Tribeca
Global Natural Resources

Tribeca Global Natural Resources Insights

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Humanoid Robots: An EV Analogue?

Dear Investor,

Humanoid robots are real. They are currently being used in well-structured environments, such as industrial production and logistics, and have a path to general purpose adoption from 2035. The advanced stage of this technology and swiftness with which it is being commercialised were readily apparent during a research trip we took to China last month (notes available here).

Production is expected to ramp up significantly from 2025 and grow at a rate analogous to electric vehicles (EVs) from 2013 and smartphones from 2003 based on the view that humanoid robots will be the next widely adopted terminal device. Industry leaders believe adoption will be massive: Elon Musk, CEO of Tesla, sees one billion in circulation by 2040 and Jensen Huang, CEO of NVIDIA, believes that they will become as common as cars. As each robot is roughly 75kg and more than 50% base metals, battery metals and rare earths, this is a theme that is expected to tighten commodity markets.

Portfolio Manager, Ben Cleary, sets out below a brief overview of humanoid robots, the expected rate of sales growth and the positive impact this will have on materials demand moving forward. The Tribeca Global Natural Resource Strategy is strategically exposed to metal producers that will provide diversified torque to this thematic.

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Humanoid Robot 101

What are humanoid robots?

Somewhat obviously, humanoid robots are robots that resemble the human form, often incorporating a torso, head, two arms and two legs. Reasons for their development are manifold but relate primarily to solving labour shortages and driving efficiencies in the industrial and logistics sectors. They are shaped like humans because that is who the built world has been designed for, making it easiest for them to adapt to the environment they will be interacting with. The enhanced mobility of their form is what sets them apart from existing industrial robots. This is enabled by several highly specialised parts, including actuators, dexterous hands, control systems and a vision system. More on this below.

Exhibit 1: Humanoid robots require specialised parts for their enhanced adaptability
Annotated diagram of a humanoid robot using Tesla's Optimus model

Rotary actuators
Devices using fluid or electrical power to produce a controlled, finite rotation. Used in the neck, shoulder, wrist, elbow, torso and hip.

Vision System
A complex system using various types of cameras and LiDAR to capture visual information of the surrounding environment.

Control system
AI system in charge of information processing and decision making (supported by AI chips and algorithms) and a motion control system.

Linear actuators
Devices converting rotary motion (from a motor) into linear motion. Commonly used to push, pull, lift or slide objects. Found in the arm, ankle, elbow and knee.

Dexterous hands
A key enabler of the performance of complex and delicate tasks, including picking up small items and handling fragile objects. The degrees of freedom of current designs ranges from 6-42 versus 27 in human hands.

Source: *Tribeca Investment Partners, BofA Global Research, Companies.*

Who makes them?

Humanoid robots are being developed by some of the world's leading innovators, the most recognisable of which is Tesla. While they have been in the works for more than a decade, the recent surge in artificial intelligence (AI) technology used for training and programming these robots has accelerated their development.

Exhibit 2: Major humanoid robot models launched in recent years

Leading humanoid robot developers include Tesla, Unitree Robotics and UBTech

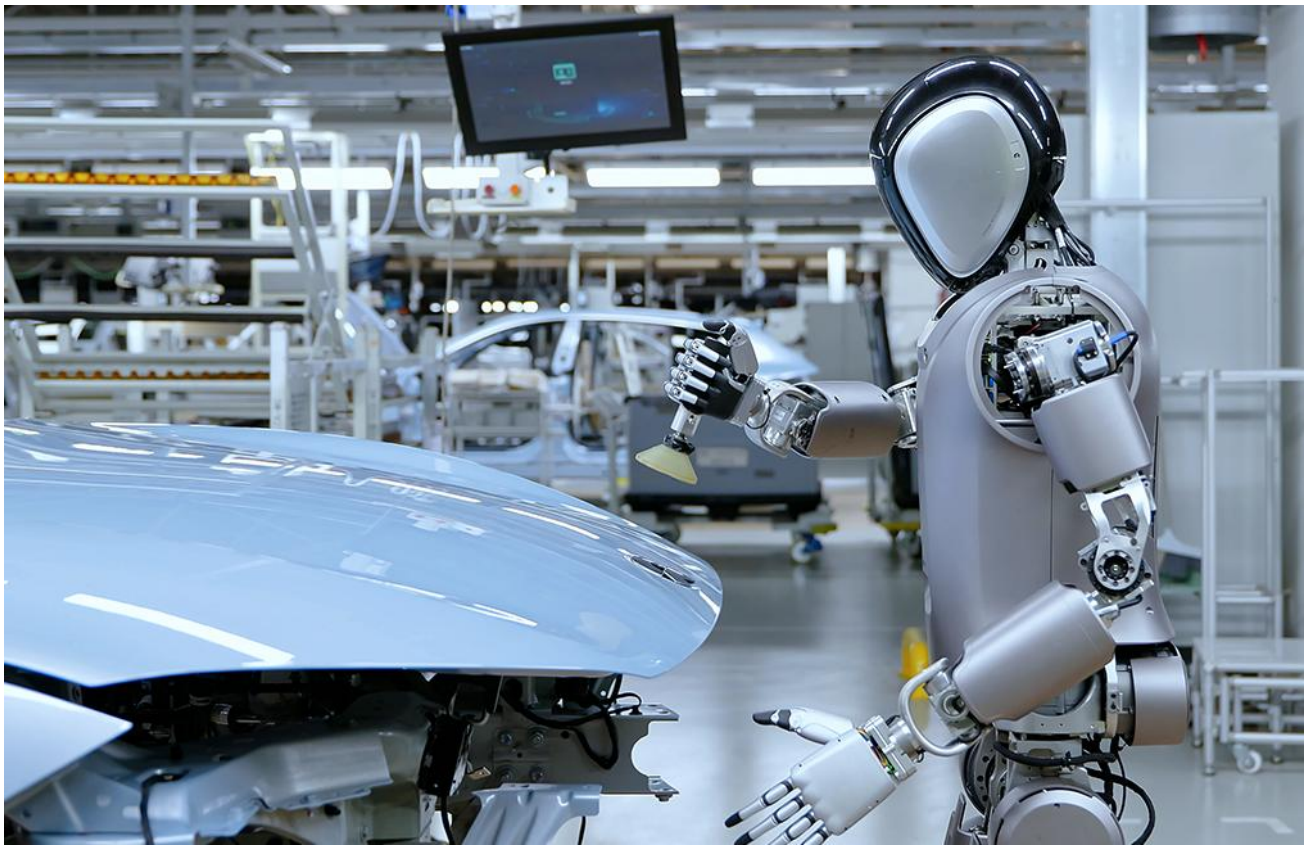
Company	Country	Product name	Launching time	Height (m)	Weight (kg)	Degrees of freedom	Application	Max. Speed (km/h)	Selling price
Tesla	US	Optimus Gen 2	2023	1.73	57	28 (body) + 11 per hand	Replace humans in dangerous and repetitive tasks	8	US$20-30k in the long run
Agility Robotics	US	Digit	2023	1.75	65	20	Warehouse delivery	5.4	Expected <US$250k
Unitree Robotics	China	H1	2023	1.8	47	19	Research & Education	11.8	US$90k
Unitree Robotics	China	G1/G1 Edu	2024	1.32	35/35+	23/23-43	Research & Education	7.2	US$16k
UBTech	China	Walker S1	2024	1.72	76	28 (excluding hands)	Manufacturing (training in auto factories)	Not specified	US$70k
Engine AI	China	SE 01	2024	1.7	55	32	Not specified	7.2	US$20-30k
XPeng	China	Iron	2024	1.78	70	62 (full body), 15 (hand)	Manufacturing	Not specified	Not specified
AgiBot	China	AgiBot A2/A2-Max/X1	2024	1.30-1.75	33-85	34-67	Interactive service, heavy duty special purpose etc.	>3.2	Not specified
Fourier Intelligence	China	GR-2	2024	1.75	63	53	Manufacturing, service, healthcare, research	5	Not specified
Figure AI	US	Figure 02	2024	1.68	70	35	Manufacturing, logistics, warehousing, and retail	4	Not specified
Sanctuary AI	Canada	Phoenix Gen 7	2024	1.7	70	20 (Hands)	Manufacturing	5	Not specified

Source: *Tribeca Investment Partners, BofA Global Research, Companies.*

What are they used for right now?

Humanoid robots are currently being used in small batches across well-structured or semi-structured environments, such as industrial production and logistics, mainly for material handling, assembly, sorting and quality check tasks. Chinese robot manufacturer UBTech's Walker S series, for example, has been deployed in the auto factories of BYD, Zeekr and Dongfeng. These programs are no longer purely for R&D. At a meeting in May, UBTech informed us that their Walker S1 model could replace two BYD factory workers with salaries of US$25k each. At an average selling price of US$70k per unit, the auto manufacturer's investment breaks even in less than two years. On a productivity adjusted basis, ie considering the Walker S1 can work 24/7/365, the payback period is likely less than one year.

Exhibit 3: UBTech's Walker S1 humanoid robot performing manual work in a BYD China factory
Employed to move, sort and place materials as well as perform quality inspections and assembly



Source: *Interesting Engineering.*

What will they be used for in the future?

Given the pace of AI advancement, it is expected that humanoid robot capabilities will continue to improve exponentially, enabling real-time interaction with humans before 2030. This should support massive adoption in commercial applications and a second stage of rapid growth.

From the middle of the next decade, we believe significant adoption for general purposes such as within households is possible. At this stage, annual sales growth should be parabolic, thanks to a much larger user base and greater affordability. This broader adoption is what creates the potential for humanoid robots to be the next widely adopted terminal device after EVs and smartphones.

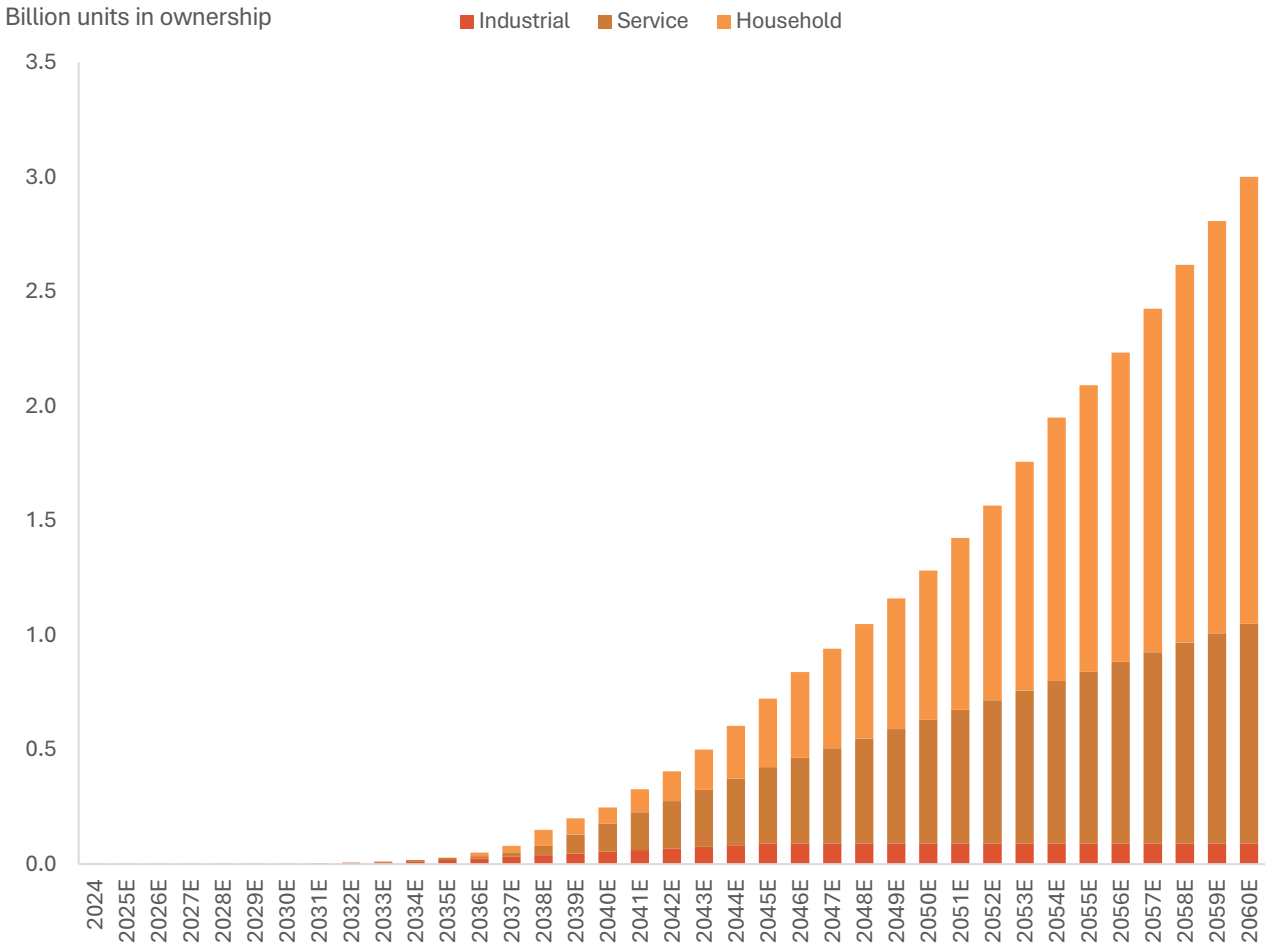
The Big Picture

Total Addressable Market

The pace of adoption remains a subject of debate. Industry leaders have put forward some mind-blowing numbers. Elon Musk, CEO of Tesla, views that humanoids will be one of the biggest products in history, that there will be one billion in circulation by 2040, and that they could ultimately number 30 billion. Jensen Huang, CEO of NVIDIA, estimates that they will become as common as cars with significant breakthroughs expected in the next two to three years. Jian Zhou, CEO of UBTech, recently expressed that the world may need 20-30bn humanoid robots: now in factories, soon for high-risk tasks, and eventually in homes worldwide.

Analyst estimates vary widely but are more closely aligned to the views of Huang. Bank of America, for example, estimates three billion units in ownership by 2060. This translates to 0.3 units per capita, which is slightly higher than that of passenger vehicles (0.2 units currently) but lower than that of smartphones (0.9 units currently). Similarly, Morgan Stanley estimates one billion humanoid robots in circulation a decade earlier (ie by 2050). Bank of America sees the end-application of humanoid robots in the steady stage will be split 65%/32%/3% between the household/service/industrial sectors, respectively.

Exhibit 4: Bank of America forecasts total units in ownership could reach three billion by 2060E
Total humanoid robot units in ownership by end-application



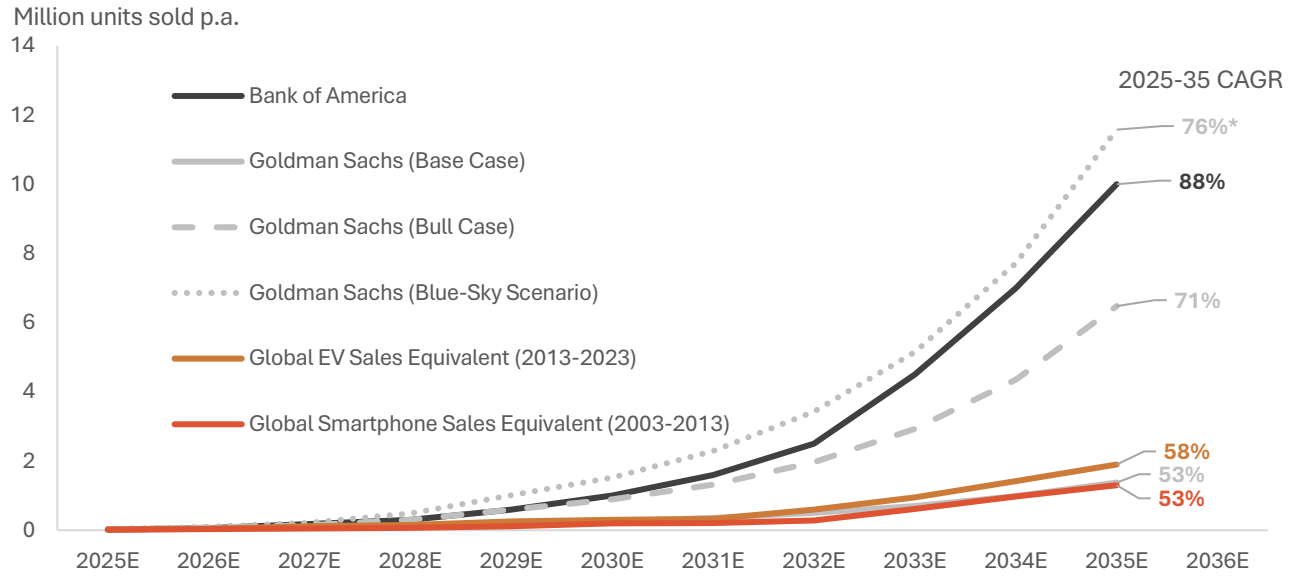
Source: *Tribeca Investment Partners, BofA Global Research Estimates*.

How do we get there?

While production to date has been limited, recent progress suggests that the global humanoid robot industry may be entering the volume production phase in 2025. Indeed, many developers are planning a rapid rollout. Tesla, the most ambitious, plans to ship several thousand units of its Optimus model in 2025 and is targeting an increase of 10x that to 50-100k units per annum in 2026, with a further 10x increase in 2027 to 500k-1m units per year. Figure AI is also targeting shipments of 100k units by 2028. Among Chinese humanoid robot names, UBTech targets to produce 1k units of humanoid robots in 2025 and increase its annual shipments to 3-5k in 2026 and above 10k in 2027.

Sell-side analysts estimate that there will be 20k units shipped in 2025, although growth rates applied to this base vary. Goldman Sachs assumes that growth over the next decade will be similar to that of global smartphone sales growth between 2003-2013 (53% CAGR), resulting in annual sales of 1.4m units in 2035. Bank of America references Chinese EV sales growth from 2013-2023, employing a CAGR of 88%, which results in annual sales of 10m units by 2035. While Morgan Stanley do not provide detailed near-term forecasts, they estimate that there will be annual sales of 6m units by 2035. Based on these estimates, we use a 2035 sales range of 1-10m units to evaluate commodity market impacts. It is also useful to consider Morgan Stanley's estimate of 46m units sold in 2040.

Exhibit 5: Humanoid robots are forecast to grow at similar rates to EVs and smartphones
Annual humanoid robot sales estimates and implied growth rates from 2025-2035



Sources: Tribeca Investment Partners, IDC, IEA, Goldman Sachs Global Investment Research, BofA Global Research.
** NB: GS Blue-Sky starts from a higher number of sales in 2025, which is why it is higher than BofA despite a lower rate.*

Risks to global humanoid robot adoption

There are, of course, risks to the above outlined estimates. Foremost, we see that AI regulations on privacy and data security could affect the evolution of embodied AI. For example, the proposed EU AI Act encompasses comprehensive rules banning certain applications that pose a threat to citizens' rights and democracy, e.g., emotion/facial recognition technology. Additionally, the non-availability of high-performance processor chips, a market dominated by the US, to Chinese companies may hinder their progress. Further, the non-availability of some high-end machine tools required to make precision parts may slow the process.

What Does This Mean for Commodity Demand?

Given the existing market remains limited, we do not see the availability of critical materials as a near term bottleneck. However, humanoid robots are set to add meaningful demand to critical mineral markets in coming decades. Each robot weighs around 75kg and is comprised mostly of base metals, battery metals and rare earths. Morgan Stanley estimates that each will use, on average, 7kg of copper, 2kg of lithium and 0.9kg of the rare earth minerals neodymium and praseodymium (NdPr). Manufacturers have also indicated 25kg of aluminium will be used in the frames of their designs.

1. Base Metals: Copper and Aluminium In Focus

Copper is used in the battery packs, actuators and wiring of humanoid robots. It is also a key component in the associated charging infrastructure. While the ultimate breakdown of materials in each robot will obviously vary by manufacturer, total copper content could be as high as 9kg per unit. Assuming sales of 46m units per annum, as expected by 2040, would add 400kt of copper demand (1.8% of 2024 demand). Absent a solution for this market's deficit, this is material.

Aluminium will be used in the skeletal structure of humanoid robots due to its strength and lightweight nature. During our recent trip to China, two manufacturers, UBTech and GGII, stated that approximately one third of each humanoid robot's weight will be aluminium – equating to approximately 25kg per robot. Like copper, near term shipments of humanoid robots are immaterial for the broader aluminium market, but by 2040, we expect an incremental 1.4mtpa of demand (1.6% of 2024 demand).

2. Battery Metals: Lithium a Beneficiary but Can This Balance The Market?

Humanoid robots developed to date generally use a lithium-ion battery pack contained within the torso of the robot. Based on an assumed 3kWh average capacity per battery, this results in an estimated lithium content of as much as 3kg per robot. This could add demand of up to a few per cent of recent supply which, while not insignificant, would not be large enough to balance the currently oversupplied market. Modelled out to 2040, the demand stimulus is more material but still not enough to become meaningfully bullish on lithium just yet.

3. Rare Earth Elements: A Red Herring?

Morgan Stanley also estimates that up to 1.3kg of NdPr rare earth elements are required per robot. Rare earths are the critical components in permanent magnets which enable the physical movement of robots via actuators. Each humanoid can include, on average, 40 actuators. Based on Morgan Stanley's forecasts, humanoid robots could drive additional demand of as much as 13ktpa by 2035, or as much as 20% of the current market. When using the even greater 2040 estimates, it appears that humanoid robots could almost double the demand for rare earths. While the prize in rare earths appears large, it is worth pointing out that there is a significant risk of substitution from alternative magnet technologies with cheaper and more plentiful inputs.

How the Tribeca Global Natural Resources Strategy is Positioned

We believe that the best investment opportunity at this stage remains up the supply chain as key humanoid robot developers are either private (except for Rainbow Robotics in Korea and UBTech in China) or are R&D projects under large businesses (Tesla, Nvidia, Apple, BYD, Xiamoi, Xpeng etc). It doesn't get much further up the supply chain than the metals used to make these robots.

The Tribeca Global Natural Resources Strategy remains materially exposed to high-quality bottom of the cost curve base metal producers such as Freeport McMoRan (FCX US) and Alcoa Corporation (AA US). These companies provide significant leverage to the structural deficits in copper and aluminium and the above-discussed demand pull from humanoid robots over the medium-to-long term.

We are more cautious on battery metals and rare earths. As gleaned from a recent trip to China, further supply cuts in the lithium market are required for the currently soft pricing environment to turn around. While humanoid robots will bring incremental demand to the lithium market, we don't think this is enough to balance it just yet. Similarly, while longer term NdPr demand growth from humanoids is compelling, we view that the substitution risk takes the gloss off. In any case, the parabolic nature of humanoid growth provides ample time to monitor trends within this market.

Conclusion

Humanoid robots are real. They are currently being used in industrial production and logistics applications and have a path to broader adoption from 2035. They have been put forward as the next terminal device and, accordingly, have growth projections analogous to EVs from 2013 and smartphones from 2003. Industry leaders and analysts see that these products will become at least as common as cars, and maybe even outnumber flesh-and-blood humans.

As discussed above, the incremental demand pull that humanoid robots will have on commodities such as copper, aluminium, lithium and rare earths is generally limited over the next decade. Given the parabolic nature of their growth, however, humanoid robots will serve to further tighten these markets in the longer term. Our preferred exposure at this point remains base metals rather than battery metals and rare earths, given the already tight nature of the copper and aluminium markets.

The Tribeca Global Natural Resources Strategy remains materially exposed to high-quality bottom of the cost curve base metal producers which provide diversified torque to this thematic.