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Thematic Investing

Physical AI: Mapping the Humanoid Value Chain

SIGNATURE

While often framed as a hardware opportunity, humanoids are as much an AI compute story as a robotics one. We examine the full humanoid value stack (and identify 100+ companies), from foundation models and compute infrastructure to actuators, sensors, batteries and other enabling components.

Humanoids are as much a compute story as a robotics one. Humanoids represent the next AI frontier, extending intelligence from the digital to the physical world. While often framed as a hardware opportunity, the constraint, at least today, is intelligence. Unlike traditional robots, humanoids require perception, reasoning, and adaptive behavior, making compute a key enabler. Although large-scale economic deployment is likely closer to 2035 than 2030, compute is needed earlier to support simulation, synthetic data generation, and foundation model training. By contrast, hardware faces a chicken-and-egg problem: scaling is constrained until reliability, safety, and autonomy are proven, while low volumes limit cost reduction, supplier investment, and standardization. Actuators dominate costs (~30–50%), with high-precision gearing supply concentrated in Japan and rare earth dependencies heavily concentrated in China.

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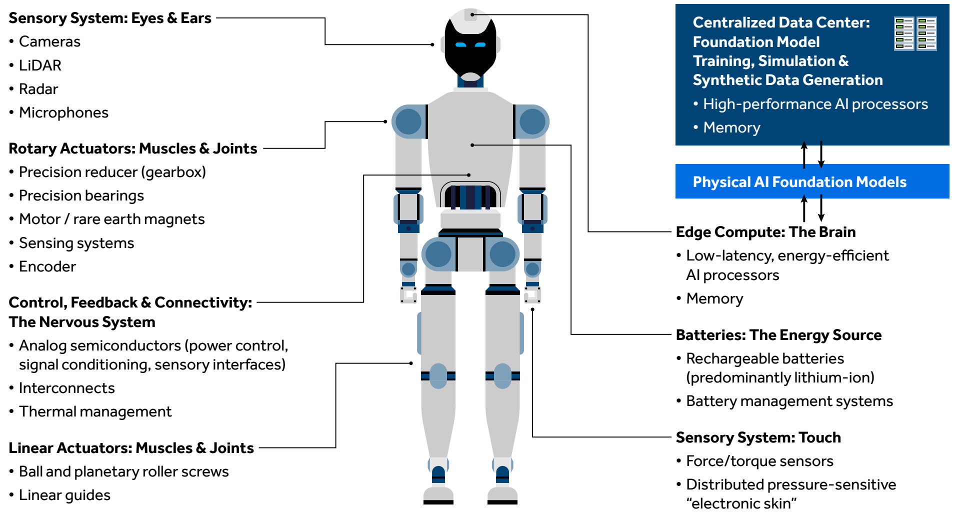
FIGURE 1. Anatomy of a humanoid: from compute to components



Source: Barclays Research

CONTENTS

Executive Summary

Humanoids are coming as AI gets physical. "Physical AI" is the embodiment of AI in the real world, spanning autonomous vehicles, drones, advanced industrial automation, and ultimately humanoid robots. Humanoids represent the next frontier of AI, extending intelligence from digital workflows into physical environments while offering a unique advantage: the ability to operate within existing human-designed infrastructure, including factories, warehouses, and homes. In this sense, AI's disruption may expand beyond cognitive work and into physical labor, helping address growing labor shortages driven by aging populations, urbanization, and changing workforce preferences, particularly across dirty, dull, and dangerous jobs (the "3 D's"). While the humanoid market remains small today, at roughly $2-3bn, forecasts range from $10-25bn by 2030, with more optimistic scenarios reaching ~$200bn by 2035, as detailed in Global Macro - AI gets physical: Ten things to know about humanoids.

It's early: large-scale economic deployment of humanoids could be a 2035+ event. Unlike traditional industrial robots, humanoids are intended to operate autonomously in dynamic, human-centric environments, requiring perception, reasoning, and adaptive behavior. Much of today's humanoid hype, however, reflects scripted demos, human-controlled teleoperation, or task-specific automation, rather than true, general-purpose autonomy. Progress remains constrained by limited real-world training data, the absence of a "GPT moment" for Physical AI foundational models, and stringent safety, reliability, and regulatory requirements. Humanoid deployment may ultimately mirror autonomous vehicles, which have taken more than a decade to progress from early optimism toward broader deployment. As a result, large-scale economic adoption is likely closer to 2035 than 2030, with near-term deployments focused on narrow, controlled industrial use cases that augment human labor rather than replace it, while expanding as reliability, autonomy, and capability improve.

Humanoids are as much a compute story as a robotics story. While investor attention often centers on hardware—actuators, sensors, and batteries—the initial constraint is intelligence. Humanoid development relies on three compute layers: simulation to generate synthetic data and train policies, foundation model training to build perception-to-action intelligence, and on-robot inference under tight latency, power, and safety constraints. These workloads should scale ahead of physical robot deployment, creating incremental demand for data center infrastructure, AI accelerators, memory, storage, networking, and power. Near-term value is likely to accrue first to the enabling stack — AI infrastructure, simulation, foundation models, edge compute, memory, and proprietary data — while hardware suppliers benefit as deployment moves from pilots to scaled production. In our view, this is the next leg of the broader AI compute demand story and an early way to play the humanoid theme.

Hardware, by contrast, faces a classic chicken-and-egg problem. Large-scale production is hard to justify before reliability, safety, and autonomy are proven, while low volumes slow cost reduction, supplier investment, and standardization. Within the hardware stack, reducers—high-precision gearing systems embedded in actuators—have high barriers to entry and are led by Japanese players such as Harmonic Drive Systems and Nabtesco, while rare earth materials—particularly magnets used in high-performance motors—create strategic dependencies, with supply chains heavily concentrated in China.

Economics, not hardware cost alone, will determine adoption. Today's ~$50k–$150k prototypes reflect low volumes and customization, with targets of ~$20k–$30k at early scale and <$10k–$20k at maturity driven by scale, integration, and standardization. Importantly, lower hardware costs alone do not guarantee adoption. Over the longer term, humanoids may increasingly help build other humanoids, creating a self-reinforcing manufacturing flywheel that lowers costs and accelerates scale. Ultimately, humanoid adoption will depend on the cost per productive hour, which reflects not only purchase price, but also uptime, reliability, maintenance requirements, utilization, and task capability. A $50k robot operating reliably for 22 hours per day may be far more economical than a $10k robot operating only 4 hours per day due to frequent failures, downtime, or limited functionality.

The supply chain will likely be shaped by geopolitics as much as technology. China currently leads in humanoid deployment volumes and holds strong positions across several parts of the value chain, including rare earth processing, motors, batteries, and robot manufacturing. However, growing U.S. and European scrutiny of Chinese technology and industrial supply chains could influence market access, procurement decisions, localization requirements, and ultimately the geographic distribution of production and deployment. As a result, humanoid supply chains may become increasingly regionalized over time, with parallel hardware, software, and manufacturing ecosystems emerging across China and Western markets.

Sector-level thoughts: We provide sector-level perspectives for the European Technology Hardware & Asia Semis; U.S. Auto & Mobility; U.S. Industrial Technology & Distributors; European Capital Goods; and China Technology.

FIGURE 2. **Summary of company mentions by value chain subcategory**

Subcategory	Public Companies
Compute & Models	AMD.US, AMZN.US, GOOG.US, INTC.US, MBLY.US, META.US, MSFT.US, MU.US, NVDA.US, QCOM.US, SKHY.US, TSLA.US, TSM.US, 005930.KS
Actuators: Muscles & Joints	
- Actuator Reducer & Bearing	SHA0.GY, SKFB.SS, TKR.US, 000333.CH, 000837.CH, 002008.CH, 002046.CH, 002472.CH, 002896.CH, 058610.KS, 2049.TT, 300503.CH, 389500.KS, 3952.HK, 4583.TT, 496320.KS, 603667.CH, 6268.JT, 6302.JT, 6324.JT, 6471.JT, 6472.JT, 6473.JT, 6479.JT, 6480.JT, 6481.JT, 6594.JT, 688017.CH
- Actuator Motors	ALNT.US, MOG/A.US, NOVT.US, PH.US, RRX.US, 000333.CH, 002747.CH, 002979.CH, 2308.TT, 300124.CH, 300503.CH, 603728.CH, 6506.JT, 6594.JT, 688160.CH, 6954.JT
- Integrated Actuator Modules	MOG/A.US, PH.US, RRX.US, SHA0.GY, TKR.US, TSLA.US, 000333.CH, 000581.CH, 002747.CH, 002979.CH, 108490.KS, 2308.TT, 300503.CH, 389500.KS, 6268.JT, 6324.JT, 6479.JT, 6594.JT, 688160.CH
- Actuator Materials	LYC.AU, MP.US, NEO.CN, 000970.CH, 300748.CH, 4063.JT, 6762.JT
Control, Feedback & Connectivity: The Nervous System	ADI.US, ALGM.US, APH.US, IFX.GY, MCHP.US, MELE.BB, MPWR.US, NOVT.US, NXPI.US, ON.US, RSW.LN, STM.US, TEL.US, TXN.US, 002747.CH, 2308.TT, 6479.JT, 6723.JT, 6806.JT
Sensory System: Eyes, Ears & Touch	AME.US, APH.US, CGNX.US, IFX.GY, KN.US, NOVT.US, NXPI.US, OUST.US, RSW.LN, TEL.US, TXN.US, 002241.CH, 2018.HK, 2983.HK, 603501.CH, 6758.JT, 6861.JT
Batteries: The Energy Source	F.US, GM.US, QS.US, TSLA.US, VOW3.GY, 002594.CH, 006400.KS, 096770.KS, 300750.CH, 373220.KS, 6752.JT, 7203.JT

The companies referenced in this report are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Barclays Research

Humanoid System Architecture Overview

Humanoids are complex, integrated systems spanning six core layers:

- **Compute & Foundation Models: The Brain (~10–15% of bill of materials).** Compute forms the intelligence layer of the humanoid and becomes increasingly strategic as humanoids move toward greater autonomy. Compute spans three layers: (i) simulation compute to generate data and train policies in digital environments; (ii) foundation model training to build the perception-to-action intelligence layer; and (iii) on-robot inference to execute decisions locally under tight latency, power, and safety constraints. This drives demand for both data-center AI infrastructure and specialized edge processors embedded in each robot.

- **Actuators: Muscles & Joints (~30–50% of BoM).** Actuators convert electrical commands into controlled physical motion at each joint, enabling a humanoid's movements. A full-size humanoid typically incorporates ~40–70 actuators, broadly corresponding to its degrees of freedom (DoF). Actuation remains the largest cost driver, reflecting the complexity, precision, and component count required for human-like mobility and dexterity. Electric actuators are built around four core elements: a motor, reducer (high-precision gearing), sensing system, and control electronics. Notably, high-precision reducers have high barriers to entry, are led by Japanese players such as Harmonic Drive Systems and Nabtesco, and could become a bottleneck as production scales. Upstream, rare earth materials—particularly neodymium magnets (NdFeB) magnets used in high-performance motors—create strategic dependencies, with supply chains heavily concentrated in China. Increasing system complexity, combined with the need for lower costs, greater reliability, and scalable manufacturing, is driving a shift toward integrated actuator modules that combine motors, reducers, sensing systems, and control electronics into increasingly compact, modular, and manufacturable designs.

- **Control, Feedback & Connectivity: The Nervous System (~10–15% of BoM).** Control systems coordinate sensing, computation, and motion across the robot, processing signals and regulating power flow to enable precise, reliable, safe, and energy-efficient operation across dozens of joints. While less visible than motors and reducers, these technologies are embedded throughout the robot and play a critical role in determining how accurately, efficiently, and safely a humanoid moves. Value is likely to shift toward highly integrated actuator-control architectures that combine sensing, motion control, power management, connectivity, and thermal optimization within compact modules. This creates opportunities across analog semiconductors, power electronics, sensing, interconnects, and thermal-management suppliers, with content generally scaling alongside actuator count.

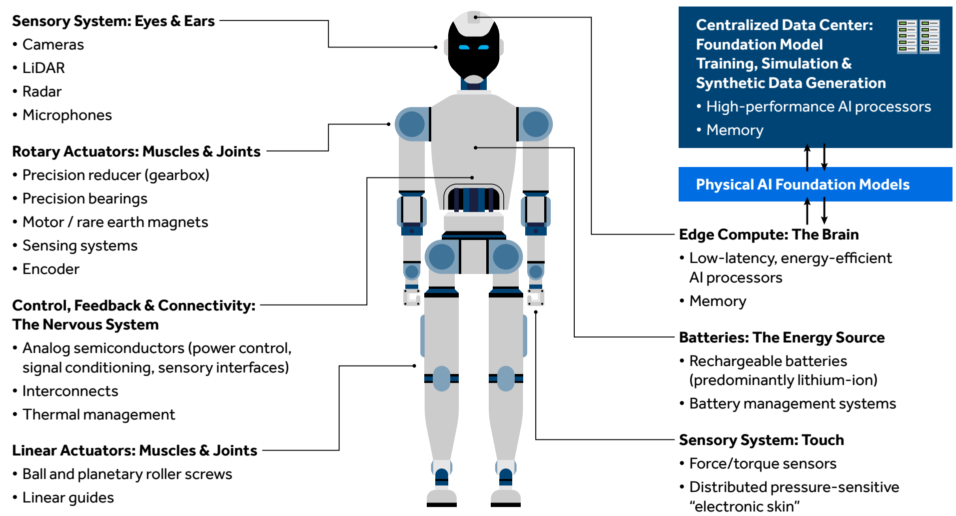
- **Sensory: Eyes, Ears & Touch (~10–15% of BoM).** Sensory systems enable interaction with the environment, including vision (cameras, LiDAR, radar), audio (microphones), and tactile sensing (force/torque sensors, electronic skin). Together, these provide real-time awareness for navigation, manipulation, and human interaction. While vision benefits from commoditization, tactile and force sensing remain earlier-stage and relatively higher cost.

- **Battery: The Energy Source (~5–10% of BoM).** Humanoids are untethered and rely on rechargeable batteries—typically lithium-ion—for power. While benefiting from EV-driven cost curves, batteries remain a key constraint on runtime, weight, and safety, with most systems operating only a few hours per charge. As a result, battery swapping is emerging as a key enabler—particularly in warehouse, logistics, and manufacturing settings—allowing continuous operation, minimizing downtime, and avoiding long charging cycles.

- **Structure: The Body (~5–10% of BoM).** The structural system forms the physical framework of the robot, including the chassis, housings, and mechanical supports. It must balance strength, weight, and durability while maintaining human-like proportions. As designs scale, structural components are expected to benefit from design-for-manufacturing (DFM), modularization, and tooling, supporting cost reduction over time.

Note: Cost ranges are directional and intended to highlight the relative economic importance of each subsystem rather than provide a precise bill of materials. Actual content varies significantly by robot architecture, component integration, and production scale, and percentages are therefore not additive.

FIGURE 3. **Anatomy of a humanoid: from compute to components**



Source: Barclays Research

Humanoid Cost Trajectory: From Prototypes to Scale

Humanoid adoption will ultimately be determined by economics, not hardware cost alone. Today's systems remain expensive due to low volumes, custom designs, and limited standardization, while future cost reductions will be driven by scale, simplification, and integration rather than a single breakthrough.

Importantly, lower hardware costs alone do not guarantee adoption. Humanoids become economically viable when their cost per productive hour is attractive relative to human labor or alternative automation, including collaborative robots (cobots)—robots designed to work safely alongside humans—and autonomous mobile robots (AMRs)—self-navigating robots used for tasks such as transporting materials within warehouses and factories. This depends not only on purchase price, but also on uptime, reliability, maintenance requirements, utilization, and task capability. A $50k robot operating reliably for 22 hours per day may be far more economical than a $10k robot operating only 4 hours per day due to frequent failures, downtime, or limited functionality.

Competition is therefore not limited to replacing human workers. In many industrial environments, humanoids must compete with existing automation that is already proven, reliable, and cost-effective. Cobots excel at repetitive manipulation tasks in structured environments, while AMRs are increasingly used for material transport and logistics. As a result, humanoids are most likely to gain traction where a single platform can perform a variety of tasks, operate within existing human-designed infrastructure, and deliver flexibility that would otherwise require multiple dedicated automation systems. Their value proposition is strongest in environments where adaptability and task diversity outweigh the efficiency advantages of specialized automation.

As a result, humanoids are likely to achieve economic viability first in narrow, controlled industrial environments where flexibility provides a clear advantage over existing automation, with broader deployment following improvements in reliability, autonomy, and overall system intelligence. Adoption may also increasingly occur through Humanoid-as-a-Service (HaaS) business models, where customers pay for robot labor or productive hours rather than purchasing robots outright, shifting the focus from capital expenditure to operating economics and lowering barriers to adoption.

Potential phases of humanoid cost reductions:

- **Phase 1: Prototype stage (~$50k–$150k+) — high cost, low volume, engineering-led.** Current humanoids are built in low volumes with highly customized designs, where cost is driven more by engineering complexity than manufacturing efficiency. Systems rely on custom actuators, precision reducers, and low-volume components, alongside manual assembly, calibration, and non-optimized integration layers. Actuation dominates the cost stack (~30–50%), with reducers and motors representing key bottlenecks due to limited suppliers and high precision requirements. At this stage, economics are secondary to capability development, with the primary focus on validating locomotion, manipulation, and early autonomy while generating initial data sets.
- **Phase 2: Early scaled production (~$20k–$30k target) — simplification and integration.** As platforms move toward commercialization, leading humanoid developers are targeting ~$20k–$30k unit costs, representing the first step toward economic viability. Cost reduction in this phase is driven by design simplification (standardized architectures and reduced over-engineering), vertical integration (in-house motors, actuators, and electronics), supply-chain localization, and manufacturing scale through design-for-manufacturing (DFM). However,

these targets remain aspirational and dependent on achieving sufficient reliability and uptime.

- **Phase 3: Long-term mass market (<$10k–$20k potential) — standardization, automation and commoditization.** At maturity, sub-$10k–$20k hardware costs are targeted under conditions of high-volume production, standardized architectures, and automated manufacturing. Over time, humanoids may increasingly help build other humanoids—assembling components, tending production lines, and supporting factory operations—creating a self-reinforcing manufacturing flywheel that lowers costs and accelerates scale. This phase requires fully modular actuator platforms, commodity sensors and electronics, and mature global supply chains supported by learning curve effects. While many components such as structure, wiring, and commodity sensors are highly deflationary, others—particularly precision reducers and rare earth materials—are likely to remain structural bottlenecks. As a result, meaningful cost compression is achievable, but not uniformly across the stack, reinforcing that long-term cost declines depend as much on system architecture and supply-chain maturity as on scale alone.

Geopolitics may also shape the trajectory of humanoid adoption and supply-chain development. China currently leads in volume of humanoid deployments (see AI gets physical: The decade of the robot belongs to China) and holds strong positions across several parts of the humanoid value chain, including rare earth processing, motors, batteries, and robot manufacturing. However, growing U.S. and European scrutiny of Chinese technology, industrial supply chains, and critical infrastructure could influence procurement decisions, localization requirements, tariffs, and market access. For example, the proposed U.S. Against Adversarial Robotics Dominance (GUARD) Act seeks to restrict Chinese-made robots—including humanoids and robotic dogs—on national security grounds (see AI gets physical: GUARD your robots). As a result, humanoid supply chains may become increasingly regionalized over time, potentially creating parallel hardware, software, and manufacturing ecosystems across China and Western markets.

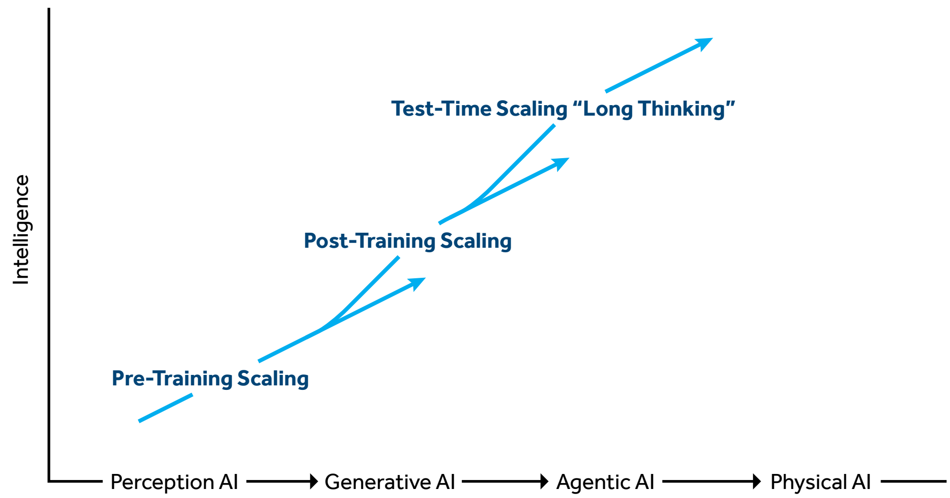
During our time at recent robotics conference (Physical AI: Robotics Summit Highlights Humanoid Scaling Hurdles), several industry participants described China as a high-volume test bed for humanoid experimentation, supported by faster product cycles, broader supplier depth, and greater risk tolerance. However, they noted that many current Chinese humanoid platforms remain focused on demonstrations and entertainment, rather than demanding industrial applications requiring strength, reliability, safety certification, and autonomy. In their view, the U.S. and parts of Europe may remain competitive in developing industrial-grade humanoids capable of performing economically valuable work at scale.

Compute & Foundation Models: The Brain

Humanoids are as much an AI compute problem as a robotics one. While often framed as a hardware story—centered on actuators, sensory systems, and batteries—the primary constraint today is arguably intelligence. Unlike traditional industrial robots, which rely on deterministic, pre-programmed control, humanoids require continuous perception, reasoning, and adaptive decision-making in unstructured environments. As the industry evolves from scripted or human teleoperated systems toward greater autonomy, the bottleneck is shifting from hardware capability to data, models, and compute efficiency. The “brain” of the robot—spanning simulation, foundation models, and on-robot inference—is therefore emerging as the key source of differentiation. The humanoid compute requirement spans three layers:

- **Simulation compute** to generate synthetic data and train policies in digital environments.
- **Foundation model training** to build the perception-to-action intelligence layer.
- **On-robot inference** to execute decisions locally under tight latency, power, and safety constraints.

FIGURE 4. **Phases of the industrial AI revolution & AI scaling laws**



Source: Nvidia, Barclays Research

Together, these layers drive demand for both data center AI infrastructure and specialized edge processors embedded within each robot. As humanoid development accelerates, simulation and training workloads may increasingly compete with large language models (LLMs) and generative AI for finite data center capacity—while creating incremental demand for accelerators, memory, storage, networking, and power infrastructure. It also elevates the importance of proprietary data, advantaging companies with robot fleets, simulation platforms, or access to large-scale human and robot demonstration data sets.

> "Most robots are pre-programmed or teleoperated for narrow, repetitive task sequences. They lack the ability to truly learn for themselves or adapt to unpredictable environments. Moreover, transferring learned skills from one robot body to another remains incredibly difficult. To take on the hardest problems at scale, robots of every shape and size need AI models giving them the ability to think, act, and interact intelligently to safely complete tasks."
>
> *— Google DeepMind: Gemini Robotics 2 brings whole body intelligence to robots*

Simulation Compute: The Digital Training Ground

A fundamental challenge for Physical AI is the lack of high-quality, robot-centric data, as detailed in Physical AI: Robotics Summit Highlights Humanoid Scaling Hurdles. While large language and vision models benefit from internet-scale datasets, there is no comparable repository for training machines to interact reliably with the physical world.

To address this, developers increasingly rely on synthetic data generated through large-scale simulation and digital twins of robots and their environments. These environments enable humanoids to learn locomotion, manipulation, and task execution before real-world deployment.

However, simulation is not a substitute for reality. The sim-to-real gap remains material, as variables such as lighting, friction, and rare edge cases are difficult to model. The likely path is hybrid: simulation accelerates pre-training, while real-world deployment, often supervised, provides high-quality edge-case data. For example, NVIDIA's Issac GR00T robotics foundation models combine internet-scale human video, real-world robot demonstrations, and synthetic data to improve generalization across different robot embodiments.

Alongside simulation, world models are emerging as a complementary layer. Whereas foundation models drive behavior by deciding what to do, world models learn to predict what will happen in response to actions—enabling planning, scenario evaluation, and synthetic data generation.

> "China's humanoid boom has solved the most visible part of the problem: figuring out how to hobble together a body. The harder part now is building a brain. The next AI race may be less about ever-bigger Large Language Models than about "world models," ones that can understand the physical realm and give robots something closer to common sense."
>
> — *Bloomberg: Humanoids Have Bodies. They Still Need Brains, July 2026*

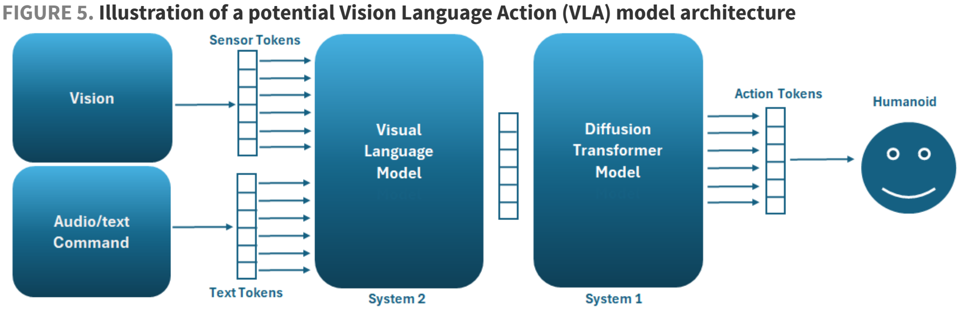
Foundation Model Training: Building the Brain

OpenAI's release of Chat GPT-3 in 2020 is widely viewed as an inflection point for large language models (LLMs), but this "GPT moment" was built on a prior architectural breakthrough: the transformer architecture and self-attention mechanism introduced in Google's 2017 paper, *Attention Is All You Need*. This innovation enabled models to process information in parallel and capture long-range relationships between tokens, supporting dramatically larger, more capable, and more scalable LLMs.

Humanoids arguably still lack a true "GPT moment" breakthrough that enables reliable, general-purpose perception and action. The challenge is not just capability, but achieving the reliability required for real-world deployment across diverse environments and a long tail of edge cases.

This gap between human and machine capability is captured by Moravec's paradox. In the 1980s, roboticist Hans Moravec observed that tasks humans find effortless—perception, navigation, and basic dexterity—are extraordinarily difficult to automate, while tasks humans find difficult, such as advanced mathematics or chess, can often be solved efficiently by computers. This helps explain why digital AI has scaled faster than Physical AI: robots must master perception, manipulation, and real-time interaction with the physical world.

FIGURE 5. Illustration of a potential Vision Language Action (VLA) model architecture



Source: Nvidia & Barclays Research

One promising direction for Physical AI is the emergence of Vision Language Action (VLA) models, which unify perception, language understanding, and motor control within a single architecture. Rather than relying on separate vision, planning, and control pipelines, VLAs translate observations and instructions directly into actions, creating a tighter link between understanding and execution.

Another useful way to frame this architecture comes from Daniel Kahneman's *Thinking, Fast and Slow*, which separates intelligence into System 1 (fast, intuitive action) and System 2 (slow, deliberate reasoning). A similar approach is emerging in robotics, where low-latency control policies handle real-time execution while larger reasoning models perform planning, task decomposition, and long-horizon decision-making.

Google DeepMind's latest Gemini Robotics stack illustrates this layered architecture. Gemini Robotics ER 2, an embodied reasoning Vision Language Model (VLM), serves as the high-level planning layer, interpreting instructions, understanding the scene, planning multi-step tasks, tracking progress and coordinating execution. Gemini Robotics 2 serves as the Vision Language Action (VLA) layer, converting vision and language inputs into motor control and whole-body movement, while Gemini Robotics On-Device 2 is a more efficient VLA optimized for local deployment on robotic hardware.

This all suggests that future humanoids are unlikely to rely on a single monolithic model. Instead, they may combine reasoning, perception-to-action intelligence, simulation, and real-time control into an integrated intelligence stack.

> "For the first time, our model can now control entire humanoid robots, translating intent into intelligent whole-body control. While our robots have more to advance in movement speed, this is an important step towards the skills needed to complete more complex, real-world tasks that require whole-body coordination."
>
> *— Google DeepMind: Gemini Robotics 2 brings whole body intelligence to robots*

Training these systems is highly compute-intensive and requires a diverse mix of internet-scale semantic data, real robot demonstrations, teleoperation data, synthetic simulation data, and embodiment-specific post-training. As a result, competitive advantage is likely to accrue to players that best integrate data, models, compute, and deployment into a continuous learning system. Furthermore, early deployments can create powerful data flywheels, where real-world usage generates edge-case data that improves models and enables broader deployment over time.

On-Robot Compute: The Edge Intelligence Layer

Once deployed, humanoids must run inference locally with low latency, high reliability, and strict power constraints. Perception-to-action feedback loops—across dozens of actuators and sensor streams—often require responses within tens of milliseconds to maintain balance, coordination, and safety.

Running large foundation models directly on the robot is therefore often impractical. This creates a design challenge where performance per watt, latency, and thermal efficiency are critical. Models must be compressed, distilled, or re-architected for edge deployment. For example, NVIDIA's GR00T N1.6 (~3B parameters) reflects the push toward smaller, deployable models.

Compute Hardware & Software Ecosystem

The humanoid compute ecosystem spans data center infrastructure, edge processors, memory, and software platforms. **Nvidia** has built a leading end-to-end Physical AI stack spanning: Jetson (on-robot edge compute); Omniverse (3D simulation and digital twin platform for generating synthetic data); Isaac Sim (robotics simulation environment built on Omniverse for training and validation); and Isaac GR00T (robotics foundation model initiative using VLA architectures to connect perception, language and action). Taken together, Omniverse creates the digital world, Isaac Sim trains robots within it, GR00T develops intelligence, and Jetson deploys it on the robot.

AMD, **Intel**, and **Qualcomm** provide alternative edge compute solutions, with trade-offs across performance, power, and software ecosystems. The market is unlikely to be winner-take-all, as developers optimize for different constraints. **Tesla** has also outlined longer-term ambitions around vertically pursuing its own dedicated chip fabrication facility (a 'Terafab') to support edge compute for autonomous vehicles and Optimus humanoids (see U.S. Autos & Mobility: Tesla - Terafab at the core of Tesla's hyper-growth strategy).

Memory is another critical layer, particularly as foundation models and perception systems become more sophisticated. High-bandwidth memory and advanced DRAM solutions enable the rapid movement and processing of large sensor and model datasets, while NAND storage supports local data retention and model deployment. Key suppliers include **SK Hynix**, **Samsung Electronics**, and **Micron Technology**.

These systems are underpinned by advanced semiconductor manufacturing from **TSMC** and **Samsung Electronics**, whose process technologies enable continued improvements in performance, energy efficiency, and integration. We compiled a list of 400+ 'pick & shovel' companies essential to digital & power infrastructure build out in Thematic Investing Powering AI: 400+ Digital & Power Infrastructure Companies.

Foundation Models

Long-term differentiation is increasingly likely to reside in Physical AI foundation models, in which the central battleground is the data + model + compute loop. Three approaches are emerging:

- **Large AI platform providers:** Companies such as **Google**, **Amazon**, **Nvidia**, **Microsoft**, **OpenAI**, and **Meta** are extending multimodal models into the physical world, aiming to own the horizontal "brain" layer. Their advantages lie in compute scale, model capability, and ecosystem reach, positioning them to become the default intelligence layer across robot types.

- **Robotics-native AI startups:** Humanoid developers (see landscape of 35+ humanoid developers) are targeting the model layer through tight hardware-software integration. Their advantage is proprietary data and embodiment, enabling faster learning loops. Their challenge is scaling capital-intensive hardware alongside AI.

- **Autonomy players:** Autonomous vehicles companies—such as **Tesla**, **Google's Waymo** and **Mobileye**—bring experience operating large-scale Physical AI systems. Tesla is extending its autonomy stack into its Optimus humanoids, leveraging fleet data, custom AI chips, and vertical integration. Waymo has emphasized a simulation-first, world model–driven approach, leveraging large-scale virtual environments and learned environment dynamics. Mobileye is exploring the extension of its vision-first architecture and automotive-grade systems into humanoid platforms.

FIGURE 6. Humanoid compute & model ecosystem

Company	Ticker	Domicile Country	Mkt Cap	Equity Analyst	Sector
AI Platforms / Foundation Models					
Amazon	AMZN.US	US	$2943 bn	Ross Sandler	US Internet
Google	GOOG.US	US	$4433 bn	Ross Sandler	US Internet
Meta	META.US	US	$1485 bn	Ross Sandler	US Internet
Microsoft	MSFT.US	US	$3630 bn	Raimo Lenschow	US Software
NVIDIA	NVDA.US	US	$5357 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Autonomy Players					
Google	GOOG.US	US	$4433 bn	Ross Sandler	US Internet
Mobileye	MBLY.US	Israel / US	$7 bn	Dan Levy	US Autos & Mobility
Tesla	TSLA.US	US	$1278 bn	Dan Levy	US Autos & Mobility
Edge Compute					
AMD	AMD.US	US	$797 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Intel	INTC.US	US	$517 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
NVIDIA	NVDA.US	US	$5357 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Qualcomm	QCOM.US	US	$166 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Memory					
Micron Technology	MU.US	US	$1042 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Samsung Electronics	005930.KS	South Korea	KRW 1414799 bn	Simon Coles	European Technology Hardware
SK Hynix	SKHY.US	South Korea	$1128 bn	Simon Coles	European Technology Hardware
Semiconductor Manufacturing					
Taiwan Semiconductor Manufacturing Co.	TSM.US	Taiwan	$2165 bn	Simon Coles	European Technology Hardware
Samsung Electronics	005930.KS	South Korea	KRW 1414799 bn	Simon Coles	European Technology Hardware

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Bloomberg & Barclays Research

Actuators: Muscles & Joints

Actuators sit at the core of humanoid movement and dexterity. Actuators are integrated mechanisms that convert electrical commands into controlled physical motion at each joint, enabling a humanoid's movements (e.g., walking, lifting, grasping). Rotary actuators provide rotational motion, while linear actuators provide straight-line motion. A full-size humanoid typically incorporates ~40–70 actuators, broadly corresponding to its powered joints or degrees of freedom (DoF).

Actuation systems can be broadly categorized as electric, hydraulic, or pneumatic. For humanoid robots, electric actuation offers the best balance of precision, efficiency, controllability, and scalability required for stable locomotion and dexterous manipulation. Hydraulic systems, while capable of high force and power density, are generally too complex and maintenance-intensive for commercial deployment, while pneumatic systems lack the precision required for coordinated multi-joint motion.

Electric actuators are built around four core elements: a motor, reducer (gearbox), sensing systems, and control and power electronics. The motor generates high-speed, low-torque output, which the reducer converts into low-speed, high-torque joint motion. Sensors provide position and motion feedback, while control and power electronics regulate current and enable real-time operation. Together, these components form a closed-loop servo system enabling precise, coordinated motion.

Increasing system complexity, combined with the need for lower costs, greater reliability, and scalable manufacturing, is shifting the challenge from optimizing individual components to designing and coordinating the actuator system as a whole. This is driving a transition toward integrated actuator modules that combine reducers, motors, sensing systems, and control electronics within increasingly compact and modular designs.

Actuator Precision Reducers & Bearings

Reducers are high-precision gearing systems that sit at the core of each actuator. They convert a motor's high-speed, low-torque output into the lower-speed, higher-torque motion required at the joint. In simple terms, they transform motor speed into usable strength. Because reducers directly affect how accurately, smoothly, and reliably a joint moves, they are among the most critical components within the actuator system. Given their technical complexity, concentrated supplier base, and high barriers to entry, they are likely to remain a key bottleneck as humanoid production scales.

Closely linked to reducers are precision bearings, which support the moving parts inside both the gearbox and the joint. While less visible than motors and reducers, these technologies are embedded throughout the robot and within many actuator systems, playing a critical role in determining how accurately, efficiently, and safely a humanoid moves.

Reducer Architecture: Harmonic vs. Cycloidal vs. Planetary

There are three main types of reducers used in humanoid robots, each with different strengths:

- **Harmonic (strain-wave) reducers** are designed for high precision and smooth motion. They use a flexible gear element to deliver near-zero backlash (virtually no slack in motion), enabling smooth, highly precise motion in a compact and lightweight form factor. Their hollow-shaft design allows cables and hoses to pass through the joint, improving packaging efficiency. As a result, they are typically deployed in smaller, precision-driven joints such as wrists, elbows, arms, and hands.

- **Cycloidal (RV) reducers** are built for strength and durability. They use a rolling disk mechanism to deliver high torque, rigidity, and durability with minimal backlash, albeit with greater size and weight. They are better suited for larger, load-bearing joints such as hips, shoulders, and legs, where stiffness, shock-load resistance, and long operating life are critical.

- **Planetary reducers** are simpler and lower cost, but generally less precise. They use a system of sun, planet, and ring gears to deliver high efficiency, compact packaging, and lower cost, but typically exhibit higher backlash and lower torsional rigidity. While generally not preferred for high-precision joints, they are increasingly used in cost-optimized and quasi-direct drive (QDD) architectures, where lower gear ratios enable more direct and responsive interaction between the motor and the joint.

In practice, most humanoid robots use a combination of reducer types. Precision joints often favor harmonic reducers, while larger load-bearing joints may use cycloidal designs. Planetary reducers are typically used where cost, efficiency, or simplicity are more important than maximum precision. Some robots also use direct-drive or linear actuators, particularly in high-load joints, reducing dependence on traditional gearboxes altogether.

Another emerging trend is the shift toward low gear-ratio and QDD architectures, as seen in systems such as Tesla and Unitree. These designs reduce reliance on complex, high-ratio gearboxes, making joints more efficient, responsive, and easier to control. The trade-off is that motors must generate more torque directly, increasing demands on motor design, thermal management, and control systems.

Competitive Landscape: Japan vs. China vs. RoW

High-precision reducers are difficult to manufacture due to tight tolerances, complex geometries, advanced materials, and long qualification cycles, creating high barriers to entry and significant switching costs. As a result, the market remains structurally concentrated, particularly at the high end. Japan maintains a clear leadership position, led by **Harmonic Drive Systems** and **Nabtesco**.

Harmonic Drive Systems is the global leader in harmonic reducers, with products widely used across robotics, semiconductor equipment, and aerospace. Its high precision, compact form factor, and established track record make it particularly well positioned for humanoid applications, especially in upper-body joints and robotic hands. The company is also expanding production capacity to support anticipated demand from next-generation robotics markets.

Nabtesco is the market leader in cycloidal (RV) reducers, with strong share in industrial robot joints. Its products offer high rigidity, durability, and load-bearing capability, making them well suited for humanoid hips, legs, and other high-stress joints. The company's expanding product portfolio is also extending its reach into more compact applications, broadening its relevance across the humanoid actuator stack.

China is rapidly developing domestic reducer capabilities, supported by policy, scale, and adjacency to the EV and industrial supply chain. Chinese companies are focused on closing the performance gap with Japanese incumbents while leveraging advantages in cost, localization, and manufacturing scale. Key players include:

- Harmonic reducers: **LeaderDrive, Laifual Drive, Zhejiang Shuanghuan**

- Cycloidal / multi-technology: **Qinchuan Machine Tool, Zhongda Leader**

- Bearing suppliers: **Sinomach Precision, Zhejiang XCC**

- Vertically integrated platforms: **Guangzhou Haozhi, Midea Group, Han’s Lasers**

Korea and Taiwan are emerging as secondary suppliers, offering diversification potential. **SBB TECH** and **SPG** are developing multi-technology reducers and targeting integrated actuator modules, while **Bonsystems** focuses on miniaturized cycloidal designs for dexterity applications. In Taiwan, **HIWIN** provides harmonic reducers and linear motion systems, while **Apex Dynamics** specializes in precision planetary gearboxes.

Outside Asia, the landscape is more fragmented but includes several relevant players. **Timken** has built a robotics drivetrain platform spanning cycloidal and harmonic technologies (via SPINEA, its precision robotics drivetrain subsidiary, and Cone Drive, its precision gearing subsidiary). **WITTENSTEIN** (private) and **Neugart** provide high-end precision gearboxes, while **maxon** (private) focuses on integrated actuator systems combining motors, gearboxes, and controls.

The precision bearing market is more mature and fragmented than reducers but remains concentrated among global leaders such as **JTEKT**, **NSK**, **NTN**, **SKF**, **Schaeffler**, **Timken**, alongside robotics-focused specialists including **THK**, **Nippon Thompson**, and **MinebeaMitsumi**, **Sinomach Precision** and **Zhejiang XCC**. Increasingly, bearings are being designed directly into actuator modules, reinforcing their role as a core supporting component.

FIGURE 7. Actuator reducer & bearing ecosystem

Company	Ticker	Domicile Country	Mkt Cap	Focus	Equity Analyst	Sector
			Japan			
Harmonic Drive Systems	6324.JT	Japan	JPY 712 bn	Harmonic reducers	Not covered	-
Nippon Thompson	6480.JT	Japan	JPY 154 bn	Cross-roller bearings	Not covered	-
JTEKT	6473.JT	Japan	JPY 687 bn	Bearings	Not covered	-
MinebeaMitsumi	6479.JT	Japan	JPY 1749 bn	Bearings & motors	Not covered	-
Nabtesco	6268.JT	Japan	JPY 589 bn	Cycloidal reducers	Not covered	-
Nidec	6594.JT	Japan	JPY 3321 bn	Reducers & motors	Not covered	-
NSK	6471.JT	Japan	JPY 596 bn	Precision bearings	Not covered	-
NTN	6472.JT	Japan	JPY 232 bn	Precision bearings	Not covered	-
Sumitomo Heavy Industries	6302.JT	Japan	JPY 737 bn	Cycloidal reducers	Not covered	-
THK	6481.JT	Japan	JPY 888 bn	Linear & bearings	Not covered	-
			China			
Guangzhou Haozhi	300503.CH	China	CNY22 bn	Integrated reducers	Not covered	-
Han's Laser	002008.CH	China	CNY98 bn	Reducer systems	Not covered	-
Laifual Drive	3952.HK	China	KRW 7 bn	Harmonic reducers	Not covered	-
LeaderDrive	688017.CH	China	CNY62 bn	Harmonic reducers	Not covered	-
Midea Group	000333.CH	China	CNY650 bn	Integrated actuators	Not covered	-
Qinchuan Machine Tool	000837.CH	China	CNY10 bn	Cycloidal reducers	Not covered	-
Sinomach Precision	002046.CH	China	CNY24 bn	Precision bearings	Not covered	-
Zhejiang Shuanghuan	002472.CH	China	CNY34 bn	Harmonic reducers	Not covered	-
Zhejiang XCC	603667.CH	China	CNY21 bn	Bearing components	Not covered	-
Zhongda Leader	002896.CH	China	CNY16 bn	Multi-tech reducers	Not covered	-

Company	Ticker	Domicile Country	Mkt Cap	Focus	Equity Analyst	Sector
Rest of World						
Neugart	Private	Germany	-	Planetary gearboxes	Not covered	-
Schaeffler	SHA0.GY	Germany	€7 bn	Bearings & actuators	Not covered	-
WITTENSTEIN	Private	Germany	-	Precision gear systems	Not covered	-
Bonsystems	496320.KS	Korea	KRW 1039 bn	Mini cycloidal	Not covered	-
SBB TECH	389500.KS	Korea	KRW 253 bn	Harmonic/RV reducers	Not covered	-
SPG	058610.KS	Korea	KRW 2344 bn	Integrated reducers	Not covered	-
SKF	SKFB.SS	Sweden	SEK 120 bn	Bearings	Timothy Lee	European Capital Goods
maxon	Private	Switzerland	-	Integrated actuators	Not covered	-
Apex Dynamics	4583.TT	Taiwan	TWD 41 bn	Planetary gearboxes	Not covered	-
HIWIN	2049.TT	Taiwan	TWD 129 bn	Reducers & motion	Not covered	-
Timken	TKR.US	US	$9 bn	Cycloidal & harmonic reducers, bearings	Not covered	-

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Barclays Research

Actuator Motors

Motor selection for actuators is driven by torque density, control precision, thermal performance, and packaging constraints. Most humanoid systems use brushless permanent-magnet motors, which are efficient, reliable, and capable of delivering precise, real-time control in a small form factor.

These motors operate within servo systems, where sensors and controllers continuously adjust movement in real time to keep joints stable and coordinated. A key constraint is torque density—how much force the motor can produce relative to its size—which directly impacts how strong, efficient, and dynamic the robot can be.

There is a clear shift toward frameless motors, which remove the outer housing and allow the motor to be built directly into the joint. This reduces weight, improves cooling, and enables tighter integration with other components such as gears and bearings. As a result, frameless designs are becoming the preferred approach for high-performance humanoid actuators.

Smaller joints—particularly in the hands and wrists—use miniature or coreless motors, where precision, responsiveness, and compact size are especially important. Suppliers such as **Regal Rexnord** (via Portescap subsidiary, its miniature motor subsidiary), **maxon** (private), and **FAULHABER** (private) specialize in these applications.

The motor market is broader and more fragmented than reducers. At the high end, companies such as **Nidec, maxon** (private), and **TQ-RoboDrive** (private) focus on high-performance, robotics-specific solutions. **Novanta** and **Allient** are also notable for compact, high-precision motor platforms used in advanced robotics.

Below this, a range of industrial automation players—including **Delta Electronics, Estun Automation, Inovance Technology, Parker-Hannifin, Bosch Rexroth** (private)**, Moog, Yaskawa Electric, and FANUC**—provide motors and control systems at scale. While not always designed specifically for humanoids, these technologies form the foundation of many robotic systems.

In China, companies such as **Guangzhou Haozhi, Midea Group, Leadshine, Kinco, and MOONS'** are building capabilities across motors, drives, and actuator components. Their focus on cost, vertical integration, and manufacturing scale positions them well for lower-cost humanoid designs as the market grows.

FIGURE 8. **Actuator motor ecosystem**

Company	Ticker	Domicile Country	Mkt Cap	Focus	Equity Analyst	Sector
Allient	ALNT.US	US	$2 bn	Torque motors	Not covered	-
Bosch Rexroth	Private	Germany	-	Motors & drives	Not covered	-
Delta Electronics	2308.TT	Taiwan	TWD 4286 bn	Servo motors	Not covered	-
Estun Automation	002747.CH	China	CNY31 bn	Servo systems	Not covered	-
FANUC	6954.JT	Japan	JPY 6345 bn	Robotics motors	Not covered	-
FAULHABER	Private	Germany	-	Miniature motors	Not covered	-
Guangzhou Haozhi	300503.CH	China	CNY22 bn	Motors & actuators	Not covered	-
Inovance Technology	300124.CH	China	CNY174 bn	Servo drives	Not covered	-
Kinco	688160.CH	China	CNY11 bn	Servo systems	Not covered	-
Leadshine	002979.CH	China	CNY19 bn	Motion control	Not covered	-
maxon	Private	Switzerland	-	Precision motors	Not covered	-
Midea Group	000333.CH	China	CNY650 bn	Motors & systems	Not covered	-
Moog	MOG/A.US	US	$13 bn	Servo actuators	Not covered	-
MOONS'	603728.CH	China	CNY22 bn	Motion components	Not covered	-
Nidec	6594.JT	Japan	JPY 3321 bn	Motors & reducers	Not covered	-
Novanta	NOVT.US	US	$6 bn	Frameless motors	Not covered	-
Parker-Hannifin	PH.US	US	$126 bn	Motion systems	Not covered	-
Regal Rexnord	RRX.US	US	$12 bn	Precision motors	Not covered	-
TQ-RoboDrive	Private	Germany	-	Frameless motors	Not covered	-
Yaskawa Electric	6506.JT	Japan	JPY 1435 bn	Servo motors	Not covered	-

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Bloomberg Research, Barclays Research

Integrated Actuator Modules

As humanoid production scales, competitive differentiation is shifting from individual components toward complete joint architectures, combining the reducer, motor, sensing, and power and control electronics into a single unit. This approach reduces wiring and integration complexity while improving performance, efficiency, reliability, and packaging. As a result, integrated actuator modules are emerging as a key locus of value creation.

Established reducer suppliers such as **Harmonic Drive Systems** and **Nabtesco** are expanding beyond standalone reducers into integrated joint solutions that combine gearing, sensing, and control functionality. In parallel, motion-control and drivetrain players—including **Schaeffler, Bosch Rexroth** (private), **Regal Rexnord** (via Kollmorgen, its motion-control and robotics subsidiary), **TQ-RoboDrive** (private), **Nidec, MinebeaMitsumi**, **Moog**, **Parker-Hannifin**, and **Delta Electronics**—are leveraging multi-domain capabilities across motors, gearing, bearings, sensing, and control to develop integrated actuator platforms.

A growing group of robotics-focused specialists is also emerging at the actuator-module level. **ROBOTIS** is known for modular smart actuators widely used in research and commercial robotics. **CubeMars** (private) has gained traction in humanoid and legged robots through low-ratio and quasi-direct-drive actuator designs. **Synapticon** (private) specializes in integrated servo drives and actuator electronics, while **SBB TECH** is leveraging its expertise in harmonic and RV reducers to expand into integrated actuator solutions for robotics and humanoid applications. **WITTENSTEIN** (private) and **Timken** (via SPINEA, its precision robotics drivetrain subsidiary) provide high-precision integrated drive systems for advanced robotic applications.

Vertically integrated companies such as **Guangzhou Haozhi**, **Midea Group, Weifu High-Technology**, **Estun Automation**, **Leadshine**, and **Kinco Automation** are pursuing similar strategies, with a focus on cost, localization, and manufacturing scale. Their ability to combine motors, reducers, electronics, and assembly within a single ecosystem positions them well for cost-driven humanoid scaling.

At the same time, several humanoid OEMs—including **Tesla, Figure AI, Apptronik, Agility Robotics,** and **Unitree Robotics**—are developing proprietary actuators to optimize performance, reduce bill-of-material costs, secure key components, and maintain control over system-level IP.

Overall, the market remains at an early stage, with no clear dominant supplier of integrated humanoid actuator platforms today. However, as volumes scale and architectures standardize, value is likely to shift toward integrated actuator modules, which could capture an increasing share of the actuator value stack. Over time, this shift could mirror the automotive model, where value concentrates with tier-1 system integrators rather than discrete component suppliers.

FIGURE 9. **Integrated actuator ecosystem**

Company	Ticker	Domicile Country	Mkt Cap	Equity Analyst	Sector
Bosch Rexroth	Private	Germany	-	Not covered	-
CubeMars	Private	China	-	Not covered	-
Delta Electronics	2308.TT	Taiwan	TWD 4286 bn	Not covered	-
Estun Automation	002747.CH	China	CNY31 bn	Not covered	-
Guangzhou Haozhi	300503.CH	China	CNY22 bn	Not covered	-
Harmonic Drive Systems	6324.JT	Japan	JPY 712 bn	Not covered	-
Kinco Automation	688160.CH	China	CNY11 bn	Not covered	-
Leadshine	002979.CH	China	CNY19 bn	Not covered	-
Midea Group	000333.CH	China	CNY650 bn	Not covered	-
MinebeaMitsumi	6479.JT	Japan	JPY 1749 bn	Not covered	-
Moog	MOG/A.US	US	$13 bn	Not covered	-
Nabtesco	6268.JT	Japan	JPY 589 bn	Not covered	-
Nidec	6594.JT	Japan	JPY 3321 bn	Not covered	-
Parker-Hannifin	PH.US	US	$126 bn	Not covered	-
Regal Rexnord	RRX.US	US	$12 bn	Not covered	-
ROBOTIS	108490.KS	South Korea	KRW 3497 bn	Not covered	-
SBB TECH	389500.KS	South Korea	KRW 253 bn	Not covered	-
Schaeffler	SHA0.GY	Germany	€7 bn	Not covered	-
Synapticon	Private	Germany	-	Not covered	-

Company	Ticker	Domicile Country	Mkt Cap	Equity Analyst	Sector
Tesla	TSLA.US	US	$1278 bn	Dan Levy	US Autos & Mobility
Timken	TKR.US	US	$9 bn	Not covered	-
TQ-RoboDrive	Private	Germany	-	Not covered	-
Weifu High-Technology	000581.CH	China	CNY16 bn	Not covered	-
WITTENSTEIN	Private	Germany	-	Not covered	-

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Bloomberg Research, Barclays Research

Actuator Materials

Materials form a critical upstream layer underpinning actuator performance, particularly within motors and electromagnetic subsystems. Key inputs include rare earth magnets, copper, and electrical steel, which directly influence torque density, efficiency, and thermal performance at the actuator level.

Among these, rare earth neodymium magnets (NdFeB) are especially strategic, as they enable the high power density required for compact humanoid actuators. However, supply chains for rare earths are highly concentrated—particularly in China—creating risks around supply security, cost volatility, and geopolitical exposure. The real bottleneck is not only mining, but also processing. Today, China extracts 59% of global rare earth materials, produces 69% of rare earth oxides, refines a staggering 91% of rare earth metals, and manufactures 94% of the permanent magnets, controlling the stages that matter most, as discussed in Critical Minerals: The magnetic pull of rare earths.

Key players include **JL MAG**, **Zhong Ke San Huan**, and **MP Materials**, which supply magnets and upstream materials critical to the actuator ecosystem. Beyond these, the broader rare earth value chain includes:

- **Magnet manufacturers** such as **Shin-Etsu Chemical** and **TDK**, which produce high-performance NdFeB magnets used in precision motors.
- **Non-China supply chain players** such as **Lynas Rare Earths** and **Neo Performance Materials**, which focus on rare earth processing, metals, and magnet production outside China.

While these companies sit outside the core actuator stack, they act as foundational enablers of motor and system performance, with supply chain positioning increasingly important as humanoid production scales.

In response to supply concentration and cost pressures, the industry is increasingly focused on material efficiency, recycling, and alternative motor designs (e.g., reduced rare-earth intensity), aiming to mitigate dependency on constrained inputs and improve long-term scalability.

FIGURE 10. **Actuator upstream material ecosystem**

Company	Ticker	Domicile Country	Mkt Cap	Focus	Equity Analyst	Sector
JL MAG	300748.CH	China	CNY35 bn	NdFeB magnets	Not covered	-
Lynas Rare Earths	LYC.AU	Australia	AUD 16 bn	Rare earth processing	Not covered	-
MP Materials	MP.US	US	$8 bn	Rare earth mining	Richard Garchitorena	North America Metals & Mining
Neo Performance Materials	NEO.CN	Canada	CAD 2 bn	Magnet materials	Not covered	-
Shin-Etsu Chemical	4063.JT	Japan	JPY 12234 bn	NdFeB magnets	Not covered	-
TDK	6762.JT	Japan	JPY 6123 bn	Neodymium magnets	Not covered	-
Zhong Ke San Huan	000970.CH	China	CNY16 bn	NdFeB magnets	Not covered	-

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Barclays Research

Control, Feedback & Connectivity: The Nervous System

Control systems, electronics, interconnects, and thermal management collectively form the "nervous system" of a humanoid robot. While less visible than motors and reducers, these technologies are embedded throughout the robot and play a critical role in determining how accurately, efficiently, and safely a humanoid moves. As systems scale from prototypes to commercial deployment, the challenge increasingly shifts from optimizing individual components to coordinating dozens of actuators, sensors, and feedback loops under tight constraints around latency, power consumption, reliability, and safety.

Control & Signal Chain Semiconductors

Analog and mixed-signal semiconductors provide the local control and signal-processing layer that governs actuator behavior. These devices process signals from sensors, execute control algorithms, and determine how the actuator responds in real time. Microcontrollers and motor-control ICs continuously adjust torque, speed, and position to maintain stable and coordinated movement. As humanoids incorporate more actuators and degrees of freedom, semiconductor content scales accordingly, increasing the importance of efficient, low-latency control architectures. Key suppliers include **Allegro MicroSystems**, **Analog Devices**, **Microchip Technology**, **Melexis**, **NXP Semiconductors**, **Renesas Electronics**, **STMicroelectronics**, and **Texas Instruments**.

Power Semiconductors

Power semiconductors regulate the flow of electricity between the battery and the motor, converting stored energy into motion. Because humanoids are battery-powered systems, power-conversion efficiency directly impacts runtime, thermal loading, and overall system performance. Improving efficiency can extend operating hours while reducing heat generation and cooling requirements. Key suppliers include **Infineon**, **On Semiconductor**, **Monolithic Power Systems**, and **Texas Instruments**.

Position Sensing & Feedback

Humanoid robots rely on continuous feedback to maintain balance, execute precise movements, and interact safely with their surroundings. Position sensors, commonly known as encoders, provide real-time information about joint location and motion, enabling closed-loop control across the robot. In simple terms, motors generate movement, while encoders determine whether that movement occurs accurately. Key suppliers include **Heidenhain** (private), **Novanta, POSITAL** (private), and **Renishaw**.

Servo Drives & Control Systems

Servo drives act as the bridge between electronics and motion, translating digital instructions into precisely controlled motor movement. They integrate power electronics, control logic, and feedback systems into a unified platform that governs actuator performance. As humanoid architectures evolve, there is growing emphasis on compact, joint-level control systems that improve modularity, simplify integration, and reduce wiring complexity. Key suppliers include **Bosch Rexroth** (private), **Delta Electronics**, **Estun Automation**, and **Synapticon** (private).

Interconnects & Wiring

Interconnects form the wiring network of the robot, carrying both power and data between sensors, actuators, compute platforms, and batteries. Humanoids present unique demands because cables and connectors must operate reliably under constant motion, vibration, and mechanical stress. As actuator and sensor counts increase, robust interconnect solutions become increasingly important for system reliability and maintainability. Key suppliers include **Amphenol**, **HARTING** (private), **Hirose**, **LEMO** (private), **Molex** (private, Koch-owned), and **TE Connectivity**.

Thermal Management

Thermal management is an increasingly important challenge as actuator density, onboard AI compute, and battery capacity continue to rise. Unlike industrial robots that can rely on larger housings or fixed installations, humanoids must dissipate heat within a compact, human-sized form factor. Thermal constraints can ultimately limit performance, runtime, and compute density, making heat management a critical design consideration as humanoid capabilities expand. As a result, thermal design is becoming a critical enabler of reliability, safety, and sustained operation. Key suppliers include **Delta Electronics** and **MinebeaMitsumi**, while continued improvements in semiconductor efficiency help reduce heat generation throughout the system.

FIGURE 11. **Humanoid control, connectivity & thermal management ecosystem**

Company	Ticker	Domicile Country	Mkt Cap	Equity Analyst	Sector
Control & Signal Chain Semiconductors					
Allegro MicroSystems	ALGM.US	US	$8 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Analog Devices	ADI.US	US	$184 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Melexis	MELE.BB	Belgium	€3 bn	Not covered	-
Microchip Technology	MCHP.US	US	$43 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
NXP	NXPI.US	Netherlands	$59 bn	Not covered	-
Renesas	6723.JT	Japan	JPY 7133 bn	Not covered	-
STMicroelectronics	STM.US	France/CH	$48 bn	Simon Coles	European Technology Hardware
Texas Instruments	TXN.US	US	$256 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Power Semiconductors					
Monolithic Power Systems	MPWR.US	US	$66 bn	Not covered	-
Infineon	IFX.GY	Germany	€78 bn	Simon Coles	European Technology Hardware
On Semiconductor	ON.US	US	$30 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Texas Instruments	TXN.US	US	$256 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Sensing & Feedback					
Heidenhain	Private	Germany	-	Not covered	-
Novanta	NOVT.US	US	$6 bn	Not covered	-
POSITAL	Private	Germany	-	Not covered	-
Renishaw	RSW.LN	UK	£4 bn	Jonathan Hurn	UK Capital Goods
Servo Drives & Control Systems					
Bosch Rexroth	Private	Germany	-	Not covered	-
Delta Electronics	2308.TT	Taiwan	TWD 4286 bn	Not covered	-
Estun Automation	002747.CH	China	CNY31 bn	Not covered	-
Synapticon	Private	Germany	-	Not covered	
Interconnects & Wiring					
Amphenol	APH.US	US	$215 bn	Guy Hardwick	US Industrial Technology & Distributors
HARTING	Private	Germany	-	Not covered	-

Company	Ticker	Domicile Country	Mkt Cap	Equity Analyst	Sector
Hirose	6806.JT	Japan	JPY 951 bn	Not covered	-
LEMO	Private	Switzerland	-	Not covered	-
Molex	Private	US	-	Not covered	-
TE Connectivity	TEL.US	Switzerland	$63 bn	Guy Hardwick	US Industrial Technology & Distributors
Thermal Management					
Delta Electronics	2308.TT	Taiwan	TWD 4286 bn	Not covered	-
MinebeaMitsumi	6479.JT	Japan	JPY 1749 bn	Not covered	-

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Barclays Research

Sensory System: Eyes, Ears & Touch

Sensory systems form the perception layer of humanoid robots, allowing them to understand and interact with the world around them. If actuators are the "muscles," sensory systems are the "eyes, ears, and sense of touch," giving the robot awareness of its environment and its own movement. These systems enable tasks such as navigation, object recognition, handling objects, and interacting with people.

Unlike many actuator components, much of the sensing ecosystem benefits from large adjacent markets such as smartphones, automotive, and industrial automation. This scale provides advantages in manufacturing, data, and investment, creating meaningful barriers to entry. As a result, many leading sensor companies are already well-established and can leverage existing technologies into robotics, particularly where performance, reliability, and integration are critical.

A typical humanoid uses a mix of sensors across its head and body, continuously collecting information about both its surroundings and its own position in real time. These systems rely on several key sensor types, each with a different role and competitive landscape:

- **Cameras** are the most important and widely used sensors. They capture visual information used for recognizing objects, understanding scenes, and interacting with people.
  Sony remains the dominant supplier of advanced image sensors, while **OmniVision** (via Will Semiconductor, its image sensor subsidiary) is another major provider. The broader machine vision ecosystem includes **Keyenc** and **Cognex**.

- **LiDAR** uses lasers to build detailed 3D maps of the environment. It is highly accurate for measuring distance and detecting obstacles, but tends to be more expensive. The market remains fragmented and fast-evolving, with companies such as **Hesai** and **Ouster** competing on performance and cost.

- **Radar** uses radio waves to detect objects and measure movement. It works reliably in difficult conditions like fog, dust, or darkness, but provides less detailed information than cameras or LiDAR. The market is more mature and concentrated, led by **Infineon**, **NXP**, and **Texas Instruments**.

- **Microphones** enable speech recognition, voice commands, and awareness of sounds, making microphones important for human interaction. **Knowles** is a leading supplier of MEMS microphones, a mature sensing technology widely used in voice-enabled consumer devices and increasingly relevant for humanoid speech recognition and human-machine interaction.

- **Tactile sensors** provide a sense of touch. They measure pressure, force, and movement, allowing robots to adjust grip, handle delicate objects, and maintain balance. These capabilities are especially important for tasks such as handling fragile items and maintaining stability during movement. Tactile systems often include sensors in joints and hands, as well as pressure-sensitive "electronic skin" on external surfaces. Tactile sensing remains early-stage and fragmented, making it a key challenge and potential differentiator as humanoid systems become more advanced. **Novanta** (via ATI Industrial Automation, its force/torque sensing subsidiary) is a leading supplier of force/torque sensors, while many developers are building proprietary solutions.

Because no single sensor is perfect, many humanoid systems use **sensor fusion**—combining multiple sensor types to improve accuracy and reliability. Supporting components are also critical. **TE Connectivity** and **Amphenol** provide connectors, interconnects, and signal transmission systems that enable reliable operation of increasingly sensor-dense humanoid platforms. Meanwhile, high-precision motion sensing remains concentrated among players such as **Renishaw**, **AMETEK**, and **Heidenhain** (private), which supply encoders and feedback systems used throughout robotics and industrial automation.

FIGURE 12. **Humanoid sensory ecosystem**

Company	Ticker	Domicile Country	Mkt Cap	Equity Analyst	Sector
Cameras & Machine Vision					
Cognex	CGNX.US	US	$12 bn	Guy Hardwick	US Industrial Technology & Distributors
Keyence	6861.JT	Japan	JPY 21251 bn	Not covered	-
OmniVision	603501.CH	China	CNY113 bn	Not covered	-
Sony	6758.JT	Japan	JPY 21266 bn	Not covered	-
LiDAR					
Hesai	2983.HK	China	KRW 23 bn	Not covered	-
Ouster	OUST.US	US	CNY138 bn	Not covered	-
Radar					
Infineon	IFX.GY	Germany	€78 bn	Simon Coles	European Technology Hardware
NXP Semiconductors	NXPI.US	Netherlands	$59 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Texas Instruments	TXN.US	US	$256 bn	Tom O'Malley	US Semiconductors & Semiconductor Capital Equipment
Audio					
AAC Technologies	2018.HK	China	KRW 48 bn	Not covered	-
Goertek	002241.CH	China	CNY84 bn	Not covered	-
Knowles	KN.US	US	$3 bn	Not covered	-
Tactile & Force Sensing					
Amphenol	APH.US	US	$215 bn	Guy Hardwick	US Industrial Technology & Distributors
Novanta	NOVT.US	US	$6 bn	Not covered	-
TE Connectivity	TEL.US	Switzerland	$63 bn	Guy Hardwick	US Industrial Technology & Distributors
Supporting Layer: Position & Motion Sensing					
AMETEK	AME.US	US	$59 bn	Not covered	-
Heidenhain	Private	Germany	-	Not covered	-
Renishaw	RSW.LN	UK	£4 bn	Jonathan Hurn	UK Capital Goods

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Barclays Research

Batteries: The Energy Source

Humanoid robots are untethered and rely on rechargeable batteries, typically lithium-ion, as their primary energy source. Battery packs are usually located in the torso or backpack, analogous to a human's core. Battery architecture directly influences runtime, payload, mobility, and cost, requiring trade-offs across energy density, power output, charging time, cycle life, safety, and weight.

While batteries benefit from mature EV-driven supply chains, they remain a meaningful cost component and a key constraint on operating time, with most humanoids today running for only a few hours per charge under typical workloads. Extending runtime depends not only on advances in battery technology but also on system-level efficiency across actuators, compute, and control software. Actuators and locomotion systems are typically the largest energy consumers, while increasing onboard AI capability raises power requirements, creating a trade-off between intelligence, autonomy, and runtime. Humanoids also face unique form-factor constraints, as battery size and weight are limited by balance requirements and human-like proportions.

To address these challenges, developers are exploring higher-energy chemistries, battery swapping, and fast charging. Swapping is particularly attractive in high-utilization environments such as warehouses, with a number of humanoid developers incorporating hot-swappable battery systems to enable near-continuous operation, while fast charging may be better suited for lower-duty-cycle applications. Safety and thermal management remain critical considerations as both batteries and onboard compute generate heat.

The Li-ion supply chain is dominated by large Asian manufacturers including **CATL**, **BYD**, **LG Energy Solution, Samsung SDI**, **Panasonic**, and **SK Innovation**, whose scale and cost advantages stem largely from the EV market. As humanoid demand remains small relative to electric vehicles, battery roadmaps will likely continue to be driven primarily by EV innovation. Automotive OEMs such as **Tesla, Toyota**, **Volkswagen**, **Ford**, and **GM** are also investing in Li-ion capacity and next-generation battery technologies, indirectly supporting humanoid development. Looking ahead, improvements in energy density, cycle life, charging speed, safety, and cost, alongside emerging technologies such as silicon-anode and solid-state batteries, could meaningfully extend operating time and improve humanoid economics. **QuantumScape** is pursuing solid-state battery technology aimed at improving energy density, safety, and charging performance relative to conventional lithium-ion batteries.

FIGURE 13. Humanoid battery ecosystem

Company	Ticker	Domicile Country	Mkt Cap	Equity Analyst	Sector
Battery Cell & Technology Suppliers					
CATL	300750.CH	China	CNY1911 bn	Jiong Shao	China Technology
LG Energy Solution	373220.KS	South Korea	KRW 77571 bn	Not covered	-
Panasonic Holdings	6752.JT	Japan	JPY 11086 bn	Not covered	-
QuantumScape	QS.US	US	$3 bn	Not covered	-
Samsung SDI	006400.KS	South Korea	KRW 34007 bn	Not covered	-
SK Innovation	096770.KS	South Korea	KRW 18444 bn	Not covered	-
Auto OEMs / Battery Ecosystem					
BYD	002594.CH	China	CNY791 bn	Jiong Shao	China Technology
Ford	F.US	US	$57 bn	Dan Levy	US Autos & Mobility
GM	GM.US	US	$78 bn	Dan Levy	US Autos & Mobility
Tesla	TSLA.US	US	$1278 bn	Dan Levy	US Autos & Mobility
Toyota	7203.JT	Japan	JPY 42537 bn	Not covered	-
Volkswagen	VOW3.GY	Germany	€38 bn	Henning Cosman	European Autos & Auto Parts

Market cap as of 8/5/2026. The companies referenced are included for informational purposes only to illustrate the humanoid value chain and should not be construed as investment recommendations
Source: Bloomberg & Barclays Research

Structure: The Body

The structural system forms the physical framework of the humanoid, analogous to the human skeleton and outer body. It includes the chassis, linkages, housings, and mechanical supports that integrate and protect actuators, sensors, and electronics while maintaining human-like proportions. The structure must balance strength, weight, stiffness, and durability, as these directly impact mobility, energy efficiency, and precision—heavier or less rigid designs increase actuator load and reduce overall system performance.

A growing component of this layer—particularly in early-stage humanoids—is the use of 3D printed (additive manufactured) parts. These are widely used in prototyping and low-volume production due to their flexibility and speed. 3D printing enables:

- Rapid iteration and design optimization, allowing developers to refine complex geometries quickly
- Lightweight, topology-optimized structures, reducing mass while maintaining strength
- Integration of multiple parts into a single component, lowering assembly complexity

However, 3D printed parts also come with trade-offs. They are typically more expensive at scale, have longer cycle times, and may offer lower consistency and durability compared to traditional manufacturing methods. As a result, while additive manufacturing is critical in development and early deployments, scaled production is expected to shift toward design-for-manufacturing (DFM) approaches, including casting, stamping, molding, and modular assemblies.

From a cost perspective, structure represents a mid-single-digit share (~5–10%) of total BoM, but is one of the most deflationary categories over time. As designs standardize and volumes increase, the transition away from 3D printed components toward high-throughput manufacturing should drive meaningful cost reductions and improved reliability, making structure less of a long-term bottleneck relative to actuators or advanced sensing systems.

Sector Thoughts

European Technology Hardware & Asia Semis

Simon Coles, CFA Barclays, UK

For our coverage, the largest relative humanoid beneficiaries, in our view, could be **Infineon** and **STMicroelectronics** who can supply a wide range of semiconductors for humanoids. **Samsung Electronics** and **SK hynix** benefit from further memory demand. **TSMC** benefits from another source for leading edge processors whilst semicap benefits from further increases in chip demand volumes. While current deployment volumes remain small, humanoids represent another end market requiring a combination of compute, memory, power management, sensing, motor control and connectivity, broadly increasing semiconductor content intensity.

STMicroelectronics appears well positioned across multiple layers of the humanoid stack. The company already participates in industrial and automotive markets that share many of the same requirements, including microcontrollers, motor-control ICs, power management and sensing. As humanoid platforms scale, semiconductor content should increase broadly with the number of actuators, sensors and control systems deployed in each robot. STM has indicated a semiconductor content opportunity of $600+ per humanoid, and we believe is working with the leading humanoid robot players already.

Infineon is similarly leveraged through power semiconductors, motor control, connectivity and radar. Humanoids are effectively highly electrified systems containing dozens of motors and actuators that require efficient power conversion and control. The company's strength in industrial automation and automotive electrification positions it naturally within the emerging humanoid supply chain.

Samsung Electronics and **SK hynix** are exposed through the memory attached to on-robot compute. Current humanoid architectures increasingly resemble compact AI inference systems, requiring DRAM and NAND alongside the main processor. More importantly, demand extends beyond the robot itself. Simulation, synthetic data generation and Physical AI model training all consume datacenter compute and memory resources, creating an additional driver of AI-related memory demand.

TSMC will benefit if humanoid robot volumes are significant. Each processor required is likely to be manufactured on TSMC's advanced logic processors. It also already makes nearly all of the advanced logic chips that go into datacentres and so any further demand driven by humanoids will help as well.

Semicap companies could benefit from material increases in TAMs for all of logic and memory. If humanoid robots are significant, then we would argue advanced logic and DRAM forecasts are too low. This could also give more confidence on analog chip demand requirements medium to longer term given the variety of chips required. This could support further WFE spending on top of current AI-fueled expectations.

More broadly, humanoids represent a potentially attractive opportunity because they combine characteristics of several existing semiconductor end markets simultaneously, including AI servers, industrial automation, autonomous vehicles and edge computing. While the timing of widespread adoption remains uncertain, the theme reinforces our positive long-term view our sector.

U.S. Autos & Mobility

Dan Levy BCI, US

Humanoid robots have become increasingly intertwined with the auto industry as of late, with a number of auto companies working to develop humanoid bots (i.e. TSLA, RIVN, MBLY) and auto OEMs contemplating the usage of humanoid bots in the manufacturing process in the future. Broadly, we see humanoid bots as an attractive opportunity for autos, with revenue opportunities for auto companies involved in producing humanoids and/or supplying parts for humanoids.

Tesla's efforts in robots are central to the company's bull case. We see several key considerations:

- Tesla is widely viewed as a leader in humanoid bots, with a wide following on its Optimus bots; alongside AV, Optimus/bots are at the core of Tesla's efforts in physical AI, with some of the uberbulls viewing the TAM for Optimus as limitless.

- Tesla is taking a novel approach to manufacturing and is designing new parts/components for Optimus; management has noted that Tesla had to establish brand new supply chains or move to in-house production as there were no existing suppliers for the parts. Moreover, Tesla's efforts in chips (AI5 development, Terafab) are also key in the product development/roll-out. And the V3 Optimus will integrate xAI's Grok for natural language interaction.

- Optimus V3 is set to enter volume production later this year as Tesla's Fremont factory, though the production ramp was guided to be slow given the number of new parts for the robot. Tesla is building a line capable of 1mn units/year at Fremont, followed by a 10mn units/year line in Texas.

- Optimus bots currently perform basic tasks in Tesla's factories, but they are not used in material ways. Optimus is aimed to be general-purpose – a more ambitious approach than others taking a more targeted approach, but a reminder of the significant opportunity ahead. Tesla expects Optimus to be useful to external companies sometime in '27.

Rivian has ties to humanoids through Mind Robotics. Mind was initially a project within Rivian to develop robots that would enable RIVN to operate manufacturing plants more efficiently, and last November it was spun out into a separate company, though RIVN CEO RJ Scaringe remains the CEO of Mind Robotics; the most recent disclosure cited RIVN with a 38% ownership stake in Mind. RIVN and Mind remain closely connected - Mind uses data from RIVN to train its AI model, and RIVN will be Mind's first customer for robots.

MBLY acquired humanoid robotics company Mentee in January, as management believes companies with exposure to physical AI through both AV and robotics will have an edge over their competition. Mentee's V4 robots were guided for volume production starting in 1Q27, with the first deployment to be B2C as MBLY wants to first build a humanoid capable of generalized operations/uses cases, rather than customizing to business requirements. '28 production was guided to 500 units.

We also see OEMs outside of our coverage using humanoid robots, with BMW partnering with Figure to test Figure robots in its factories and Hyundai's plans to deploy Boston Dynamics humanoid robots at its Georgia plant starting in '28.

U.S. Industrial Technology & Distributors

Based on our discussions with industry participants at industrial automation trade show such as AUTOMATE, we believe there is $400-$1,200 of sensor and connector content opportunity on a humanoid robot. This compares to $100-$400 of content on an autonomous mobile robot (AMR). Humanoid content exceeds industrial robot content (including AMRs and cobot robot arms) for several reasons: humanoids require advanced vision systems (multiple cameras), AI compute modules, distributed control systems, power distribution, comms networks, and actuators throughout the humanoid robot body.

FIGURE 14. Based discussions at AUTOMATE, we believe connector companies (APH, TEL) can offer the following components for humanoids.

Category	Functional Content Description	Estimated Content ($/robot)
Vision & Sensing	Hardware linking cameras, depth sensors, positioning systems, proximity sensors, and environmental awareness systems to the robot's processors	$40-$120
Control & Communication	Interfaces connecting processors, memory, wireless modules, networking hardware, and control electronics throughout the robot	$75-$200
Power Distribution	Components that route electrical power from batteries and power electronics to compute systems, sensors, motors, and actuators	$100-$300
Movement	Power and signal hardware within the robot's joints, actuators, hands, arms, legs, neck, and torso motion systems	$150-$450
Total		**$390-$1,170**

Source: Barclays Research

European Capital Goods

Timothy Lee, CFA Barclays, UK | Jonathan Hurn, CFA Barclays, UK

Early-stage exposure to humanoids for Cap Goods limited for now. In the European Capital Goods space, exposure to humanoids is relatively limited at the moment but is growing. **SKF** recently announced that it was forming a JV with a Chinese player Leaderdrive (LD, a leader in reducers, not covered) to make components for humanoids, following its peers Timken and Schaeffler (both not covered) to enter the humanoid supply chain. This gives SKF direct exposure to the humanoid supply chain. **Renishaw** in the UK supplies humanoids with magnetic encoders and calibration tools that provide robots with micro-precision, balance, and spatial awareness. Direct exposure for other names would be rather limited (compared with the whole Renishaw group). Automation component suppliers like **ABB** also offer products like actuators which could be applied in humanoids as well, but the exposure to humanoids is likely very limited compared with the whole group. On the other hand, **Siemens** has been working towards bringing physical AI to the factory floor, including the piloting of humanoids from Humanoid (not covered) in its factory in Germany, leveraging its strategic partnership with NVIDIA; while **Schneider** is also partnering with humanoid players (e.g. Zhejiang Humanoid) on industrial automation-robotic integration with the offering of industrial automation / digital twin software. Overall, humanoids currently represent a small end market for European Cap Goods on average, and we think long-term growth potential would lie in the deployment growth of humanoids, whether the companies involved would be able to gain meaningful market share, whether they can increase wallet share in the humanoid supply chain, as well as how competition plays out.

The SKF-LD partnership. LD is a leader in harmonic drives (no.1 in China and no.2 globally), which is a key component for humanoids, used in rotary joints, and they are supplying players like Tesla's Optimas, Figure and Ubtech (both not covered). With a focus on humanoids in industrial applications, SKF estimates it will be able to cover c80% of the bearing BOM (bill of materials) for humanoids, with c45% (Cross-roller / Flexible bearings) covered by the JV and c35% (Thin section & new bearings types) developed in-house. For the remaining 20% (mainly for hands and fingers), SKF is assessing whether this could be addressed better by a greenfield operation or via a partner in the future. Meanwhile, as they do not supply products like sensors and electronics, like Schaeffler, and are not engaged in system integration, the share of overall humanoid BOM could be comparably lower than its close peers. The JV is expected to be operational by the end of 2026.

Renishaw - focusing on the feedback niche. Renishaw has an emerging but strategically attractive exposure to humanoid robotics through RLS, its associate company specialising in magnetic position encoders. Its products provide real-time joint-position feedback—critical for balance, coordination and precise motion control—with the portfolio focused on compact, non-contact encoders for space-constrained robotic joints: AksIM-2 targets larger load-bearing joints such as shoulders, elbows, hips and knees; Orbis addresses rotating joints where space or alignment is challenging; and the miniature RM08 is suited to fingers, grippers and other end-effectors. The recently launched AksIM-4 Dual Concentric strengthens this positioning by combining motor- and joint-position feedback in a single ultra-thin device, reducing component count, cabling and joint size—attributes particularly relevant to next-generation humanoids with a high number of tightly packaged axes. Renishaw already has a reference application with PAL Robotics, where its magnetic encoders support articulated humanoid platforms requiring accurate feedback across multiple degrees of freedom. While Renishaw does not separately disclose humanoid-related revenue and near-term exposure is likely modest, the opportunity could be material as a humanoid may require position sensing across dozens of joints, creating meaningful content if the market progresses from development platforms into scaled production.

China is potentially a big market but be aware of competition. The SKF-LD JV is based in China and will serve the China market, plus targeted markets, such as Europe, Japan and the US, leveraging SKF's global network. Based on the work done by our FICC Thematic team (see report from Zornitsa Todorova AI gets physical: The decade of the robot belongs to China), China was the biggest market for humanoids in terms of shipments in 2025, and will potentially continue to be the biggest market. We believe there are also a lot of players in the supply chain / potentially moving into the supply chain, including auto parts suppliers who have been shifting gear to the humanoid supply chain, as well as factory automation component suppliers who are already supplying to traditional industrial robotics companies. LD is a leader in reducers, especially harmonic drives, but there will likely be more competitors on the whole actuators, or in other components like ball screws, etc., from China, Taiwan, or other regions.

Deployment is key for humanoid exposure to expand. Humanoid deployment is still at a very early stage. We believe the most common industrial verticals for the deployment of humanoids will be automotives or automotive parts. The automotives industry has one of the highest levels of automation and robotic deployments in its production lines, the parts and components of automotives are similar to humanoids, and the tough automotives market pushes autos OEMs to improve efficiency and auto parts makers to improve utilization. In addition, some other manufacturing industries may be exploring pilot deployment, e.g. Airbus utilizing humanoids from Chinese player Ubtech (not covered) in its China facility. Ubtech partnering with Foxconn in manufacturing, and SF Express (not covered) in logistics. On the other hand, Hexagon is partnering with Pilatus (private, in aerospace) and Fill (private, in machinery).

China Technology

Simon Coles, CFA Barclays, UK

We view robotics as an emerging long-term application for CATL's battery technology while BYD's aim is at the robotics itself. Unlike electric vehicles, humanoid robots require batteries that optimize not only energy density but also power density, fast charging, lightweight system integration, and safety under frequent charge-discharge cycles. These requirements favor suppliers with leading cell chemistry and system integration capabilities. **CATL** has begun executing on this opportunity through multiple strategic collaborations. In 2025, CATL collaborated with Spirit AI to integrate its in-house developed robotics batteries into the company's humanoid robot platform. More recently, CATL partnered with Galbot to jointly develop battery-powered humanoid robots and related industrial applications, while Galbot's S1 became the first heavy-duty humanoid robot to be deployed on CATL's own manufacturing line. While commercial demand remains nascent today, we believe CATL is well positioned to capitalize on the growth of the humanoid robotics market, with batteries potentially becoming a meaningful end market over the coming decade. **BYD**, on the other hand, is making headlines with its recent announcement that it will introduce its first humanoid robot in August. The company first assembled its robotics team in 2022, and this will be the first time it unveils its progress. Similar to other OEMs that have embarked on their robotics journey, such as XPEV, BYD plans to deploy two to three robots in each of its offline vehicle showrooms at first in the future as a proof of concept before selling them to external customers. That said, the company will likely only showcase a physical prototype, with the mass-production timeline remaining uncertain. Management also shared that BYD is looking to establish an open development platform on which other players can jointly develop robotics with BYD to foster industry development.

Related Reports

- Thematic Investing - Physical AI: Robotics Summit Highlights Humanoid Scaling Hurdles
- Thematic FICC Research - AI gets physical: Ten things to know about humanoids
- Thematic FICC Research- AI gets physical: The decade of the robot belongs to China
- FICC Research - Global economic drivers: How humanoid robotics matters for macro
- Global Macro - From macro to markets: Embodied AI: Wealth creation or economic displacement?
- Thematic FICC Research - The future of work: AI gets physical
- Thematic FICC Research - AI gets physical: The decade of the robot
- Thematic FICC Research - AI gets physical: GUARD your robots

Appendix

Humanoid Developers

FIGURE 15. **Humanoid developer landscape (excluding China)**

Company (Status / Founded / HQ)	Robot Product / Program	Commercial & Production Status	Funding / Key Investors & Partners	Supply Chain	Perception Stack
1X (Private, 2014, US/ Norway)	NEO – home/consumer humanoid for safe, autonomous household tasks; can switch to remote human teleoperation via 1X "Expert" for complex chores.	Pre-orders opened late 2025 (US$200 deposit; US$20k unit price). First deliveries expected in 2026. Vertically integrated NEO Factory in Hayward, CA ramping to ~10,000 units/year; a second facility (San Carlos, CA) slated for late 2026, enabling capacity ~100,000+ units/ year by end-2027 with added automation.	$100M Series B (Jan 2024); $23.5M Series A2 (Mar 2023). OpenAI Startup Fund (investor).	Does extensive in-house development of critical components (custom "Revo2" actuators, batteries, transmissions, structures, sensor integration) to control costs and mitigate supply risks. Reports it has built ~17k Revo2 motors since production ramp-up with design continuously refined since 2015.	NVIDIA Jetson AGX Thor platform serves as each robot's on-board computer. Runs 1X's video-pretrained world model (1XWM) as the core AI policy for perception and motion planning.
Agility Robotics (Private, 2015, USA)	Digit – humanoid for automating repetitive, labor-intensive tasks in warehouses and factories (bulk tote handling, machine tending, etc.).	Opened RoboFab factory (Salem, OR) in late 2023, with initial output in the low hundreds per year, scalable to >10,000 units/year at full capacity. First Digits delivered to select partners in 2024 (Agility Partner Program); broad commercial availability targeted for 2025.	$150M Series B (Apr 2022). Investors/pilot partners include Amazon, DCVC, Playground Global; strategic partnerships with Toyota (RaaS pilot), GXO (logistics deployment), Schaeffler (investor & manufacturing collaborator), and NVIDIA (AI/simulation partner).	Contract manufacturing & supply partnerships (e.g., forging supply of robotics parts through Schaeffler). Built a new Oregon facility to centralize assembly of Digit's sophisticated leg and arm mechanisms.	On-board AI (vision & control) runs on Nvidia Jetson (plans to upgrade to Jetson Thor for next-gen Digit) and uses NVIDIA's Isaac Sim for virtual training at scale, integrated with Agility's Arc cloud platform for remote management and software updates.
Apptronik, Inc. (Private, 2016, USA)	Apollo – general-purpose humanoid designed to safely perform repetitive tasks alongside humans in factories & warehouses (parts transport, packing, assembly support). Next-gen Apollo prototype scheduled debut in late 2026.	Pilot stage – delivered pilot Apollo units to Mercedes-Benz (auto assembly line deployment, late 2024). Manufacturing partnership with Jabil to build Apollo at scale starting 2025. Volume production to commence after next-gen launch (expected late 2026).	$935M Series A (Feb 2026) led by B Capital. Investors include Google, Mercedes-Benz (pilot/strategic partners); John Deere, Qatar Investment Authority. Jabil serves as key contract manufacturing partner. Also collaborating with Google DeepMind (AI research partner).	Emphasizes mass manufacturability – in-house developed high-torque actuators (reducing SKUs and hardware cost) and simplified component bill of materials for efficient assembly. Partnering with Jabil provides global supply chain access and high-quality volume production processes ("robots building robots" concept with Apollo assisting on its own line).	NVIDIA Jetson AGX Orin (current prototype compute; planned upgrade to Jetson Thor). Extensive use of NVIDIA Omniverse for digital twin simulation in design and test; working with Google DeepMind on specialized AI algorithms for learning and control to accelerate capabilities.

Company (Status / Founded / HQ)	Robot Product / Program	Commercial & Production Status	Funding / Key Investors & Partners	Supply Chain	Perception Stack
Beyond Imagination (Private, 2018, USA)	Beyond Bot – a teleoperated humanoid (mobile base with dual robotic arms) extending skilled human labor via telepresence. Targeted at factory, pharma lab, and manufacturing support with remote human-in-the-loop control (via VR suit) and autonomous assist.	Pre-commercial – prototypes tested in controlled settings. Aimed to commence first enterprise pilot deployments by 2025–26, initially focusing on environments like pharmaceutical and biotech labs, manufacturing cells, etc., where remote human dexterity is needed.	$100M Series B (May 2025).	Uses off-the-shelf industrial robotic arms and sensors interfaced with proprietary control systems to accelerate prototyping. Focus on teleoperation reduces need for complex advanced autonomy hardware; prioritizes reliable connectivity and human safety features.	"Aura" OS – a unified platform enabling seamless integration of human teleoperators and AI modules. Real-time remote control is combined with assistive autonomy for routine tasks. Plans to incorporate large language and vision models for improved semi-autonomy over time.
Boston Dynamics (80%-owned by Hyundai Motor Group (005380.KS), 1992, USA)	Atlas – humanoid for a broad range of heavy industrial tasks (material handling, assembly) designed to operate safely around people. Also produces non-humanoid robots: Spot quadruped, Stretch logistic robot.	Industrial prototype phase – "productized" Atlas unveiled Jan 2026; undergoing trial deployments in Hyundai factories (e.g., parts kitting and sequencing tasks) under oversight. Plans to integrate Atlas into select Hyundai production lines by ~2028 and ultimately expand to complex assembly tasks by ~2030. Hyundai constructing a U.S. robot plant (target ~30k units/year by 2028) to facilitate eventual volume production.	80% stake acquired by Hyundai Motor Group (2021). Key partners: Hyundai Mobis (supplying drivetrain & actuators), Google DeepMind (integrating foundation AI models), NVIDIA (providing advanced hardware & simulation).	Leverages Hyundai's automotive supply chain: standardized EV-grade motors, sensors, and structural components for high reliability and manufacturability. Designed to minimize unique parts count and maximize robustness in factory conditions.	Atlas's on-board computing is powered by NVIDIA Jetson AGX Thor, enabling real-time multi-sensor fusion and complex AI-driven control. Integrated with Boston Dynamics' Orbit fleet management software (currently used for Spot) for logging, updates, & coordination. Atlas is being enhanced with DeepMind's multi-modal AI models for advanced decision-making and dexterous skills.
Engineered Arts (Private, 2004, UK)	Ameca & Mesmer – ultra-realistic social humanoids for interactive experiences (museums, exhibitions, marketing). Focused on human-like expressions and conversational ability.	Limited production / rentals – ~200 life-like robots delivered worldwide, mostly to museums, theme parks, exhibitions. Building capacity gradually (not yet mass-producing). R&D on next-gen walking/dexterous capabilities (e.g., improved locomotion & AI conversation) ongoing via a Redwood City (US) lab.	$10M Series A (Dec 2024) led by Helium-3 Ventures (Matt Bellamy). Notable installations: MSG Sphere (Las Vegas), GSK (pharma expo events), Computer History Museum (CA).	In-house development of expressive servo actuators and realistic silicone facial/skin systems ("Mesmer" platform) for lifelike appearance. Low-volume craft manufacturing and customization per client use case.	Tritium AI platform integrates third-party large language models and multimodal AI, enabling naturalistic conversations and interactions. Units remain Internet-connected for continuous learning and content updates delivered remotely.
Figure (formerly AI Inc.) (Private, 2022, USA)	Figure 01/02/03 – working towards a full-size general-purpose humanoid for warehouse, logistics & light manufacturing tasks; current prototypes (Figure 01/02) used in test environments.	Pre-commercial – prototypes have completed over 1,000 hours in pilot testing (part-handling trial at a BMW facility in 2024). Scaling engineering & manufacturing — building a pilot production facility in California (BotQ) to produce first saleable units by ~2025–26.	$675M Series B (Mar 2024, co-led by Microsoft & OpenAI). >$1B Series C (Sep 2025) includes Brookfield, NVIDIA, and Intel Capital.	Vertical integration strategy: developing many sub-systems in-house. Negotiating supply agreements for actuators and sensors to support anticipated high volume of production. Partial reliance on contract manufacturers (for complex chassis and transmissions) until its own facilities scale.	After first integrating OpenAI's GPT-based models, Figure developed its own "Helix" AI for onboard robot learning and control. Relies on extensive simulation (Microsoft Azure cloud + NVIDIA GPU clusters) to train diverse skills before deploying to physical units.
Google DeepMind (Alphabet subsidiary (GOOG), 2010, UK & USA)	Robotics AI R&D – AI research lab developing general-purpose foundation models and advanced AI algorithms for robotics (e.g., multi-modal large models like "Gemini"). Provides software, but not physical robots.	R&D only – no commercial hardware. Contributes to robotics through partnerships. Examples: integrating DeepMind's AI models into Boston Dynamics' Atlas (to improve cognition), collaborating with startups (Apptronik, Figure) on their robot autonomy.	A division of Alphabet (acquired in 2014). Partners include Boston Dynamics, Apptronik, Toyota Research, and others on robotics AI.	Not a hardware maker; focuses on cloud compute, data, and software. Robotic partners include Boston Dynamics (integrating AI into Atlas) and Apptronik (Apollo's AI).	Operates large-scale cloud training on Google's TPU/GPU data centers to develop cutting-edge robotics algorithms. Develops high-level cognitive control and perception models that can be integrated into partner companies' robots (e.g., vision-language models, reinforcement learning frameworks) to enhance their autonomy and versatility.

Company (Status / Founded / HQ)	Robot Product / Program	Commercial & Production Status	Funding / Key Investors & Partners	Supply Chain	Perception Stack
Hexagon AB (HEXA-B.SS, 1975, Sweden)	AEON – industrial humanoid developed through Hexagon's Robotics division, focused on manufacturing, warehousing, inspection, reality capture, and industrial automation tasks.	Announced in 2025 and currently in pilot/development phase. Initial deployments are expected to focus on industrial environments where Hexagon already has deep customer relationships across manufacturing, logistics, energy, and infrastructure.	Strategic partners include NVIDIA (AI and simulation), Schaeffler (actuation and industrial systems), Microsoft (cloud infrastructure), and maxon (motion systems).	Leverages Hexagon's existing industrial ecosystem, including metrology, digital twins, reality capture, manufacturing software, autonomous systems, and industrial automation technologies. External partners contribute key hardware components including actuation and motion systems.	Built around Hexagon's industrial digital-twin platform and AI software stack. Uses NVIDIA Isaac technologies for simulation and training, integrating computer vision, spatial intelligence, digital twins, and industrial workflow automation to enable autonomous operation in complex industrial environments.
Kawasaki Heavy Industries (7012.JP, 1896, Japan)	Kaleido (RHP) – long-running in-house humanoid R&D platform (latest prototype Kaleido 9). Aimed at proving heavy-lift, rough-terrain humanoid capabilities for disaster response and industrial support.	R&D only – prototypes (Kaleido series) regularly demonstrated (e.g., carrying 18 kg payload in 2025 trials) but no commercialization plans yet. Focus on incremental technology improvements; emphasis on robotics research over near-term productization.	Corporate-funded R&D (KHI). Partnerships: co-founded a “Physical AI center” in Silicon Valley in 2026 with NVIDIA, Microsoft, Fujitsu to explore advanced AI integration.	Applies KHI’s heavy machinery expertise: custom hydraulic/pneumatic actuators, industrial controllers, robust exoskeleton-based designs. Prototypes built at KHI labs.	Incorporating cutting-edge AI from partners (e.g., Nvidia Isaac Sim used for simulation, Microsoft’s cloud AI for control prototypes). Focus on stability and precision under extreme conditions; uses classical control algorithms complemented by emerging cognitive modules.
Mentee Robotics (Acquired by Mobileye (MBLY), 2019, Israel)	Third-generation, fully integrated humanoid (in development; no brand name public yet) built for autonomous operation in industrial and logistics tasks, with in-house actuators, dexterous hands, and advanced perception.	Pre-commercial – accelerated development under Mobileye (since acquisition in 2026). Prototypes in testing; proof-of-concept deployments expected ~2026 in controlled environments (e.g., Mobileye’s facilities). First limited production run targeted ~2028, likely leveraging Mobileye/Intel’s manufacturing resources.	Acquired by Mobileye in Jan 2026 (~$900M deal). Previously bootstrapped.	Integrates Mobileye’s automotive-grade vision sensors and high-precision drive systems into humanoid hardware. Developing proprietary actuators (high torque-to-weight) and tactile hands in-house to maintain tight integration and cost control.	Leverages Mobileye’s computer vision and RSS safety frameworks from autonomous driving; employs few-shot learning pipelines to allow robots to rapidly learn new tasks with minimal human demonstrations.
Mind Robotics (Private - Rivian spinout, 2025, USA)	Factory automation robotics R&D – not a humanoid form factor (focuses on mobile manipulators & multi-axis arms). Aims to create AI-driven hardware for complex EV manufacturing tasks (assembly, material handling).	R&D stage – prototypes tested within Rivian’s EV production lines; no commercial product offerings yet. Using Rivian’s facilities as testbeds during 2025–26. Targeting external pilot systems in automotive & aerospace by 2027–28, if R&D milestones met.	$500M Series A (March 2026) co-led by Accel & Andreessen Horowitz; spin-out from Rivian Automotive (major shareholder and development partner).	Initially repurposes off-the-shelf industrial robot components (arms, mobile bases) for quick prototyping; long-term, hardware manufacturing would be outsourced to established automotive/ robotic partners if scaled.	Emphasizes foundation model-driven planning – training large AI models on Rivian’s production data. Heavy use of simulation on Rivian’s high-performance computing, combined with on-robot GPUs for real-time control and adaptation.
NEURA Robotics (Private, 2019, Germany)	4NE-1 – full-size “cognitive” humanoid in development for heavy-duty industrial use, aiming for high strength (arms targeting ~100kg lift).	Pilot trials – prototypes are undergoing evaluation in select industrial settings; no public sales yet. A strategic partnership with Schaeffler (2025) will supply actuators and refine design, with plans to deploy thousands of NEURA units across factories by the mid-2030s. A manufacturing facility in Germany is being established to support future production.	~€8M seed/angel (2019–21). Schaeffler (strategic manufacturing & integration partner); support from local government programs in Germany.	Emphasizes high-performance hardware (strong servo motors, heavy-payload gearboxes). Pursues a European-centric supply chain for quality control and autonomy. R&D and assembly operations co-located in Germany; iterative design influenced by pilot feedback from industrial partners.	Focused on proprietary “Industrial Cognitive Engine” – combining large language models with symbolic AI reasoning – to enable advanced decision-making.

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PAL Robotics (Private - sub of Royal Group (UAE), 2004, Spain)	TALOS – a human-size force-controlled bipedal robotics platform for R&D and custom enterprise solutions (e.g., assembly assistance). Also sells TIAGo mobile manipulators and custom robots for specific use cases.	Low-volume R&D sales – a handful of TALOS units sold to research institutions (e.g., used by Airbus for assembly process trials). No mass production plans; primary business is project-based development of custom robotic solutions (TALOS, TIAGo, etc.).	Self-funded plus EU grants. Collaborations: Airbus (R&D pilot for airplane assembly tasks using TALOS); EU Horizon research programs.	Uses standardized actuators and ROS-based control frameworks, allowing high customization per client use case. Low-volume, in-house assembly of robots.	Primarily open-architecture control – supports ROS-based frameworks and custom sensor integration. No dedicated in-house AI system provided.
Rainbow Robotics (277810.HK, 2011, South Korea)	HUBO & RB-H – humanoid R&D platforms (building on KAIST's Hubo series) for research and tech development; also sells collaborative robot arms (cobots) and mobile robots (current revenue generators).	Humanoids in R&D – no commercial humanoid product yet; focus on advancing biped locomotion & manipulation. Uses HUBO derivatives as testbeds while generating revenue via cobots and mobile robots for industrial clients.	Public listing in 2021. Samsung Electronics acquired ~35% stake by 2025.	Leverages KAIST's decades of humanoid research (Hubo labs) and reuses components from existing robot products (cobot actuators, controllers) for humanoid prototypes. Samsung partnership opens access to high-efficiency manufacturing and supply chain resources if commercialization proceeds.	Current prototypes utilize ROS and Rainbow's custom motion control algorithms.
Sanctuary AI (Private, 2018, Canada)	Phoenix – full-size general-purpose humanoid designed for "labor-as-a-service" in workplaces (retail, warehouses, manufacturing). Gen 7 (2023) introduced 20-DoF humanlike hands (25 kg lift capacity).	Pilot phase – completed successful retail pilot (Mark's shop, 2023: 110+ tasks performed by Phoenix via mix of autonomy & telecontrol). Iterating Gen 8 prototypes (2024) to improve dexterity and reliability; expanding pilot programs into logistics and manufacturing (multi-week trials) through 2026. Aiming for late-decade productization.	C$75+ million raised (2018–2023), including C$58.5M Series A (Mar 2023) and C$30M federal SIF funding. Investors: Bell Canada, Verizon, Export Development Canada, Workday Ventures. Partners: Apptronik (hardware collaboration on joint designs); Cycorp (cognitive AI research).	Early prototypes assembled in-house using off-the-shelf actuators and sensors; now exploring contract manufacturing for initial production scale-up. Key hardware components (e.g., actuators, batteries) currently sourced from established robotics suppliers, with plans for custom designs as volumes grow.	Cognitive architecture ("Carbon") – multi-module AI (vision, language, memory, motor control) that combines large language models with logical reasoning for general intelligence. Training approach blends human teleoperation demonstrations with reinforcement learning to teach skills.
Tesla (TSLA, 2003, USA)	Optimus ("Tesla Bot") – general-purpose humanoid targeting unsafe, repetitive, or mundane tasks in factories (long-term vision includes consumer use). Built using Tesla's EV components (electric actuators, high-density battery packs, FSD computer).	Prototype phase – multiple Optimus units (Gen 2/3) built since 2021; tested internally in Tesla's automotive plants. As of 2024, two bots performing simple autonomous tasks (material transport, basic assembly) at a Tesla factory. Tesla aims to achieve large-scale production in the late 2020s (long-term goal of tens of thousands of units once safety and performance are proven).	Self-funded via Tesla's internal R&D.	Leverages Tesla's existing EV supply chain (in-house motors, power electronics, FSD computer chips) to reuse proven components and minimize costs. Plans for mass production involve expanding Optimus assembly at Giga Texas using Tesla's Gigafactory infrastructure. Tesla designs its AI chips (FSD, Dojo D1) internally but outsources fabrication to chip foundries (e.g., TSMC, Samsung). Elon Musk has also expressed interest in establishing a dedicated chip fabrication facility (a 'Terafab').	Autopilot-derived AI: Optimus leverages Tesla's vision-first perception approach, neural-network tooling, and training infrastructure originally developed for Autopilot/FSD, with models trained on Tesla's Dojo supercomputing platform. Current prototypes employ a hybrid control approach, combining learned perception and motion primitives with scripted task logic and supervised testing, resulting in limited but improving autonomy.

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Toyota Motor Corp. (7203.JT, 1937, Japan)	T-HR3 – advanced teleoperated humanoid (~1.5 m) for assistive and remote presence tasks (e.g., healthcare, construction, disaster relief). Toyota also produces a smaller Human Support Robot (HSR) – a wheeled assistive service robot.	R&D focus – T-HR3 prototypes have been publicly demonstrated since 2017 (remote-controlled via master arm exosuits) but no current commercialization plans. Toyota's robotics projects remain long-term research efforts (some limited pilot tests in internal facilities and at "Woven City" living lab).	Internally funded by Toyota (Toyota Research Institute). Collaborations with academic partners (University of Tokyo, MIT) for robotics and AI research.	Harnesses in-house automotive-quality servos, sensors, and high-reliability control hardware. Prototype production performed at Toyota's R&D groups; if commercialized, would leverage Toyota's manufacturing and supply chain infrastructure.	Teleoperation-centric – T-HR3 is primarily controlled by a human operator via Toyota's full-body Master Maneuvering System exosuit with visual and force feedback. The robot itself has minimal autonomous perception or decision-making.

Source: Company reports & Barclays Research

FIGURE 16. **Humanoid developer landscape (China)**

Company (Status / Founded / HQ)	Robot Product / Program	Commercial & Production Status	Funding / Key Investors & Partners	Supply Chain	Perception Stack
AgiBot (Zhiyuan Robotics) (Private, 2023, China)	Expedition A2 – full-size general-purpose humanoid designed for multi-sector deployment (manufacturing, logistics, retail, security)	Early mass production – delivered 5,000 units by late 2025, with management targeting continued scaling through 2026. Deployed across multiple pilot verticals; still refining autonomy and robustness.	Undisclosed private funding; founded by ex-Huawei executives.	Vertically integrated manufacturing centered in Shanghai. In-house design and production of motors, actuators, batteries, and soft materials; tightly coupled domestic supplier network enabling rapid cost-down and fast production ramp.	Proprietary embodied-AI stack (GO-series foundation models) integrating vision, language, and control. Extensive use of simulation and large-scale real-world data collection; on-board NVIDIA Jetson-class edge compute
AI2 Robotics (Private, 2023, China)	AlphaBot series – full-size general-purpose humanoids for diverse industrial tasks (auto, factories).	Pre-commercial / pilot – initial prototypes deployed in late 2025 (e.g., trial at a Dongfeng auto plant). Aggressive scaling plan (1,000→10,000 units in 2026) reliant on internal ramp-up (not yet validated).	Raised ~CNY 1 B (~US$150 M) across multiple quick rounds in 2025 (state-owned industry funds, private VC, and internet giants).	Heavy vertical integration – developing core hardware (actuators, sensors) and end-to-end manufacturing capacity internally; targeting vehicle-scale production efficiency (AI-driven assembly lines) by 2026.	Vision-Language-Action "AlphaBrain" – a powerful embodied AI model guiding planning & control. Extensive synthetic data pre-training and simulation to enable generalizable skills with minimal real-world fine-tuning; large-scale cloud training.
Booster Robotics (Private, 2023, China)	T1 & K1 – medium (T1) and compact (K1) humanoids for R&D, education, and competitions.	Commercial – launched K1 globally via online platforms in late 2025 (1,000+ unit orders; 700+ units delivered to 200+ clients across 20+ countries). Booster-powered teams won RoboCup 2025 (Adult & Kid sizes) using these platforms.	$28 M raised (2023–25).	Standardized design & manufacturing – leverages modular, affordable hardware (mass-produced actuators, controllers) to achieve scale.	Open SDK & multi-sensor stack – built on NVIDIA Orin & Isaac SDK. Integrates vision & LiDAR for perception; developer-friendly API for custom behaviors. Emphasizes stability and ease-of-use over advanced autonomy (for learning & competitive programming).
DEEP Robotics (Private, 2017, China)	DR02 – full-size industrial humanoid, also Lynx series wheel-leg robots and Jueying quadrupeds.	Prototype / R&D – unveiled DR02 (Oct 2025). Focusing on extensive field testing for harsh environments (power grid inspections, emergency response). Scaling plans undisclosed (emphasis on technology demonstration and partnerships).	CNY 500 M Series C (~US$70 M, Dec 2025).	Leverages existing supply chain from quadrupeds for motors and perception systems; modular "quick-detach" component design for faster maintenance.	Embodied AI platform – multi-sensor (vision + thermal + LiDAR) fusion and robust autonomy optimized for hazardous scenarios. Developing "DeepVLA" navigation & multi-modal control system to enable stable autonomous operation across varied environments (e.g., outdoors, extreme weather)

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ENGINEAI (Private, 2023, China)	T800 – full-size industrial humanoid for inspection, manufacturing, and heavy-duty tasks; complemented by PM01/SA01 platforms.	Initial mass production ramp in 2026 – in 2026 with a target throughput of one T800 unit per 15 minutes (~10k per year). First T800 batches delivered; second production base planned in Zhengzhou to expand capacity.	$200 M Series B (Apr 2026)	Highly automated, closed-loop factory covering component testing, assembly, and quality control. Full-stack in-house R&D across joints, actuators, and control electronics; multi-regional manufacturing footprint planned.	Multi-modal embodied-AI architecture trained heavily in simulation; reinforcement learning for locomotion and manipulation. NVIDIA Jetson-based edge compute for on-robot inference.
EX Robots (Private, 2013, China)	EX humanoid series – hyper-realistic bionic humanoids (lifelike androids) for entertainment, hospitality, and R&D.	Limited production – small-scale build-to-order manufacturing (roughly 2–4 units per month) for museums, expos, and special projects; pricing ~CNY 1.5–2 M per unit. No large deployments (intended for exhibit and demonstration scenarios).	Not available.	In-house fabrication of lifelike components – internal production of silicone skin, robotic animatronics, and custom micro-motors. Focus on bespoke assembly rather than mass manufacturing; single-site factory in Dalian.	Expressive AI – proprietary software emphasizes facial expression recognition and emotional interaction. A multi-modal interaction system (vision + voice + expression mapping) drives human-like facial movements and reactions; high actuator density in head/face for fine emotional cues.
Flexiv (Private, 2016, China/USA)	Rizon series – adaptive 7-DoF robotic arms (upper-body robots) with force control for flexible manufacturing tasks.	Commercial – shipped 100+ Rizon units by 2020; serving industrial customers (auto, electronics) with repurchase orders and initial paid deployments. Expanding into new industries (logistics, agriculture, healthcare) with upcoming dual-arm and mobile platforms (e.g., MICO, Enlight).	>US$122 M total raised. Strategic partnerships with major Chinese manufacturers (for integration into assembly lines and distribution channels).	Hybrid production model – core hardware (force-control actuators, sensors, and control boards) and algorithms developed in-house; final assembly at dedicated factories in China (Shenzhen, Foshan) for cost efficiency. Strategic supply agreements for key components.	Adaptive control & force-sensing AI – advanced closed-loop force feedback and computer vision allow fine manipulation and assembly tasks. Combining proprietary force control algorithms with conventional machine vision and deep learning for flexible automation in dynamic environments (not LLM-driven).
Fourier (Fourier Intelligence) (Private, 2015, China)	GR-1 / GR-2 – electric, full-size general-purpose humanoids evolved from Fourier's exoskeleton platform.	Small-batch production / early commercial – GR-1 units shipped to research labs and pilot customers from 2024. GR-2 launched in 2024 and remains in testing; broader commercialization expected after design stabilization post-2025.	¥400 M Series D (~$60 M, Jan 2022) led by SoftBank Vision Fund; Prosperity7 (Aramco) also investor.	Core proprietary electric actuators ("Fourier Smart Actuators") enable non-hydraulic architecture optimized for manufacturability. Mix of in-house assembly and domestic component suppliers.	Vision-language-action stack supported by heavy simulation training. Teleoperation and task learning supported through multi-modal perception and ROS-compatible tooling.

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GAC (Guangzhou Auto) (2238.HK, 2005, China)	GoMate – third-generation embodied-intelligence humanoid with hybrid wheel–biped mobility (38 DoF).	R&D / internal pilots – unveiled December 2024. Internal trials within GAC factories during 2025; component-level batch production planned first, followed by small-batch whole-robot production targeted for 2026.	Corporate-funded R&D by GAC Group.	Leverages automotive-grade components and GAC's EV supply chain, including solid-state battery technology (~6-hour runtime). Variable wheel–leg chassis improves stability and energy efficiency.	Vision-centric navigation and decision stack adapted from autonomous driving research; fusion of vision, inertial, and haptic sensing.
Galbot (Private, 2023, China)	Galbot S1 & G1 – bipedal service humanoids for retail and logistics support (unmanned stores, pharmacy robots).	Initial commercial deployments – ~10 humanoids implemented in Beijing pharmacies (2025) performing autonomous order retrieval and delivery; planning to roll out 100 robot-run stores nationwide by late 2025.	~CNY 2.4 B (~US$335 M) raised (mid-2025) from strategic investors (e.g., CATL) and local government funds.	Vertical stack – designs own hardware (servo motors, control boards) and custom electronics. Partners with Bosch for industrial-grade components. Emphasizes cost-effective fabrication and durability (target <¥600k per unit) via AI-optimized design workflows.	Sim2Real AI paradigm – heavy reliance on synthetic data pre-training to reduce real-world data needs. Combines high-fidelity simulation with minimal targeted real-world fine-tuning. Focuses on robust vision and dexterous object handling with minimal human supervision.
Hiwonder (Private, 2015, China)	Tonybot & DIY Kits – small-scale open-source humanoids and robotics kits (e.g., 17-DoF Tonybot for STEM education).	Commercial – ongoing low-volume product sales since ~2017. Thousands of programmable kits and mini-humanoids sold globally via e-commerce (Amazon, AliExpress) for hobbyist, school, and STEM use.	Self-funded (no major VC rounds). Profitable from kit sales; partnerships with electronics distributors to reach overseas customers (AliExpress, Amazon).	Modular manufacturing – leverages off-the-shelf microcontrollers (Arduino/ESP32/ Jetson) and standard servo components; designs custom servo lines (LX series) for higher performance. Assembly in Shenzhen; kits emphasize user-friendly build & customization.	Educational AI – supports accessible programming (Scratch, Arduino, Python) with integrated vision and speech modules for demonstrations. Provides multi-modal interaction on advanced models (Tonybot uses small language models for voice & vision interplay) to teach coding and AI concepts.
Kepler Robotics (Private, 2023, China)	Forerunner K2 – general-purpose humanoid emphasizing hybrid wheel–leg mobility for energy efficiency.	Pilot / small-batch production – initial K2 units (dozens) delivered to partners for co-development. Limited production underway; broader rollout dependent on pilot outcomes.	Undisclosed early-stage venture funding.	Rapid-iteration manufacturing using domestic suppliers; hybrid mobility reduces actuator count and battery load, simplifying production.	Standard vision and LiDAR perception combined with proprietary motion planning; cloud-connected telemetry for continuous software improvement.

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Leju Robotics (Private, 2016, China)	AELOS / ROBAN / KUAVO series – humanoids from compact educational models to full-size **Kuavo** general-purpose robots (industrial & service).	Pre-production / early manufacturing – established a high-volume humanoid production line (Guangdong) in early 2026 with target capacity ~10,000 units/year. Small-scale deliveries (Aelos/Roban kits) since 2018; scaling up mass production of Kuavo full-size robots through 2026.	~¥1.5 B (~US$200 M) raised in 2025. Early backers (2019–21) included Tencent AI Accelerator, Microsoft Accelerator, Lenovo Capital, etc. Partnering with Schaeffler (actuator supply).	Ecosystem approach – vertical integration of core components, plus global partnerships (with Huawei, Alibaba, Haier) to leverage supply chain depth. Automated assembly lines (one robot build ~30 min) planned to support widespread adoption.	Open-source & large-model integration – built on ROS with proprietary gait-control algorithms. Integrating large models (Huawei's Pangu) for high-level cognition. Targets multi-industry deployment (from retail guides to manufacturing co-workers) via adaptable AI.
Noetix (Private, 2023, China)	Bumi – compact consumer humanoid (94 cm, 12 kg) for family-friendly companionship and education; also larger N2 (118 cm) in development.	Pre-commercial – Bumi launched Oct 2025 (~¥9,988 on JD.com); thousands of pre-orders across national shopping festivals (Singles' Day, 12.12). N2 prototype ran a half-marathon demonstration in Apr 2025, garnering 2,500 orders (targeting shipments mid-2026).	No formal VC funding disclosed (likely seed-funded by founders & local grants; part of Beijing humanoid innovation hub).	Low-cost design – repurposes smartphone-grade components (batteries, sensors, SoCs) for affordability. Lean assembly in Beijing and partner EMS facilities to achieve consumer-level pricing (~US$1,400).	Consumer-grade AI & control – proprietary motion control system for smooth walking and interactive gestures; open programming interfaces for educational use. Emphasizes limited autonomy (1–2 hr battery, supervised mode) with basic vision & voice modules for family-friendly interactions.
RobotEra (Private, 2023, China)	STAR1 – high-performance humanoid optimized for speed and outdoor mobility (record ~3.6 m/s).	R&D / pilot – prototypes demonstrated record-setting runs in 2024. No commercial deployments announced; focus remains on robustness and stability.	Angel and early institutional funding (undisclosed).	Custom lightweight structures and shock-absorbing joints; low-volume prototype manufacturing using advanced machining and rapid prototyping.	Vision- and IMU-based perception with GPU-accelerated control optimized for high-speed locomotion and balance.
UBTECH Robotics (9880.HK, 2012, China)	Walker S1 / S2 – full-size humanoids for factory and commercial service roles.	Early commercial deployments – Walker units delivered to automakers and logistics firms; 500+ pre-orders reported as of 2024 (per IPO filings). Production scaling following 2023 IPO.	Hong Kong IPO (December 2023). Pre-IPO strategic investor Tencent; key partners include Foxconn and BYD.	Designs core servos and controllers in-house; Foxconn partnership supports scalable assembly. Supply chain largely China-centric with automotive and electronics overlap.	Vision- and SLAM-based navigation with sensor fusion (cameras and LiDAR); cloud-edge coordination over 5G for fleet management and updates.

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Unitree Robotics (Private, 2016, China)	G1 – compact humanoid developer platform (~1.3 m) aimed at R&D and education; complements Unitree's quadruped lineup.	Early shipments – G1 kits delivered to labs and developers starting late 2024. Focus remains on developer and research markets rather than enterprise deployment.	Bootstrapped via product sales (no major outside VC disclosed).	Cost-optimized design using standardized parts; manufacturing scale and supplier relationships inherited from high-volume quadruped robot production.	NVIDIA Jetson Orin NX with ROS-based open software stack enabling developer experimentation and customization.
Xiaomi Corp. (1810.HK, 2010, China)	CyberOne – full-size humanoid concept showcasing Xiaomi's AI and hardware capabilities.	R&D only – internal pilots in Xiaomi EV factory during 2025–26. No commercialization roadmap disclosed.	Internally funded by Xiaomi.	Repurposes Xiaomi smartphone and IoT supply chain components (cameras, sensors, SoCs) for rapid prototyping; internal actuator and controller development.	Xiaomi in-house vision, speech, and emotion-recognition AI; largely teleoperated with limited autonomy, focused on human–robot interaction.
XPENG Robotics (XPeng Inc. subsidiary (9868.HK), 2020, China)	IRON – highly anthropomorphic humanoid for service and industrial scenarios.	Pre-production – next-generation IRON unveiled November 2025. Mass production targeted by end-2026, with first commercial deployments (retail and enterprise) expected in 2027.	Funded by XPeng Motors via internal R&D; Alibaba Cloud acts as a technology partner for mapping and cloud infrastructure.	Full-stack in-house development drawing on automotive supply chain (actuators, hands, batteries, proprietary Turing AI chips). Dedicated humanoid robot factory under construction in Guangzhou.	XPeng "Physical AI" stack combining vision-language-action foundation models with high-TOPS on-board compute derived from autonomous driving systems.

Source: Company reports & Barclays Research

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