STUDY

Humanoid robots 2026

The convergence moment for a new market

Roland Berger

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Humanoid robots are moving from science fiction to industrial reality. Advances in AI and robotics hardware are making it increasingly feasible to build machines capable of operating in human-designed environments. At the same time, labor shortages are strengthening the need for new forms of automation. This marks a convergence moment where technological capability meets market demand, bringing humanoid robots closer to real-world deployment across industry and beyond.

If current trajectories hold, the economic implications could be substantial. As part of the broader move toward physical AI, humanoid robots are likely to evolve into a multi-trillion-dollar industry – according to our projections, representing a market of up to USD 750 billion by 2035 and up to USD 4 trillion by 2050, comparable in scale to the automotive industry today. For industrial, automotive and electronics companies, humanoid robots thus represent a significant growth opportunity and, at projected operating costs of just two dollars an hour, a potential lever for major efficiency gains.

What distinguishes the current wave of development from previous automation cycles is how robots are learning and adapting. Advances across key technologies such as advanced actuators, edge computing and generative AI/vision-language models (VLMs) provide the foundation for interpreting complex and unpredictable environments. With working-age populations projected to decline by up to 22 percent in some regions by 2050, industries also face a structural labor gap that traditional automation cannot fully address. Humanoid robots offer a distinctive advantage: they can operate within processes and infrastructure designed for human workers, performing diverse tasks without expensive product and facility redesign.

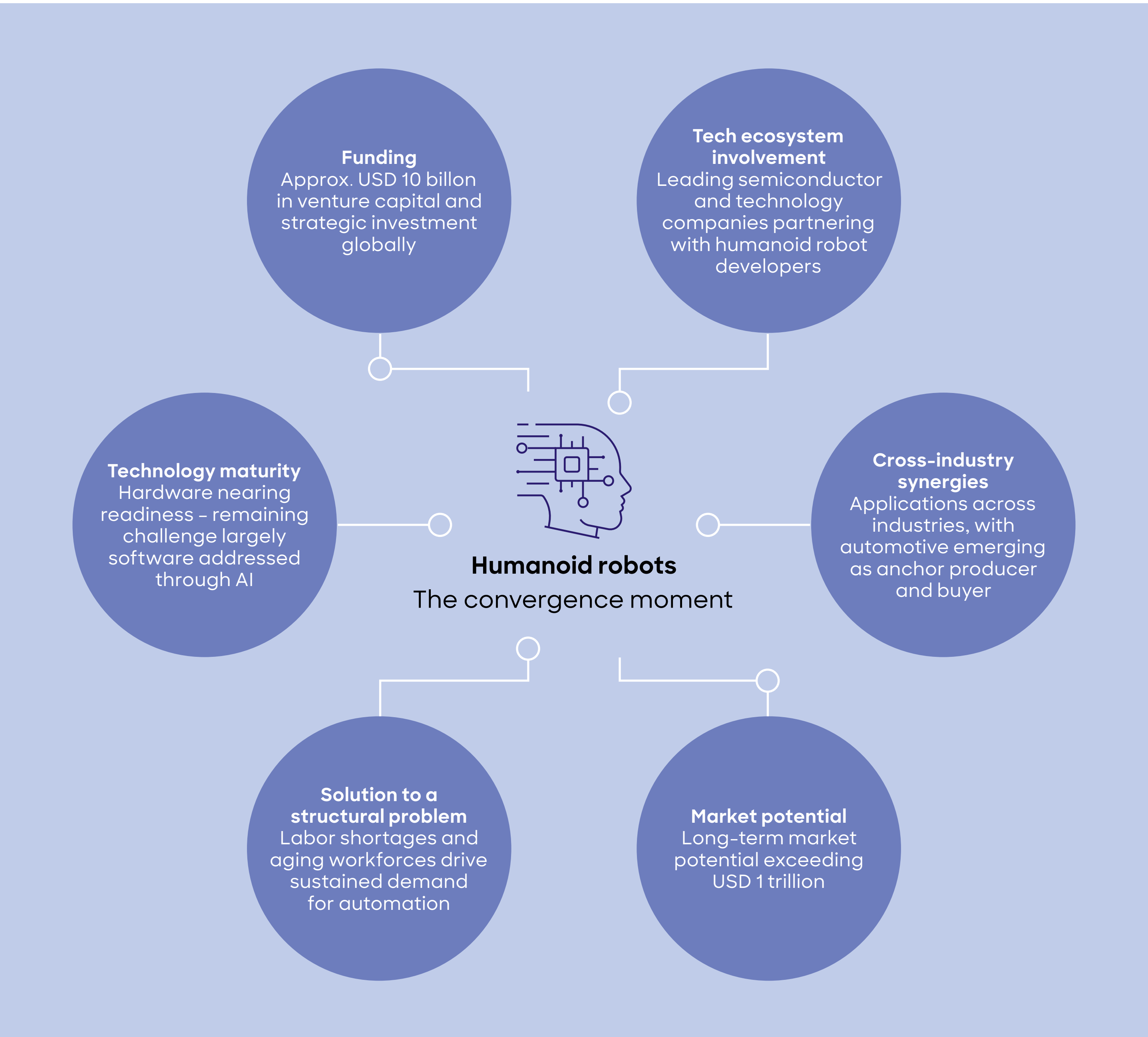
Perhaps the strongest validation of this trajectory is the breadth of industry engagement already emerging. Early prototypes are being deployed in manufacturing facilities, while logistics operators are testing warehouse applications. Combined with equity investments of approx. USD 10 billion and partnerships with leading semiconductor players, humanoid robotics is moving beyond speculation toward commercial reality. The key question is no longer whether humanoid robots will emerge as a viable technology, but how quickly they will scale – and which companies position themselves early enough to capture the opportunity.

Contents

Cover AI generated

1/ A trillion-dollar market – with uncertain timing

Market growth scenarios and the economics of humanoid robots



The humanoid robotics market today remains in its prototyping phase, with deployments measured in dozens rather than thousands. Yet projections indicate exponential growth. Based on our market modeling, we expect the industry to reach USD 300 billion at the OEM level by 2035 under baseline scenarios, rising to USD 750 billion in more optimistic trajectories. Over time, this points to a trillion-dollar market, even if the timing of large-scale adoption remains uncertain. These estimates are based on modeled unit economics, projected demand patterns and analogies to supply chain ramp-ups in other industries.

The economic fundamentals increasingly support this trajectory. At projected costs of USD 20,000–30,000 per advanced humanoid robot including all training costs, the operational economics become transformative. With an hourly operating rate of approximately USD 2 – a fraction of human labor costs in developed markets – these robots can deliver compelling returns in industrial environments while also becoming accessible to private consumers for household tasks. This dual-market potential addresses labor shortages across manufacturing, logistics and services while opening entirely new consumer markets.
▶ A

A Not all humanoids are created equal

Advanced and entry-level robots differ in capabilities, dimensions and price

	Advanced	Entry-level
Price range in 2035	USD 20,000-30,000	USD 8,000-10,000
Height and weight	165-180 cm, 65-80 kg	120-140 cm, 30-40 kg
Features	Powerful, full-sized systems designed for complex tasks across industries, offering high adaptability, strength and advanced AI capabilities	Compact and affordable systems focused on basic functions, with lightweight design and a limited task range suited to simple automation and service applications

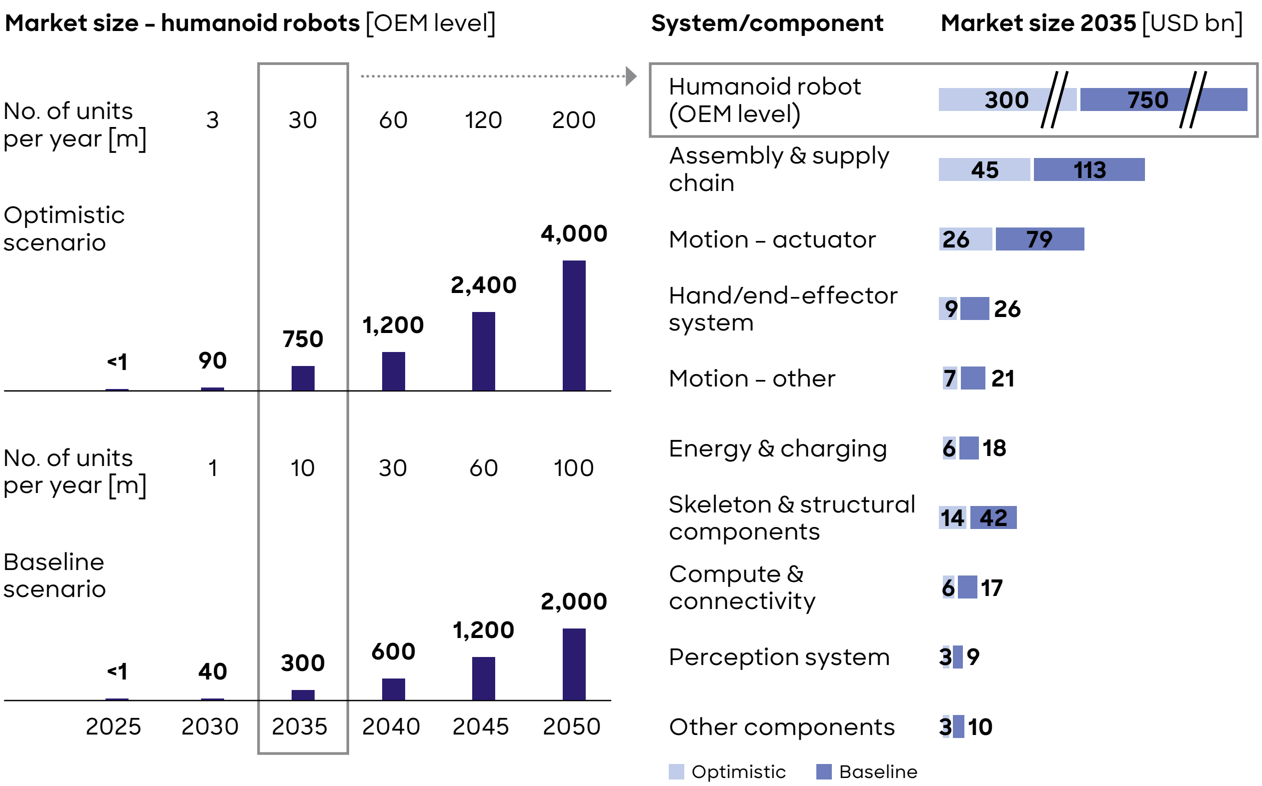
Source: Market interviews, desk research

THE EMERGING HUMANOID ROBOTICS INDUSTRY ECOSYSTEM

The opportunity extends far beyond finished robots – the surrounding value chain is also expanding rapidly. By 2035, body actuators alone represent a market worth between USD 26 billion and USD 79 billion, with hand actuators adding a further USD 9 billion to USD 26 billion. Compute and connectivity systems, perception systems, structural components, energy and charging systems, and other subsystems contribute more than USD 35 billion. The assembly and supply chain segment – encompassing assembly costs, overhead, energy and labor – could reach between USD 45 billion and USD 113 billion, creating substantial opportunities for equipment manufacturers and service providers. ▶B, C

B The next automotive industry?

Global humanoid robotics market size by system/component, 2035 [USD bn]



Source: Roland Berger Humanoid Robots market model, market interviews, desk research

Looking beyond 2050, the potential could approach the scale of the automotive industry. The global automotive market generates roughly USD 2.5 trillion annually in vehicle sales alone, with substantial additional value in parts, services and manufacturing infrastructure. As humanoid robots achieve mass deployment across industrial and consumer markets, similar economics could emerge. Under optimistic scenarios, this could mean OEM-level revenues exceeding USD 4,000 billion annually, with component, service and manufacturing equipment markets together creating a total addressable market approaching automotive-scale proportions. Realizing this potential will depend on sustained technological progress, but the economic drivers and market structure suggest humanoid robotics could become one of the defining industrial sectors of the mid-21st century.

C 3x the price

Component cost breakdown of advanced vs. entry-level humanoid robots

	Single humanoid robot [USD]		**Total market size** [USD bn]		
Categories	**Advanced**	**Entry-level**	**Advanced**	**Entry-level**	**Total**
Motion – actuator	4,000	1,265	60	19	79
Hand/end-effector system	1,400	333	21	5	26
Motion – other	1,072	342	16	5	21
Energy & charging	845	380	13	6	18
Skeleton & structural components	1,950	820	29	12	42
Compute & connectivity	800	345	12	5	17
Perception system	465	166	7	2	9
Others (e.g. connectors)	440	230	7	3	10
Total	11,000	3,900	165	58	223

Source: Roland Berger Humanoid Robots market model, market interviews, desk research

2/ Technological readiness

Hardware is maturing, but software and ecosystem gaps remain

Over the past years, humanoid robots have made substantial progress. Current prototypes already demonstrate functional mobility and dexterity, allowing robots to execute tasks in controlled and semi-structured environments. Core subsystems – compute, sensing, actuation and power – are validated at a pilot level.

However, technical feasibility does not yet translate into scalable industrial readiness. Hardware development

D Mind the gap

Hardware maturity assessment of current R&D prototypes

	Mass commercialization ready now			
	Compute & connectivity	**Perception system**	**Energy & charging**	**Skeleton & structural comp.**
Maturity				
Description	• Processing and communication architecture • Enables real-time data processing	• Vision: cameras, 3D sensors • Touch: e-skin • Motion: IMU, accelerators	• Li-ion cells + BMS • Thermal management	• Machined/cast aluminum/steel parts • PEEK[1] materials for strength/weight
Current status	• Sufficient processing power • Edge AI enables on-device inference • 5-10 ms control loops	• Vision hardware is mature • 3D structured light for next generation • E-skin evolution ongoing	• Current run time 2-8 hours per charge • Target for 2028: 16 hours • Automotive battery directly transferable	• PEEK[1] proven in aerospace and medical • Modular design enables flexible component replacement
Key challenges	• Regulation (e.g. ICTS) creates deviating standards: China and Western countries • Compute vs. battery • Heat dissipation in compact form	• Need 100+ sensors/ hand for human-level touch • Process multimodal data streams in real time	• Achieve 16 hours running time without weight penalty • Fast charging (30-60 min.) degrades battery lifespan	• PEEK is 5-10x more expensive than normal industrial plastics • Long-term durability is unproven at scale • Optimize strength-to-weight ratio

Low High

1 Polyetheretherketone: a high-performance, semicrystalline thermoplastic known for extreme temperature resistance (up to 250°C), superior mechanical strength and exceptional chemical resistance

Source: Market interviews, desk research, past Roland Berger projects

has reached an advanced pre-commercial stage: systems operate reliably in demonstrations and early pilots, but cost efficiency, long-term durability, scalability across use cases and supply chain robustness remain under development.

The remaining gap is no longer about "can it work?" – but about whether it can operate reliably, affordably and at scale. ▶ D

Mass commercialization in 1-3 years

	Motion system – actuator	Motion system – other	Hand/end-effector system	Other components
Maturity				 
Description	• Motors & reducers • Multiple rotary & linear actuators (25-35) per robot • Tendon for hand	• Encoders, drives and torque sensors • Bearings	• Multi-DOF robotic hands and grippers • Underactuated/fully actuated fingers • Tactile sensing	• Wiring harnesses • Displays, audio • Connectors, fasteners
Current status	• Transition to axial flux motors + cycloidal reducers • Cost declining drastically (up to 50 %)	• Response time <5-10 ms latency • Force-torque feedback enables safe interactions • Bearing and encoder are mature technology	• Early commercial dexterous hands (low-mid volume) • Limited robustness for continuous industrial use • Perception and control still in early stages	• Automotive-grade connectors • Display and audio are mature and cost-effective technology
Key challenges	• Axial flux motors and cycloidal reducers need 1-3 years to mature • 50-90 % cost reduction required • Balance power & safety	• Coordinate 30-50 DOF in real time • Long bearing wear unproven (e.g. in continuous bipedal movement) • Reduce vibration/noise	• Human-like dexterity at industrial cost • Improve durability • Reduce actuator count • Integrate tactile sensing without higher complexity	• Route 30-50+ cables through moving joints • Electromagnetic interference shielding • Design for serviceability

Low High

Source: Market interviews, desk research, past Roland Berger projects

Industry consensus points to initial hardware design stabilization around 2028-29, with supply chain maturation expected to follow thereafter. As a result, commercialization will unfold gradually rather than simultaneously across all subsystems. Three recurring constraints must be overcome to bridge the gap between today's prototypes and commercially viable systems.

1. **The cost-performance imperative:** Commercial deployment requires substantial cost reductions – estimated at 50-90 percent for critical subsystems such as actuators – while simultaneously maintaining or improving safety and performance characteristics.

2. **The durability gap:** A major challenge remains the durability of complex systems in demanding production environments. For example, advanced robotic hands currently have a lifespan of less than one year in volume applications, necessitating frequent and costly replacements.

3. **Ongoing technology transitions:** Several subsystems are progressing through generational shifts, such as the move toward axial flux motors and cycloidal reducers. While these transitions may improve performance, they could extend adoption timelines by approximately one to three years as new designs are validated and standardized.

Actuators – the core value driver

Actuators represent the single most critical subsystem in humanoid robots. They determine torque density, dynamic performance, energy efficiency and ultimately cost structure. Current systems rely primarily on electric motors combined with harmonic or cycloidal gearboxes. The industry trend is moving toward fully integrated actuator modules combining motor, gearbox, drive electronics, torque sensing and thermal management into a compact unit.

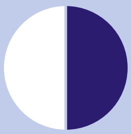
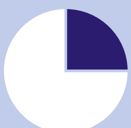
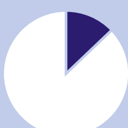
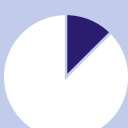
Key technological levers include higher torque density motors, low-backlash high-efficiency reducers, alongside integrated force and torque sensing and improved thermal management. Cost-optimized manufacturing at scale will be essential for commercialization.

Software and ecosystem maturity

While hardware platforms are approaching functional adequacy, the broader ecosystem – including software architectures, data infrastructure, supply chain industrialization and regulatory frameworks – remains materially less mature. According to expert assessments and interviews with industry stakeholders, ecosystem readiness currently trails hardware development by an estimated three to five years. Physical systems operate in pilot environments with increasing reliability, but the enabling conditions required for repeatable, large-scale deployment are still in the process of evolving. ►E

E Smart robots need smarter software

Software and ecosystem maturity assessment

		Description	Current status	Key challenges
Software – trailing hardware by 3-5 years	**VLM**[1] 	• Core system combining perception and reasoning • Enables zero-shot learning[2]	• GenAI compressing development cycle • Controlled environment tasks approaching human level • Open-ended environments still need 5-10 years	• Difficulty with context-based reasoning • Reliable transfer of virtual training to physical environment • Local computing power requirement is high (200+ TOPS)
	Training data 	• Multimodal datasets: vision, tactile, proprioception, force feedback • Capture diverse environments, tasks, failure modes, recovery strategies	• Public data scarcity: LLM text corpora exist; robot manipulation data doesn't exist at scale • Limited open-source datasets for robotics AI training • Leading humanoid OEMs are collecting proprietary data	• Data generation bottleneck prevents LLM-alike large-scale training • Need labeled, multi-angle and multimodal recordings – exponentially more expensive than text • Data becomes a competitive advantage and proprietary asset of leading OEMs, leading to a fragmented ecosystem
Ecosystem – not yet ready for mass commercialization	**Supply chain** 	• Global supplier networks across US, Europe and China with regional specialization • Integration of existing automotive, electronics and robotics supply chains	• No mature end-to-end supply chain yet: US focused on software; China focused on industrialization • Dual supply chain – regulated components (high-cost) sourced from Western countries; standard components (low-cost) sourced from China	• Most Tier 2 suppliers are still in the testing phases: 1-2 years minimum to progress to mass production stage • Suppliers are hesitant to invest in capacity • ICTS/export controls force 2-3x cost premiums for critical components
	Regulation 	• Safety standards for human-humanoid robot collaboration • Export controls (ICTS), AI governance (EU AI Act), product compliance (CE, FCC)	• No harmonized global standards: US/EU/China pursuing divergent regulatory paths • ICTS impact: 13 critical components face exclusion from Chinese suppliers • Safety certification undefined: existing standards do not apply to humanoids	• Standards timeline: 2-3 years minimum for ISO ratification, industry adoption, certification infrastructure • Fragmented regulation across US, EU and China • Unclear who bears responsibility for AI-driven physical errors

Maturity: ☐ Low ■ High

1 Vision-language model, 2 A machine-learning capability where a model can correctly handle tasks it was never explicitly trained on, without seeing labeled examples beforehand

Source: Market interviews, desk research, past Roland Berger projects

The primary bottleneck has shifted from mechanical engineering to AI architecture and data strategy. Leading developers are transitioning toward vision-language models and end-to-end learning systems that directly connect perception to actuation. Inspired by autonomous driving architectures, these approaches reduce manual programming and enable adaptive task execution.

Hierarchical AI stacks are emerging as the dominant design: a high-level reasoning layer (vision-language and foundation models) enables task planning and contextual understanding, while a low-level control layer translates intent into precise motor commands closely coupled to the robot's kinematics. This architecture supports gradual expansion from single-task training toward broader generalization – a prerequisite for cross-industry deployment.

However, the shift to learning-based systems introduces several structural dependencies that will shape how the ecosystem evolves:

Data as the core constraint
Unlike generative AI systems, humanoid robots require synchronized sensor-to-actuator data from real-world environments. Such data is proprietary and costly to generate, and remains scarce in real-world operating environments. Synthetic data, teleoperation, industrial partnerships and fleet learning are therefore essential components of competitive strategy.

Simulation as an accelerator, not a substitute
Physics-based simulation environments (world models) enable scalable training and reduce early-stage data requirements. Yet the sim-to-real gap persists, limiting the feasibility of purely virtual training. Real-world validation therefore remains indispensable.

Compute infrastructure as a barrier to entry
Training humanoid foundation models demands substantial AI hardware clusters and distributed training pipelines, alongside optimized inference systems. This increases capital intensity and favors players capable of vertically integrating hardware, software and AI infrastructure.

Beyond software and data, the broader industrial ecosystem will also shape the pace of deployment. Supply chain maturity will determine how quickly humanoid robots transition from low-volume pilots to economically viable mass deployment. Today's systems are largely assembled from custom-developed, high-cost, low-volume components.

Scaling requires a shift from engineering-driven sourcing toward platform-based, automotive-style supply ecosystems. Current developers depend heavily on specialized suppliers for actuators, precision gearboxes, sensors and control electronics. These suppliers operate at limited scale, with extended lead times for critical components such as harmonic drives and high-torque motors, creating bottlenecks even in pilot programs.

Regulatory frameworks represent an additional deployment constraint. Existing safety standards were developed for traditional automation systems operating within fixed, enclosed zones, as well as for collaborative robots ("cobots") with defined operating envelopes and predictable tool configurations. Humanoid robots, by contrast, function in dynamic, human-centric environments, can change position, height and tools, and manipulate a wide range of objects. This variability makes it significantly more complex to define consistent risk profiles and renders existing safety concepts insufficient.

Future regulatory frameworks will therefore need to address movement speed, force limits, object interaction, reaction times and AI-driven decision processes. Establishing such standards requires extensive testing, validation protocols and empirical safety data – particularly in regulation-intensive markets. At present, no harmonized global framework exists: companies must navigate a fragmented landscape of machinery directives, workplace safety rules, product liability regimes and emerging AI governance requirements. This fragmentation increases compliance complexity and extends time-to-market.

Humanoid robots are moving from science fiction to reality - the key gap is in software and data for AI models.

3/ Two ecosystems, two scaling curves

China's deployment-led strategy and the West's AI-driven approach

The humanoid robotics market is not evolving as a single global race. As technological readiness improves, two ecosystems are emerging with distinct scaling logics: North America and EMEA (Europe, the Middle East and Africa), pushing AI-first "generalist" robot architectures; and China, industrializing faster with a manufacturing and deployment flywheel. These contrasting approaches shape how quickly robots reach real-world deployment and where competitive advantages are likely to emerge. ▶F

WESTERN ECOSYSTEM: AI-FIRST, CAPITAL-RICH, SCALE-POOR

Western leaders are increasingly positioning themselves as AI and software companies, betting that competitive advantage will come from foundation models and vision-language systems, supported by proprietary datasets that enable robust autonomy in unstructured environments. The capital base supports this view: North America has nearly the same funding (USD 3.8 billion) despite having fewer startup OEMs than the Chinese ecosystem.

The constraint is less mechanical design and more "data plus deployment": real-world training data, validation cycles and safety cases. In the current snapshot, Western production remains largely in the pilot phase, slowing iteration and delaying software maturation.

CHINESE ECOSYSTEM: DEPLOYMENT-FIRST, SCALE-DRIVEN LEARNING

China is pursuing a volume-led strategy: deploy robots into defined, controlled workflows such as entertainment and logistics, iterate rapidly and drive the cost curve down through manufacturing scale. That approach is visible in output: more than 15,000 units in 2025 – at least 30 times North America's volume and over 150 times that of EMEA.

Policy support and IP (intellectual property) leadership reinforces the industrialization push, with a clear roadmap toward ecosystem build-out and scaled deployment. China also leads patenting in humanoid robotics, signaling sustained investment in core capabilities – not only assembly capacity.

STRATEGIC IMPLICATIONS

These contrasting strategies are creating two distinct industrial flywheels and three strategic positions in the emerging market. China currently benefits from a scale advantage, building a powerful data and cost flywheel through rapid deployments. North America, by contrast, commands deep capital pools and strong AI capabilities but will need a step change in production scale to close the "data plus deployment" gap. EMEA occupies a more constrained position, with a smaller startup base and limited funding, combined with minimal projected 2025 output. This increases the risk of long-term dependence on either Chinese hardware platforms or US AI stacks.

Geopolitics is likely to reinforce these differences. Export controls, procurement rules and "trusted supply chain" requirements are pushing the industry toward parallel technology stacks and regionally anchored supply chains – effectively creating separate technology markets with limited cross-border interoperability.

F Different regions, different strengths

Startups, funding, production and technological maturity by region

	North America	EMEA	China	RoW	Total
No. of startup OEMs [#]	25	22	39	20	106
No. of auto/tech/ industrial OEMs [#]	2	2	13	6	23
Startup OEM funding [USD bn]	3.8	0.8	4.1	0.3	9
Production 2025 [#]	~500	~100	~15,000	~300	16,000
Technological maturity					

Source: Desk research and public information

4/ Where value will emerge first

Labor shortages, productivity gains and first deployment opportunities

Regardless of these emerging ecosystem differences, the initial economic drivers of humanoid robot adoption will be remarkably similar across regions. Beyond rising factor costs, labor scarcity is emerging as a critical challenge across both developed and developing economies. Current target low-cost countries, particularly in Eastern Europe, are projected to experience double-digit workforce declines by 2050, fundamentally shifting the economic rationale for production location strategies. This demographic pressure is particularly acute in countries making significant investments in humanoid robots. China, for instance, faces severe labor scarcity due to the long-term effects of its former one-child policy, creating strong incentives for automation adoption. ▶ G

G The labor pool is shrinking

Working-age population trends and unemployment across selected countries

Working-age population in 2025 & corresponding unemployment rate

	Working-age population [m]	Unemployment rate [in % of working population]
India	1,002	4.2%
China	987	4.6%
European Union	278	5.9%
United States	224	4.2%
Indonesia	195	3.2%
Brazil	147	6.0%
Nigeria	134	3.1%
Mexico	89	2.7%

	Working-age population [m]	Unemployment rate [in % of working population]
Japan	72	2.5%
Turkey	60	8.5%
Germany	52	3.7%
Poland	25	3.0%
Romania	12	6.0%
Czech Republic	7	2.8%
Hungary	6	4.5%

Global labor development

The European Union faces population decline after decades of growth. By 2050, it is expected to become the world's oldest region, with a median age of 48.2 years.

Countries in the former NAFTA region are growing, strengthening the competitiveness of the United States-Mexico-Canada Agreement (USMCA).

Source: UN Population Division, World Bank

But the challenge extends beyond demographics. Workers are increasingly unwilling to accept positions in harsh production environments or shift-based work models, especially in regions where alternative employment exists. Service sector jobs – typically limited to day/evening shifts and often offering flexible working arrangements – present attractive alternatives.

Working-age population forecast for 2050 & working-age population growth compared to 2025

	Working-age population [m]	Working-age population growth [%]
India	1,134	+13%
China	745	-24%
United States	232	+4%
Nigeria	232	+73%
European Union	229	-18%
Indonesia	211	+8%
Brazil	137	-7%
Mexico	98	+10%

	Working-age population [m]	Working-age population growth [%]
Turkey	57	-4%
Japan	54	-25%
Germany	44	-16%
Poland	19	-25%
Romania	9	-24%
Czech Republic	6	-18%
Hungary	5	-17%

India replaces China as the world's most populous country. China's population is already shrinking and aging rapidly.

Sub-Saharan Africa's working-age population is projected to triple to around 2 billion by 2050 – more than double that of all high-income countries combined.

Source: UN Population Division, World Bank

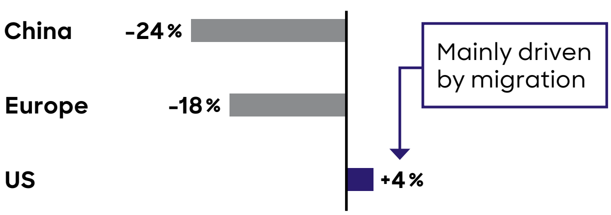
Automation is increasingly seen as a key lever for reducing workforce dependency. Advanced automation systems enable manufacturers to operate selective lights-out shifts during nights and weekends, concentrating remaining human work during preferred daytime hours. This approach addresses labor scarcity and worker preferences while maintaining production capacity. ▶ H

Modern manufacturing facilities already demonstrate high levels of automation across the value chain (see Roland Berger, "Lights-out factory"). State-of-the-art production systems integrate advanced robotics, automated material handling and intelligent control systems to achieve high levels of efficiency and consistency.

H When workers disappear, machines take the night shift

Labor scarcity and automation mitigation measures

Change in working-age population (aged 15-64), 2025-50 [%]



For German companies

>85 %
of companies are experiencing first effects of labor scarcity in their operations

4 months
is how long it takes on average until vacant positions can be staffed

For manufacturing specifically

~45 %
of manufacturing companies are already missing talent to fill their vacancies

~57 %
of companies in metalworking report operational difficulties due to staffing shortages

Key levers for tackling labor scarcity

Automation & operations
- Level of automation
- Operational excellence & efficiency
- Process maturity & repeatability
- Complexity & flexibilization
- IT systems & governance
- ▶ **Lights-out operations as a key lever against labor scarcity**

Organization & talent
- Talent acquisition
- Talent management
- Process maturity & repeatability

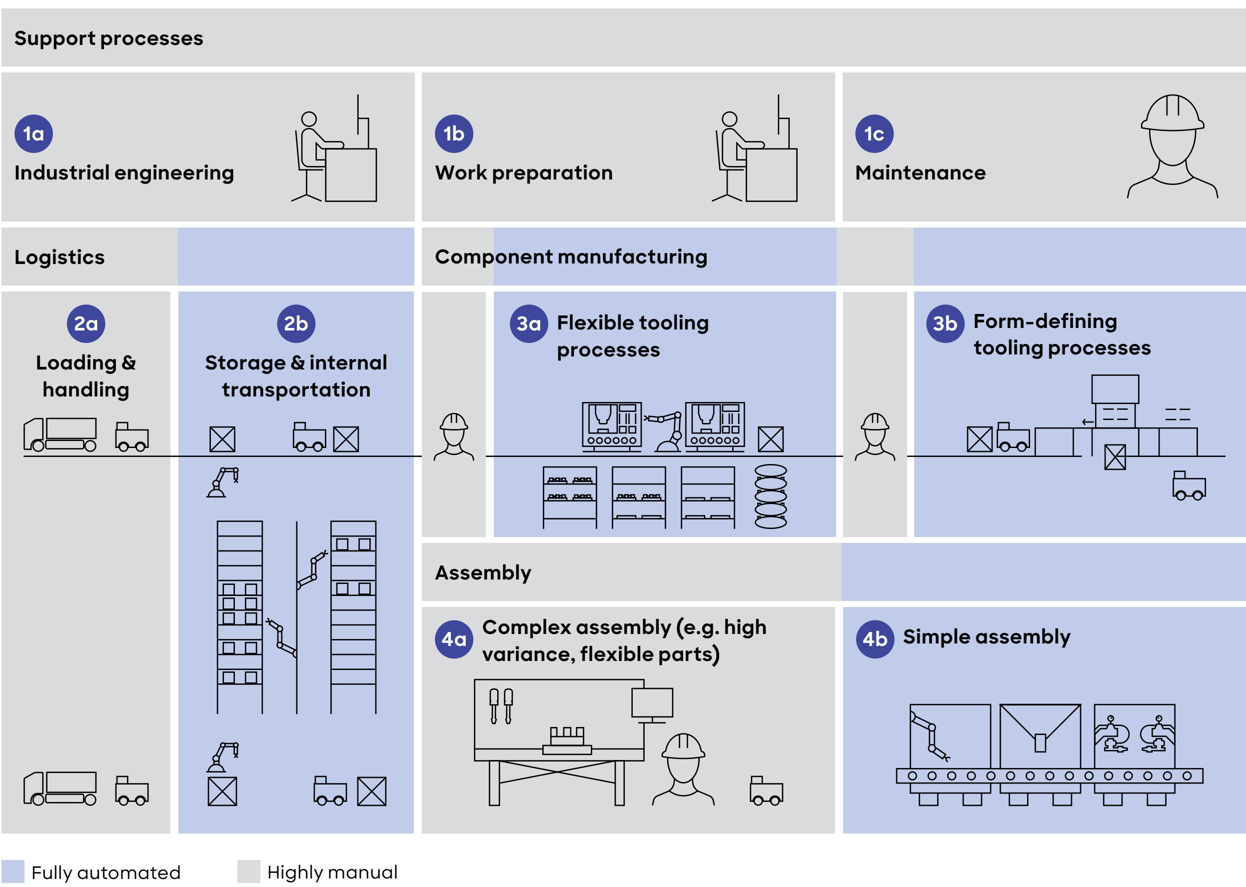
Organization & talent
- Value and supply chain setup
- Outsourcing potential
- Etc.

Source: Oxford Economics (2023), ifo Institute, IfM Bonn, United Nations, Roland Berger

Despite these advances, significant white spots remain that continue to resist traditional automation approaches, including bulk goods picking, part hanging on conveyor systems, kitting for assembly or logistics, component unpacking and machine or component assembly. These tasks share common characteristics: they either involve high variance at low volumes or require handling flexible components such as cables or hoses. Humanoid robots aim to address these challenges by replicating human dexterity and enabling flexible deployment across tasks, potentially offering lower capital expenditure compared to specialized automation solutions. ▶I

Where automation still struggles

Remaining manual activities in factory operations



Source: Roland Berger

Given current technical maturity, humanoid deployment will focus on simpler use cases in the near term and gradually expand to more complex applications as capabilities improve. In practice, deployment opportunities can be grouped into four tiers that reflect increasing task complexity and value creation:

SIMPLE USE CASES – LEARNING THE TECHNOLOGY

Initial humanoid applications focus on straightforward tasks such as picking bulk goods or parts from shelves and loading them into machines or onto conveyor belts, as well as transporting boxes in inbound and outbound logistics between storage locations. Many of these tasks can already be automated using existing technologies – AGVs for material transportation and camera-enabled robotics for picking operations. AGVs already provide substantial flexibility, which limits the incremental value of humanoid robots in these scenarios.

However, these simple use cases serve important strategic purposes. They allow manufacturers to gain familiarity with humanoid technology and build operational experience while enabling providers to capture real-world training data for software development. As a result, the primary rationale for deploying humanoids in these contexts is often technology development partnerships between manufacturers and robot providers rather than purely economic business case justification.

MEDIUM-COMPLEXITY USE CASES – UNLOCKING FIRST ADDITIONAL VALUE

The next tier addresses tasks with higher variance that require stronger generalization capabilities in the humanoid software stack. Kitting operations, involving the selection of diverse components required for manual assembly activities, demand robust pattern recognition and adaptability due to the wide range of parts involved. Success in manufacturing kitting applications is likely to open the path to logistics environments where variance levels and efficiency requirements are even higher. In logistics, picking represents a core operational activity rather than a supporting function for assembly.

Another application involves automated loading of parts into fixtures for subsequent processing by machining centers or similar equipment, where variations in part geometry often restrict conventional automation solutions. While specialized non-humanoid systems are still emerging for these tasks, major robotics and vision providers are developing similar capabilities. The distinctive advantage of humanoids lies in the flexible combination of multiple tasks. A robot could load one machine during one shift and relocate to the logistics area during another based on changing capacity requirements. When a robot can perform several tasks reliably without reconfiguration, it unlocks value propositions unattainable with conventional automation systems.

HIGH-COMPLEXITY USE CASES – EXPANDING INDUSTRIAL AUTOMATION

Managing flexible components such as cables, hoses or fabrics represents the next complexity tier. These materials are difficult for conventional automation systems to manipulate reliably because they deform and behave unpredictably during handling. The ability to process such components would enable humanoid deployment in unpacking tasks and help bridge the gap between automated warehousing systems and automated production lines.

The ability to manipulate flexible components also opens opportunities for automating repetitive assembly activities involving cable routing or tube installation. The value proposition strengthens when humanoids can be deployed across several high-complexity tasks and approach the flexibility level of human workers.

5/ Strategic implications for industry players

How companies should position themselves in the emerging value chain

VISIONARY USE CASES – THE LONG-TERM HORIZON

The final tier involves automated assembly of machines or equipment with extended assembly times (ten minutes or more per unit) and high variance. In such environments, a humanoid robot would need to interpret assembly plans autonomously, execute multi-step sequences, identify correct components and perform appropriate assembly operations.

Achieving this level of autonomy could eventually enable large-scale replacement of human labor in direct production processes. However, such capabilities will require substantial technological progress and therefore remain a long-term objective rather than a near-term deployment opportunity.

Furthermore, humanoid robots are not only relevant for production: they are likely to expand to use cases in households and services as well.

> "Automation is a key lever for reducing workforce dependency. Advanced automation systems enable manufacturers to operate selective lights-out shifts, addressing labor scarcity and worker preferences while maintaining production capacity."

The emergence of humanoid robotics will reshape large parts of the industrial ecosystem. As the market moves from experimentation toward industrial deployment, different stakeholders face distinct strategic choices. Humanoid robot developers, suppliers, industrial equipment companies, operators and AI players will all need to define their roles within the emerging value chain. The following recommendations outline the strategic priorities for each of these groups as the market begins to scale.

HUMANOID ROBOT OEMS

Build the data flywheel and industrialize the platform

Data will be the decisive frontier in humanoid robotics. The central challenge is advancing AI models to a level where robots can operate reliably in complex real-world environments. The key bottleneck is access to sufficiently large and diverse training datasets. Companies therefore need to pursue multiple pathways simultaneously to generate operational data.

Operator partnerships will play a central role in this process: manufacturers and logistics companies can provide real production environments in exchange for preferential pricing or early access to the technology. At the same time, OEMs should pursue pilot deployments of roughly ten to 50 units that prioritize data diversity rather than productivity, with the objective of generating large volumes of operational experience as quickly as possible. Synthetic data will also become increasingly important – physics-based simulation environments can help generate training data for edge cases and rare scenarios that are difficult to capture in real-world deployments. Finally, collaboration between developers may become necessary in early phases of the market, with data-sharing consortia helping to compensate for limited scale in the initial deployment cycle.

While AI will ultimately determine long-term competitiveness, hardware should not be treated as a commodity. Industrialization requires the finalization of product architecture, design-to-cost, design for manufacturability and deep partnerships across the supply base. Automotive suppliers are particularly well positioned to support this transition thanks to their experience in scaling complex electromechanical systems. Partnerships with electronics and semiconductor companies will also be essential to secure the compute capabilities, sensors and power management systems required for large-scale deployment.

COMPONENT SUPPLIERS (AUTOMOTIVE, INDUSTRIAL, ELECTRONICS, SEMICONDUCTOR)

Define your role early and co-develop the humanoid supply chain

Component and semiconductor suppliers need to decide how actively they want to pursue the opportunity in humanoid robotics. For most suppliers, the sector represents a potentially significant growth market, as humanoid robot OEMs are currently building their supply organizations and forming strategic partnerships with suppliers.

Companies are approaching the opportunity with different levels of intensity. Some will pursue a full and visible market entry, actively positioning humanoid robotics as a diversification opportunity toward capital markets, establishing dedicated teams and developing tailored products for the emerging ecosystem. Others may adopt a more selective approach through active business development, forming small teams that engage with humanoid robot companies through capability presentations and technical discussions – an approach that involves less public exposure while still creating the potential for sizable commercial opportunities. A third group of companies may initially take an observational stance, opening discussions with humanoid robot developers without actively pursuing business at this stage. This approach may suit companies that typically scale their presence later in product cycles or enter new markets once they mature through acquisitions.

Regardless of the chosen path, speed will be critical. Firms that want to compete in the fast-moving humanoid robotics landscape should establish small, autonomous teams with real decision-making authority, ideally operating outside traditional corporate structures in order to match the pace of humanoid robot startups.

At the same time, relevance will depend on co-development with OEMs. Whether the contribution is a single high-precision component, proprietary IP or a fully industrialized subsystem such as a complete limb assembly, what matters is a clearly defined value chain position. This includes areas such as motion control, actuators, IO modules, sensing technologies and other critical subsystems that form the core of humanoid robot functionality. The most competitive suppliers will not wait for finalized specifications; instead, they will take early OEM prototype designs and transform them into scalable, factory-grade products. Some will also bring elements of their own product portfolios into the equation, adding differentiated performance that the OEM cannot easily replicate alone.

A distinctive value bundle strengthens this position further. Suppliers that combine specialized components with proven performance at scale, factory access that can serve as a real-world training environment for robotic systems, operational data that accelerates machine learning and deployment readiness, and conditional purchase orders that reduce risk for both sides will move beyond a traditional bill-of-materials role. In doing so, they will become development partners that shape the roadmap rather than suppliers that simply fulfill specifications.

INDUSTRIAL EQUIPMENT AND ROBOTICS PLAYERS

Position early in the humanoid manufacturing and automation ecosystem

For industrial equipment and robotics companies, humanoids should be treated as a core strategic market rather than a side bet. Companies have a strategic choice between competing in humanoid robotics, potentially through partnerships, or focusing on integration. To capture this opportunity, industrial equipment and robotics companies need to define a clear position in the emerging value chain.

Humanoids will increasingly need to be integrated into broader automation environments and existing factories. Early movers can shape specifications and establish themselves as reference partners for leading OEMs, positioning themselves to capture an attractive share of capital expenditure as volumes scale over the coming decade.

In this model, humanoids do not replace traditional automation but complement it, operating alongside established technologies such as industrial robots, collaborative robots, autonomous mobile robots and conveyor systems. On the software side this may include the control and orchestration of humanoid fleets from multiple OEMs and the integration with factory management and line control systems. The most successful players will build integrated automation ecosystems that combine these technologies into turnkey solutions for specific industries, including automotive manufacturing, logistics and electronics production.

OPERATORS

Identify use cases early and shape the emerging humanoid ecosystem

Humanoid robots will not initially arrive as fully general-purpose systems. Their path into industrial environments will run through specific, well-defined tasks – and operators who identify those tasks early will build a meaningful experience advantage.

The most promising near-term applications lie in brownfield environments, particularly in repetitive material handling tasks. Expectations should remain realistic. Current humanoid platforms perform reliably in structured, repetitive tasks within mapped environments, while fine-grained dexterous manipulation and fully autonomous decision-making are still evolving. In many of these applications, the humanoid form factor will have limited benefits to more traditional robotics and automation solutions; however, the goal of early pilots is not immediate large-scale automation but the accumulation of operational experience before the competitive window narrows.

Humanoid robots should be embedded in a holistic physical AI strategy rather than treated as standalone technology initiatives; they represent one element of a broader transformation in industrial automation, and when deployed in isolation they risk becoming expensive pilot projects that never scale. When integrated into a coherent physical AI architecture – alongside autonomous mobile robots, machine vision systems, predictive maintenance platforms and industrial IoT – humanoid robots can instead act as a powerful force multiplier that extends the reach of existing automation technologies.

Three priorities follow. First, map how humanoid capabilities complement existing automation assets rather than duplicating them; focus initial deployments on simple, well-isolated manual tasks to enable low-risk pilots. Second, invest in internal competency. Organizations that develop in-house expertise in data management, robot supervision and system integration will scale deployments faster and retain more strategic control than those that rely entirely on external vendors. And third, prepare the workforce for a shift in roles from manual execution to supervision, exception handling and human-robot collaboration. Transition planning is a prerequisite for sustainable automation and should not be treated as a purely HR exercise.

Operators should also form strategic partnerships early. The terms of the humanoid robotics market are being defined today, not when products reach catalogue maturity. Operators who engage early will secure better economics, greater influence over product development and stronger positions in the emerging ecosystem. Those who wait will adopt what others have defined.

In practice, several partnership mechanisms can help operators participate.

Data-for-discount models:
Humanoid OEMs require real-world environments to train, validate and refine their systems – environments that simulation alone cannot replicate. Operators can offer their facilities as training grounds and, in return, negotiate preferential pricing, priority access or co-development rights. This is not a concession: it is a structured exchange in which both sides can benefit. Operators should carefully assess in which processes humanoid robots are deployed and what data they are willing to share, as this may expose process knowledge and enable competitors.

Conditional commitments:
Non-binding letters of intent or conditional purchase agreements carry minimal downside for operators, yet materially strengthen an OEM's investment case and financing position. Signaling demand early secures a seat at the development table and helps ensure that product specifications reflect real operational requirements rather than laboratory assumptions.

Choice of partners themselves:
The humanoid robotics landscape is consolidating around platform ecosystems, with leaders in China and North America scaling rapidly. Operators defaulting to foreign platforms risk dependence on external software architectures, proprietary data stacks and geopolitically exposed supply chains. Partnerships with local or regional OEMs strengthen domestic value chains and reduce technological lock-in risk.

Operators that move first will not merely gain access to superior technology on favorable terms – they will shape product trajectories and their own competitive position.

AI COMPANIES
Extend AI leadership into physical AI and robotics platforms

Leading generative AI companies have significant opportunity in humanoid robotics. Near-term, they can partner with humanoid developers, providing language interfaces or reasoning capabilities that enable natural human interaction. The larger opportunity lies deeper in the technology stack.

AI is the core driver of humanoid robot performance, and strong AI capabilities are becoming the most important success factor. Leading AI companies should evaluate expanding into physical AI and robotics directly. This could take different forms: developing humanoid capabilities internally, combining advanced AI models with robotic platforms, or pursuing partnerships with industrial robotics companies, integrating AI capabilities with established hardware engineering and deployment expertise.

EUROPE AND THE MIDDLE EAST IN THE HUMANOID ROBOTICS RACE

Europe has not yet lost the race in humanoid robotics – but it needs to accelerate. The region has a strong base of robotics and automation companies and remains an important industry nucleus. While some humanoid robot companies have emerged and attracted funding, investment lags behind the US and China. Strengthening this ecosystem will be critical as the industry moves toward large-scale deployment.

Humanoid robots could rebalance global manufacturing footprints. At an estimated operating cost of USD 2 per hour for advanced humanoid robots, even labor-intensive production could become viable in higher-cost regions. This could enable European manufacturers to locate production closer to end markets while maintaining cost competitiveness.

Europe must develop a strong domestic humanoid robotics ecosystem rather than relying on imports from North America or China. Without a local value chain, significant economic value would accrue outside the region – as already occurs in parts of the AI ecosystem.

As production becomes increasingly automated, value creation will shift from labor toward technology ownership and industrial platforms. Regions hosting humanoid robot developers, component suppliers and system integrators will capture greater economic benefits. Without domestic value creation, economic value and fiscal revenues would increasingly flow abroad.

Europe starts from a position of strength: a particularly strong base of automotive and industrial suppliers, plus a robust automation ecosystem. Together with local humanoid robot OEMs, these companies could form powerful partnerships and revitalize industrial sectors currently under pressure.

The **Middle East** is establishing itself as a global leader in AI and advanced robotics through ambitious national strategies. Saudi Arabia's Vision 2030 and the UAE's Fourth Industrial Revolution Strategy prioritize robotics and AI for economic diversification. Projects in Saudi Arabia and Dubai serve as living laboratories, integrating humanoid robots into urban infrastructure, logistics and public services as large-scale testbeds for real-world deployment.

Significant investment flows from sovereign wealth funds and government-backed accelerators, fueling local R&D, supporting startups and attracting global technology leaders to establish regional centers. The aim is a rapidly maturing ecosystem where AI initiatives create a foundation of innovation and software talent. Humanoid and mobile robots are already piloted for surveillance and customer service in airports, malls and city developments.

Universities are expanding AI and robotics programs while incubators nurture early-stage companies. Competitions, hackathons and research grants foster innovation among youth. Challenges remain in localizing supply chains and bridging the talent gap, as advanced components are imported and experienced engineers scarce.

As capabilities mature, the Middle East can not only meet domestic demand but export robotics solutions to Africa and South Asia, positioning itself as a strategic player with potential to reshape labor markets and set new automation standards.

Conclusion

At the beginning of this study we asked how quickly humanoid robots will scale. The evidence suggests that the transition from experimentation to industrial deployment has already begun, and companies across the value chain should act now to secure their position. Advances in AI and robotics hardware mean that machines will soon be able to do much of the work that humans do today, just as labor shortages and demographic change are increasing the demand for new forms of automation. As a result, technological capability and economic necessity are beginning to align. Adoption of humanoid robots will start with targeted industrial use cases and expand gradually as software capabilities improve (and costs decline). Who will win the race for leadership? That will depend on how quickly companies build real-world deployments and translate them into data, learning and industrial scale. Humanoid robotics will not transform industry overnight. But the moment of convergence has clearly arrived.

Credits

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