delivery.

Self-driving cars and trucks are arguably the most complex forms of autonomous vehicles. Beyond the obvious physical challenges, which include solving for long-tail edge cases—inclement weather, traffic anomalies, unexpected obstacles—there are perhaps even greater societal hurdles—regulation, liability and cyber security. For these reasons, fully autonomous personal vehicles, beyond the level 2 ADAS (Advanced Driver-Assistance System) features that are available in certain models today, are likely years away. However, autonomous trucks and robotaxi fleets are becoming a reality and have recently reached commercialization. Autonomous long-haul trucks benefit from the predictability of highways—fewer pedestrians, cyclists and intersections—as well as better maps compared to urban roads. Autonomous trucks can operate in pre-defined corridors, driving hub-to-hub while leaving the first- and last-mile delivery to human drivers. In April of this year, Aurora Innovation (spun out of Uber in 2020) completed its first fully driverless commercial trucking route between Dallas and Houston. Autonomous trucking has the potential to make trucking companies, like Old Dominion Freight Liners and XPO, more efficient by solving for driver shortages and reducing overall trucking costs by up to 30%. With a global addressable market of $4 trillion, the trucking industry represents a significant growth opportunity for autonomous vehicles.

*A Waymo autonomous vehicle in San Francisco, CA.*

*Source: CNBC*

Autonomous robotaxis have also made significant strides in recent years. Waymo, a subsidiary of Alphabet, currently has commercial operations in Phoenix, San Francisco, Los Angeles, Austin and Atlanta, with additional plans to launch services in Miami and Washington, D.C. in 2026. Waymo is conducting testing and mapping in cities such as Boston, Nashville, Houston and Orlando. Weekly rider volume has surged with ridership doubling in five months to nearly 10 million trips in May of 2025. Tesla recently launched a limited, invite-only robotaxi service in Austin. As previously mentioned, Tesla is training its autonomous fleet on cameras only opposed to the more extensive and expensive sensors used by Waymo and others. It will take time for Tesla's camera-only technology to advance to Waymo's level of accuracy, but in the long-term this may prove more cost efficient and allow autonomous Tesla vehicles to operate beyond the perimeter of geofenced cities. As robotaxi fleets scale, their cost-per-mile should become competitive to that of traditional ridesharing and personally owned vehicles. Tesla is expected to reach end customers through a vertically integrated consumer ride hailing app. Others, like Waymo, are testing partnerships with Uber and Lyft, who provide robotaxi fleets access to the massive user base already on their platform which would improve the utilization—and economics—of the robotaxi service. Goldman Sachs estimates the robotaxi market to grow at a compound annual growth rate of 90% through 2030.




*Source: Goldman Sachs*

**Agriculture.** Precision agriculture has been a growing trend for some time, but the industry is leveraging GenAI to drive further productivity benefits. John Deere tractors have been capable of self-steering for decades, but new sensing, edge computing and machine learning technology enables farmers to capture images in the field which are used to train AI models that allow tractors to place seeds and spray more efficiently, saving on chemicals and increasing yield.

**Defense.** Physical AI is transforming the battlefield. Venture capital backed upstarts, like Anduril, are revolutionizing the defense industry by building autonomous systems that have the potential to reduce casualties, lower costs and improve efficacy. In addition to designing autonomous hardware, such as unmanned jetfighters and drones, Anduril's operating system, called Lattice, uses AI to parse data from thousands of sources and orchestrate military action. Incumbent defense contractor RTX, perhaps best known for its Patriot air and missile defense system, recently partnered with Shield AI to infuse autonomy across its products.

> "Do you see a world where machines are fighting our battles for us?"
>
> "Oh, absolutely. It's already happening." –Palmer Luckey, Anduril CEO on *60 Minutes*

**Health Care.** Physical AI is being incorporated into various health care environments to improve patient outcomes. GE HealthCare is using NVIDIA's Omniverse and Cosmos platform to build autonomous ultrasound and X-ray devices. Foxconn's Neurobot is an AI-powered nursing assistant, performing many nursing tasks which frees up staff time to provide higher value care. Vitestro is a pioneer in robotic blood drawing. The company's Aletta system uses Doppler ultrasound-guided imaging to identify veins and robotically insert needles with extreme precision. Several companies are building exoskeleton robots, which help paraplegics walk. Robotic pharmacy dispensers improve efficiency and reduce potential for human error in filling prescriptions. BD has deployed 14,000 dispensing robots across 60 countries. Robotic surgical systems, such as Intuitive Surgical's Da Vinci platform, are becoming increasingly sophisticated and will soon be automating subtasks within the operation (e.g., suturing) under surgeon oversight and control.

**Humanoids.** Humanoids describe robots with human-like limbs that can mimic many human actions. Humanoids have a unique advantage relative to other robots given the world around us was optimized for the human form. A robot that matches our physical structure and dexterity could be far more versatile than specialized robots engineered for one specific task.

Tesla's Optimus, also known as Tesla Bot, was first unveiled in 2021. In true Tesla fashion, Optimus was designed with a high degree of vertical integration, including in-house battery packs, FSD software, actuators and custom semiconductors. Elon Musk projects that Optimus is likely to exceed the entire value of Tesla today and suggests that Optimus could eventually generate $10 trillion in revenue. Boston Dynamics, the MIT spin-off that is now owned by Hyundai and Softbank, is another leader in humanoid development. Hyundai is planning to deploy Boston Dynamics' Atlas robots into its manufacturing facilities. Amazon has reportedly been developing software for humanoid robots that could eventually displace delivery workers, which could complement autonomous long-haul and last mile trucking to deliver more items, faster, and at lower cost.

*A Tesla Optimus Humanoid*

*Source: Sky News*

Leading technology executives hold significant optimism for humanoids. OpenAI's Sam Altman expects humanoids to be standardized in daily life within the next five to ten years. Elon Musk expects humanoids to the be "biggest product ever." Morgan Stanley estimates the humanoid market could reach 1 billion units and $5 trillion by 2050 with the majority of robots being used for industrial and commercial purposes.

> "I think humanoid robots will be the biggest product ever. It's going to take a lot of compute resources… there are certain threshold breakthroughs we think we can achieve. If Optimus can watch videos, YouTube videos, how-to videos… and based on that video… learn how to do that thing, then you really have task extensibility that is dramatic because it can learn anything very quickly."– *Elon Musk, CEO Tesla, May 20, 2025*

## ECONOMIC AND SOCIETAL IMPLICATIONS

**Productivity growth.** AI software has proven to be a productivity enhancer for knowledge workers, automating cognitive tasks like data analysis, content generation and customer service. Physical AI extends automation into the realm of real-world operations. As the technology progresses, robotics will provide a precision, consistency and endurance—operating 24/7—that will be hard for human labor to replicate. In addition to output gains, Physical AI is likely to drive cost advantages over time. Robotics, while expensive today, will become more affordable with scale and will not have insurance, benefit or retirement expenses that are associated with human labor. Improved productivity has implications for the national reshoring effort. Automation has the potential to make domestic manufacturing more competitive with low-wage labor overseas. Growth in U.S. industrial production would provide a tailwind to electricity load growth, which is experiencing a resurgence—discussed in a white paper—after decades of stagnation.

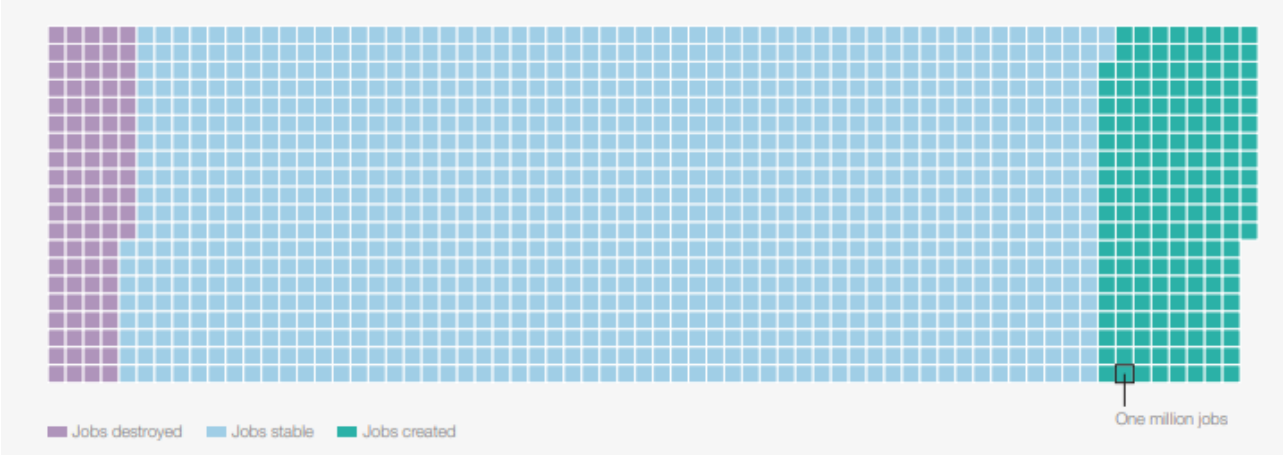
**Labor market transformation.** As with prior technological revolutions, fears have surfaced that AI will lead to widespread job obsolescence. CEOs from a broad range of industries have publicly acknowledged the potential for job displacement across both white and blue collar jobs. Recent layoff announcements from the likes of Walmart, Amazon, Microsoft, Intel and Procter & Gamble, to name a few, has stirred suspicion that some roles are already being displaced by AI.

However, there is strong historical precedent to suggest that technological revolutions often create more and higher quality employment opportunities than existed in the prior paradigm. Economist Robert Gordon, in *The Rise and Fall of American Growth*, notes that agriculture has fallen from 46% of total U.S. employment in 1870 to just 1.1% in 2009 as the mechanization of agriculture drove farmhands to seek safer, less grueling and better paying work in urban centers. A more recent example is the adoption of computerized spreadsheets, like Excel, in the 1980s and 1990s. Excel reduced the need for bookkeepers and accounting clerks, who traditionally performed calculations and ledger entries manually, but this job

loss was ultimately more than offset by growth in financial analysts, accountants and auditors who used spreadsheets to increase their productivity and incomes.

> "I think that many, perhaps most, consumers will have robots in the home within the next ten years or so… They won't have to do as much rote work and every single person gets to start every task at a more advanced starting spot… yes, with every technical transformation there will be fewer people doing some of the jobs that the technology starts to automate. There will be other jobs, we'll hire more people in AI, more people in robotics, and there'll be other jobs that the technology wants you to hire that we'll hire over time too."– *Andy Jassy, CEO Amazon, June 30, 2025*

There is early evidence that AI has already catalyzed a shift in labor force composition. Amazon's highly automated next-gen fulfillment center in Shreveport, Louisiana requires 30% more employees in areas like maintenance and engineering. In the knowledge worker realm, IBM used AI to replace a couple hundred of employees in human resources but added more programmers and sales representatives. The World Economic Forum's Future of Jobs Report 2025 indicates that while 40% of employers expect to reduce their workforce in areas that can be automated with AI, there is an expected net increase in job creation of 7% by 2030 driven by high-demand roles such as Big Data Scientists, FinTech Engineers, and AI and Machine Learning Specialists.




*Source: World Economic Forum Future of Jobs Report 2025*

Still, the potential for job displacement should not be taken lightly. This new technological era will require an effort by employers and employees to acquire new skills to stay competitive.

**Ethical considerations**: The integration of physical AI into the real world raises critical ethical concerns related to bias, privacy, safety and accountability. A 2022 study by researchers at Johns Hopkins University revealed that robots trained on internet-sourced data often replicated harmful racial and gender biases, such as associating certain ethnic groups with negative stereotypes when performing object recognition tasks. Sensitive information, such as health care and location data, has the potential to be exposed as physical AI relies on ubiquitous camera and sensor technology. Robotics that are powered by transformer architectures can "hallucinate"—generate incorrect outputs—which could pose physical danger, unlike an LLM hallucination. Finally, as autonomous robots and vehicles proliferate, there is bound to be controversy over liability in the case of an accident. Even if these systems demonstrate superior safety compared to human drivers, they will likely be held to a much higher standard to satisfy public expectations. These dilemmas underscore the need for regulatory frameworks and ethical design principles that ensure AI systems align with human rights and social values.

## CONCLUSION

> "The dream of general-purpose robotics is no longer a distant fantasy. It is being built now, one Level at a time. Each step on this path unlocks immense economic value and reshapes our world in profound ways." – *SemiAnalysis*, July 30, 20205

Physical AI represents the next frontier in artificial intelligence and automation. Enabled by breakthroughs in Vision Language Models, sensors, digital twins and the growing availability of real-world training data, physical AI systems are moving rapidly from labs to the broader economy. The commercial implications are profound. Physical AI has the potential to structurally improve productivity by filling gaps in the labor supply. For businesses, this raises strategic questions about workforce design, capital allocation and competitive positioning. For policymakers, it presents opportunities and challenges related to labor force planning, education and ethical governance. Fears of job displacement are legitimate, but history suggests that technological revolutions often improve the quality and quantity of employment over time. To capitalize on this opportunity, it is imperative for workers and institutions to adapt through large-scale reskilling.

The rise of Physical AI presents a broad and growing investment opportunity across semiconductors, robotics, automation software, AI infrastructure and industrial end-markets. Companies with differentiated capabilities in real-world data collection, edge computing and multimodal AI training may enjoy strong competitive advantages in this new era. While adoption will unfold unevenly across industries, early signs of scale and economic viability have already emerged in what has the potential to be one of the largest growth areas of the following decades.

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