COWEN

Collaborative Insights
Robotics

AHEAD OF THE CURVE® SERIES

DEUS EX MACHINA, PART III

MARCH 15, 2021

Collaborative robotics removes the physical barriers that have historically separated humans and machines, and is early stage in terms of deployment.

We partnered with cobot pioneer Teradyne and exoskeleton leader Sarcos Robotics to help us create independent market models. We see a $20B+ potential opportunity by 2026.

Our joint survey with our partners at MassRobotics showed nearly universal Covid-related demand spikes at robotics firms, with users asking for new, collaborative applications.

Private investment dollars continue to ramp, from <$1B to over $9B in the past six years, and 2021 is on pace to exceed 2020.

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In Collaboration With
massrobotics

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COLLABORATIVE INSIGHTS

March 15, 2021

VIDEO

▪ Diversified Industrials, Automation & Robotics

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COLLABORATIVE REPORT

DEUS EX MACHINA, PART III - AHEAD OF THE CURVE SERIES + VIDEO

THE COWEN INSIGHT

Part III of a collaborative, multipart series examining the global robotics landscape (see Parts I and II). Robotic development toward more complex tasks is far more symbiotic with human behavior than most likely appreciate. Replacement was always the fear, but increasingly we find the relationship is inextricably intertwined. Part III focuses on human/robot collaboration and augmentation.

We Were Already Moving Here - Now We Move Faster - Joe Giordano

Covid-19 has necessitated changes broadly across supply chains - that concept is well understood - but perhaps nowhere has the impact been so profound as on the next-generation robotics ecosystem. We began to explore this group in Part II as we looked at warehouse/logistics mobile robots. In this report, we go one step further, looking at human/robot interactions and the evolution toward collaborative robotics and human augmentation. In a post Covid world, collaborative robots will help enable socially distanced manufacturing at higher rates of efficiency, and iterations on this theme (like exoskeletons - also explored in detail here) will likely prolong careers of skilled workers, helping address one of the fundamental pain points impacting the logistics and manufacturing sectors today.

We Partnered With Established And Emerging Leaders In Collaborative Robotics And Exoskeletons - See Over $20B Combined Market Potential By 2026

Collaborative robots (cobots) have been around since 2008 when **Universal Robots** (since acquired by TER, who partnered with us for our work here) sold its first robot to a Danish industrial customer. TER is the clear market leader, commanding share north of 60%, but despite the installed base scaling over 10x since 2014, cobot share as a % of total industrial robots remains low, at <5% as of 2019. However, many factors are contributing to a likely inflection point in cobot adoption, including: **1)** a persistent shortage of skilled labor requires manufacturers to maximize production per employee and deploy technologies that can be easily programmed/changed without advanced robotics training; **2)** advances in AI and a broadening cobot ecosystem have substantially increased the type and complexity of tasks that cobots can perform; **3)** post-Covid social distancing realities lend themselves to human/cobot interaction and cellular manufacturing frameworks. Just last month robotics leader **ABB** launched two new cobot families in a clear push toward this theme. We believe that the cobot market could move from <$1B today to over $9B in 2026, if we assume that cobot density (cobots per 10k workers) reaches only 40% of global non-automotive levels.

A ramp of that magnitude also opens up meaningful opportunities across the ecosystem - from gripping technology, AI, vision, tooling, and solutions that allow traditional robots to operate collaboratively - topics we discuss in our report.

The exoskeleton market is much more in its infancy, but is one of the cleanest distillations of the collaborative theme - essentially humans and robots as one. World Robotics estimates the market to be approaching $300MM by 2023 (~40% average growth off their estimated 2020 base). However, our work with **Sarcos Robotics** - a pioneer in powered, full-body exoskeletons - suggests a market significantly larger. Based on our conversations, we see a potential $10B+ US opportunity by 2026. Many designs have military roots (Sarcos was previously part of Raytheon), but have clear applicability in any task where repetitive lifting/moving of heavy objects is required - logistics, mining, maintenance, construction, etc. Advances in battery technology and declines in component costs have significantly reduced power consumption, extended run times, and brought production costs more in line with customer value-add, making commercialization viable. We note that the Chinese non-auto robotics market began to scale post 2009, growing at a ~35% CAGR as density increased. That pattern seems like a reasonable guide. When we then consider the potential for medical/rehab exoskeletons, a market World Robotics estimates is growing by nearly 50% a year to over $400MM in 2023, we consider the exoskeleton market to be one of the most intriguing subsets of next-generation robotics that is likely to see a deployment inflection over the next few years. While market estimates today may be more reflective of addressable than realizable potential near term, the prospects look attractive.

Our Proprietary Survey Shows A Covid-Fueled Acceleration In Customer Interest, Shifts In Focus Toward Robotic Flexibility, And Dollars Continue To Flow In

We partnered with MassRobotics to conduct a survey of nearly 20 global robotics companies and found nearly 80% of participants are experiencing Covid-related accelerations in their business - with over half of those respondents categorizing that strength as 8 or higher on a 10-point scale. When asked about interest in new capabilities not previously offered, ~60% answered collaborative robots and/or autonomous mobile robots. Nearly 80% of end-users surveyed intend to make robotic investments in 2 years or less and ~90% intend to increase the % of total spend toward robotics/automation by 10 percentage points or more over the next 2-3 years. Notably, zero survey participants expect a decrease in % spend toward these applications and implementation cost was a hurdle cited by ~80% of participants. With component costs compressing, conditions appear ripe for deployment.

Private investment dollars are anticipating this trend - annual investment into private robotics/automation companies has expanded from <$1B to ~$9B over the past 6 years, and is already well above that pace through Feb. Public market activity suggests meaningful optionality for emerging competitors as paths to market have expanded and provided earlier access. We expect early movers like TER (the leader in collaborative robotics) to continue building out capabilities and for companies like ABB (undergoing a portfolio overhaul, already established in cobots, and looking to invigorate growth) to be consolidators to complement likely public entry by others.

Favorable Long-Term Trends In Cobots - Krish Sankar

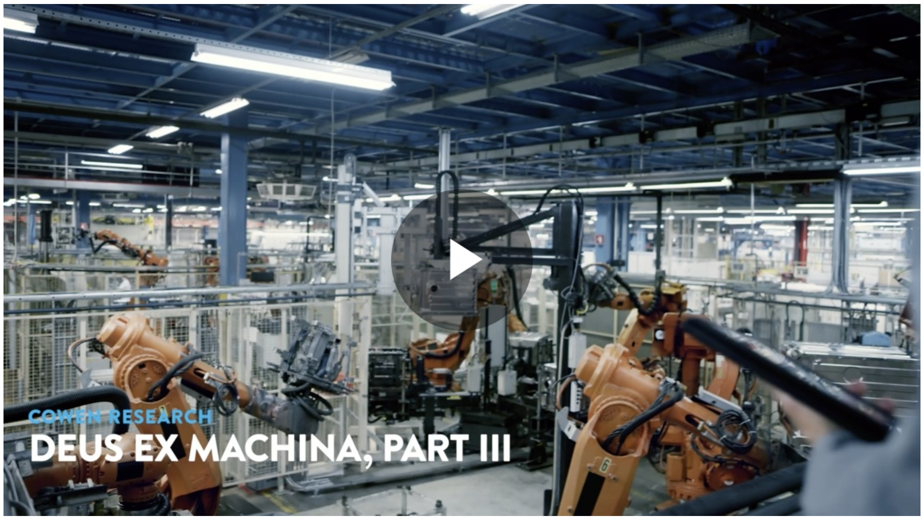
Following a digestion phase beginning in C2H19, off four years of a >40% CAGR, Universal Robot (UR) sales faced additional headwinds in C1H20 as companies adjusted budgets and reprioritized investments amid Covid-19 uncertainty – impacted auto/industrial markets represent the majority of sales. Nevertheless, we view supply chain shocks and social distancing measures over the past year to be net positives over the long run, and expect UR to continue to be a strategic (~30% CAGR) business for Teradyne following a rebound in C2H20. We model CY21 UR rev. growth of +63% Y/Y to $356M, with sales historically back-half weighted.

We believe that software innovation continues to be a key differentiator for UR, particularly in areas such as autonomous bin picking, ease/flexibility of programing, and precise vision processing & motion control as industry competition intensifies. Deepening the competitive moat, UR has focused on 1) growing its sales channel/distributors; 2) expanding the ecosystem w/kits such as the Activenav, which adds 3D sensors, autonomous motion modules, and peripherals to the e-Series cobot for quick deployment and higher machine uptime; and 3) Sub 1 year ROI (est. blended ASPs of $15K-$20K).

Bulls point to UR's industry-leading ecosystem of 700+ distributors, 400+ developers, kits, and software platform as supportive of ~45%-55% market share, growth potential of cobot TAM expansion, and a rebound in auto/industrial end markets. The bear argument points to recent lackluster performance and a risk of growth and margin compression amid increasing competition. Our view: We believe UR's ecosystem is the industry standard and sales will benefit from the expected rebound in automotive and industrial markets this year, while the 50K+ installed base offers the potential for future monetization streams from warranty/service fees, upgrades and/or subscriptions. Acquisitions like MiR/Engrid/AutoGuide add legs to Teradyne's Industrial Automation growth, albeit at a smaller scale.

Rise Of The Machines At DoD - Roman Schweizer, Cowen Washington Research Group

DoD spending on robotics R&D and purchases continues to grow annually and adoption is increasing. The U.S. Army will have the biggest market impact on adoption of robotic systems. In the near term, it is focused on unmanned ground vehicles, ranging from tank-sized vehicles down to backpack-sized robots to perform different missions. Army spending has grown from $20M/yr to over $300M/yr over five years and sizable procurement programs are underway. **General Dynamics**, **Textron**, **QinetiQ**, **Teledyne/FLIR** are early winners in vehicles, but TDY/FLIR also has opportunities in small airborne drones. Sarcos has made headway testing its exoskeletons with the Air Force, Navy and Marine Corps.



Executive Summary – Joe Giordano

Key Investment Considerations for PMs

1. Covid has highlighted the need for collaborative applications to deliver efficiently and safely to increasingly discerning and individualized consumers in a structurally tight labor market – we see a path toward $9B+ in 2026 from <$1B today. (link)
2. Industry pioneer Teradyne should continue to lead and broaden its powerful ecosystem, but a combination of startups and industrial incumbents like ABB are pushing hard into the space. (link)
3. Powered exoskeletons are a logical extension of the collaborative theme that is just now being commercialized. We see a potential $10B+ market opportunity in 2026 – Sarcos is the current leader. (link)
4. According to Washington Research Group defense policy analyst Roman Schweizer, DoD spending on robotics R&D and procurement continues to grow annually and adoption is increasing. U.S. Army will be biggest adopter with General Dynamics, Textron, QinetiQ, Teledyne/FLIR as early winners. Sarcos exoskeletons are being tested by the Air Force, Navy, and Marine Corps for various uses. (link)
5. Our joint survey with MassRobotics demonstrates the clear shift in investor needs toward collaborative applications – 80% of manufacturers are seeing a COVID spike in demand, largely for new applications. (link)
6. Private investment into the "next-gen" robotics and automation sector today is over 9x what it was 6 years ago, with 2021 ahead of 2020's pace. (link)

Part III of our robotics series explores the concepts of robotic collaboration and human augmentation (see Part I on industrial robotics HERE and Part II on logistics/mobile robotics HERE). In this report we partnered with Teradyne – the world leader in collaborative robots (through their Universal Robots brand) – and with Sarcos Robotics, a pioneer in the emerging exoskeleton market, and based on those conversations we developed independent market models suggesting a combined market opportunity of ~$20B by 2026, from closer to $1B today. We also collaborated with our partners at MassRobotics to conduct a proprietary survey of robotics manufacturers and end-users to understand Covid implications on demand trends and user preferences. Cowen's IT Hardware Analyst Krish Sankar provides his perspectives on TER, and Cowen Washington Research Group's Roman Schweizer discusses human/machine integration in defense applications (and we see TDY and APH as best positioned in our coverage to capitalize on his takeaways).

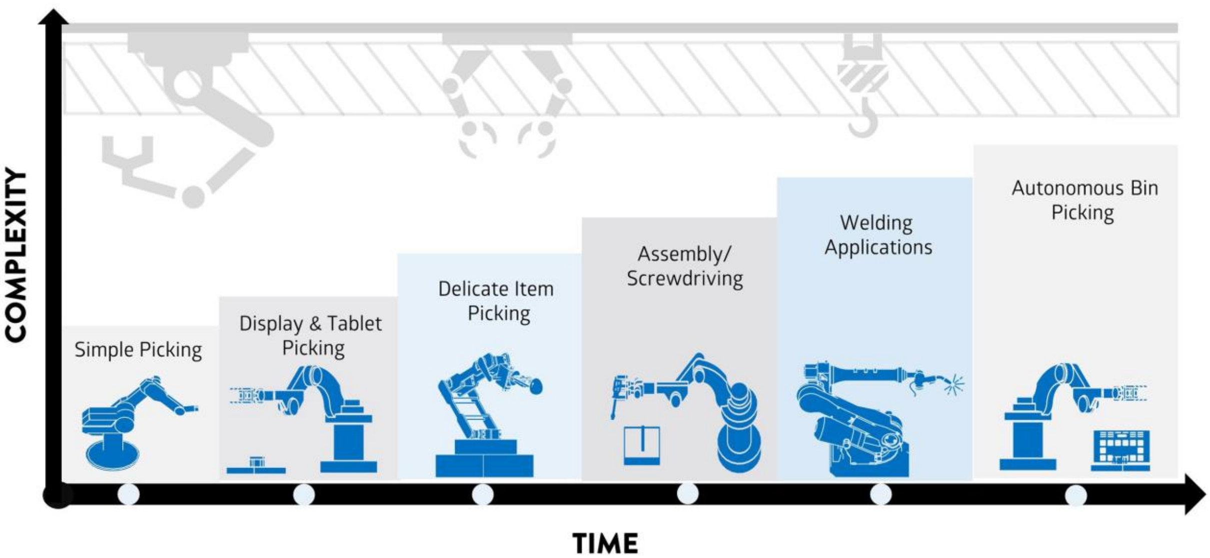
The Covid pandemic has crystalized and accelerated trends that were already in place within the robotics sector. An already stretched labor force was further stressed by distancing requirements and an explosion in eCommerce related demand, bringing tasks like fulfillment front and center within the industrial and consumer discourse. As robots have become more intelligent, more mobile, and more aware of their surroundings, the barriers between robot and human interaction have been eroding. Collaborative robots, and by extension exoskeletons – a literal embodiment of the concept where humans *enter* machines – close the loop and allow the concept of co-working to fully take hold. Survey participants on the robot manufacturing side have overwhelmingly seen a Covid-related acceleration in their businesses, and collaborative and autonomous/mobile applications are now front of mind at customers, forcing suppliers to add capabilities they hadn't previously provided.

It appears the industry has fully bought into the concept – and based on our experience we aren't sure that was the case even a few years ago outside of the leaders. Ease of programming (coding experience not needed), low cost, and quick and flexible implementation coupled with an ever-widening set of capabilities and an expanding "cobot ecosystem" of 3rd party tools and end effectors have created a robust and powerful solution. The "softer side of robotics" is no longer a cute distraction. These are real world tools capable and necessary to deal with today's problems – ones that Covid served to exacerbate, not create.

Investors seem to appreciate this – and we've seen private investment into the robotics sector continue to accelerate – scaling from <$1B to over $9B in the past 6 years. With paths to market as wide and varied as any time in the recent past, that pacing is likely sustainable – and YTD flows support that claim. Market sizing exercises like the ones we performed here are challenging for sectors that are just about to really scale – and in that sense our 2026 targets may be more representative of opportunity sets than realized dollars. At the same time, however, our assumptions are based on penetration rates that pale to that of traditional robotics, so the scale here over time is substantial. The gap between consumer demand and the ability to satisfy it cannot be filled by humans alone. Robotics is the established reconciling item. Until more recently, however, the concept of "working together" hasn't been fully realized. That's changing. We believe collaborative robotics, and by extension exoskeletons, stand as two of the most exciting growth sectors in a field undergoing significant positive upheaval.

Figure 1 Cobot Landscape Overview

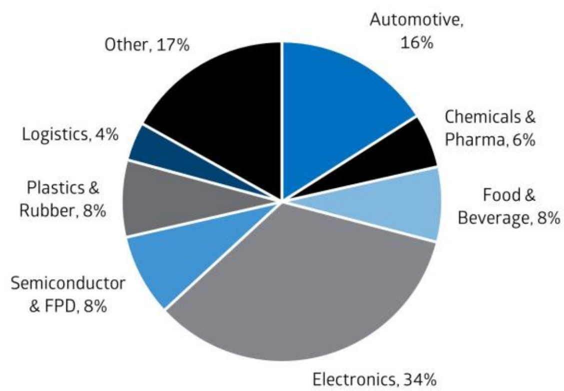
COLLABORATIVE ROBOT APPLICATIONS HAVE BECOME MORE COMPLEX OVER TIME, ENABLING A WIDER VARIETY OF USEFUL APPLICATIONS



RELEVANT STATISTICS

- Cobot Global Density was ~2.6 in 2019 vs Total Industrial Robot Density 113
- $9B+ 2026 cobot market estimate assumes density only reaching 40% of non-auto levels – still long runway
- Cobts accounted for 4.8% of Total Industrial Robot Installations in 2019

COLLABORATIVE ROBOTS BY END-MARKET



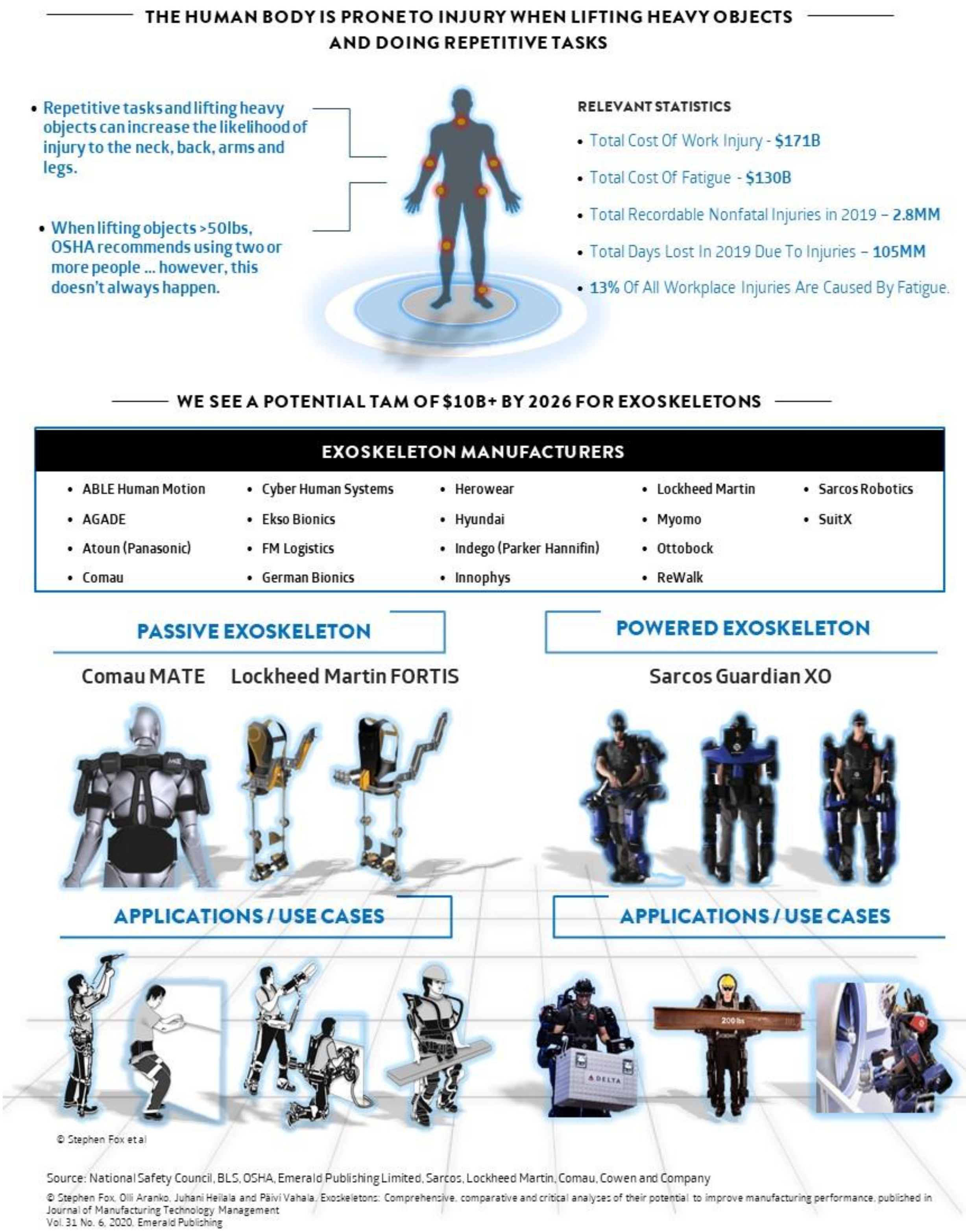
SELECT COLLABORATIVE ROBOT MANUFACTURERS

- ABB
- Bosch
- Comau
- DENSO Robotics
- Doosan Robotics
- Fanuc
- Hyundai Robotics
- Kawasaki
- KUKA
- Rethink Robotics (HAHN Group)
- Staubli
- Universal Robots
- Yaskawa

Sources: World Robotics, Interact Analysis, Company reports, Cowen and Company

Source: Cowen and Company

Figure 2 Exoskeleton Landscape Overview



Source: Cowen and Company

A Journey Toward Adaptability That Is Accelerating And Scaling

See our Cobot Primer HERE

*We partnered with the world leader in collaborative robotics, **Teradyne** (owners of **Universal Robots**), and held in-depth conversations to understand market dynamics, determine potential methodologies to estimate potential market size and explore the rapidly expanding ecosystem around cobots.*

We covered traditional industrial robots in depth in Part I of our series. These machines have been commercially available since the 1970s and are excellent at accomplishing repetitive tasks at high speeds with precision and can handle large payloads. That efficiency, however, comes with drawbacks – given the speed and force, industrial robots are required to be housed away from humans within fenced-in areas of the shop floor, programming has historically required specific training, and changeover times to switch tasks can be significant and result in downtime.

Robotics manufacturers have been able to capitalize on massive investment going on in areas like autonomous driving that are dramatically reducing component costs. In December 2020, we hosted a retail automation virtual conference (recap here). Locus Robotics CEO Rick Faulk highlighted that over the last few years, the price of building a robot has dropped significantly – a similar robot 5 years ago would have cost 8-10x what it costs today.

Advances in vision, sensing, gripping, and programming technologies coupled with expanding needs for flexible robotic operations in close contact with human workers have made collaborative robots commercially viable. An incrementally discerning consumer that desires more customized products, increasingly delivered via eCommerce, has necessitated production environments that are highly adaptable to constant change and allow an already stressed workforce to operate at peak efficiency. Traditional industrial robots will always play a key role, but increasingly manufacturers have needed to "uncage" robotic power and deploy in new ways. Collaborative robots generally handle lower weights (sub 50kg and generally closer to 5kg), but can work seamlessly with human counterparts, be programmed through example or intuitive language with no prior training and are compatible with a variety of 3rd party accessories.

Universal Robots (acquired by TER in 2015 for $285MM) sold the first cobot (the UR5) in 2008. Over the 2008-2014 period they sold ~4000 units, which represented most of the market. UR still commands over 60% share and has grown its installed base to 51,000 units in 2020, shipping 9,000 robots last year. According to data from World Robotics, global sales growth of cobot solutions have materially outpaced overall robotic shipments over the 3 years ending in 2019 (and likely did again in 2020), though penetration still stands very low at <5% of total shipments. With end-market conditions in place that justify and incentivize the use of collaborative tools, and global robotics manufacturers now beginning to more fully participate with their own offerings, we believe penetration is about to scale materially.

Figure 3 Cobot Installations, While A Small Portion Of Industrial Robot Deployments, Are Growing Significantly Faster

Annual Installations Of Collaborative Robots	2017	2018	2019
Cobot Installations	11,107	16,217	18,049
y/y growth		*46.0%*	*11.3%*
Total Industrial robot installations	399,640	422,271	373,240
y/y growth		*5.7%*	*-11.6%*
Cobot Share of Total Installations	*2.8%*	*3.8%*	*4.8%*

Source: World Robotics, Cowen and Company

We See A Potential Cobot Market Of $9B+ By 2026 From <$1B Today

Though cobots have existed for more than a decade, and many manufacturers have rolled out offerings over the years, it wasn't until recently that we have seen more material buy-in to match the leadership shown by UR. KUKA released its first cobot, the LBR iiwa, in 2013, FANUC released its cobot (the CR-35iA) in 2015, and ABB released the first dual arm cobot, the YuMi, in 2015 (and added 2 additional families in Feb 2021). Other companies that have produced cobots include Comau (to be spun-off by Stellantis, the newly formed company resulting from merger of Fiat Chrysler and Groupe PSA), Denso, Rethink Robotics (now part of HAHN Group), Omron, Aubo Robotics, and Yaskawa – for a more extensive list and examples, please see Figure 7. However, our experience at trade shows was that collaborative solutions weren't really being pushed by many of the vendors. An information gap of sorts was still in place regarding when the use of collaborative offerings made sense. As potential applications that could benefit from collaborative solutions have widened, salesforces have become more comfortable with the new offerings, and customer demand has increased, we are seeing a clear shift in messaging and behavior.

In our model we assume annual shipments increase from <20k in 2020 to nearly 300k in 2026. While this pace is ambitious, we'd note that global robotic shipments were nearing 500k units with minimal help from cobots pre-Covid and even our 2026 scenario would leave cobot penetration well below what already exists globally in other applications.

Figure 4 Cobot Deployment Model – See Potential Market Of $9B+ By 2026 Using Modest Density Assumptions

	Cobot Model By Region	2019E	2020E	2021E	2022E	2023E	2024E	2025E	2026E	Notes
A	**Estimated Cobot Denisity By Region (cobots per 10,000 workers)**									
	Europe	5.6	6.9	7.5	8.7	10.7	14.0	19.8	29.2	2019 starting point based on TER volumes and geographic splits and 2026 density assumes 40% of the regional non-auto industrial density
	North America	6.7	8.2	9.0	10.3	12.7	16.6	23.4	34.4	
	Asia	1.1	1.4	2.3	3.8	6.6	11.2	19.1	32.0	
	Other	1.3	1.6	2.4	3.7	6.1	10.0	16.9	28.0	
B	**Manufacturing Workers By Region (MM)**									
	Europe	50.9	51.4	51.9	52.4	52.9	53.5	54.0	54.5	
	y/y % change		*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	
	North America	23.7	23.9	24.1	24.4	24.6	24.9	25.1	25.4	Implied based on World Robotics density for industrial robots by region
	y/y % change		*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	
	Asia	141.8	140.4	139.0	137.6	136.2	134.9	133.5	132.2	
	y/y % change		*-1%*	*-1%*	*-1%*	*-1%*	*-1%*	*-1%*	*-1%*	
	Other	24.5	24.8	25.0	25.3	25.5	25.8	26.0	26.3	
	y/y % change		*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	*1%*	
C = A x B	**Estimated Cobot Installed Base By Region**									
	Europe	28,427	35,308	39,137	45,380	56,472	74,944	107,044	159,264	
	North America	15,793	19,615	21,709	25,120	31,178	41,264	58,788	87,295	
	Asia	15,793	19,615	32,181	52,917	89,912	150,928	255,665	423,020	
	Other	3,159	3,923	5,945	9,341	15,501	25,868	44,004	73,612	
	Global	63,172	78,462	98,972	132,758	193,062	293,004	465,501	743,191	
	y/y % change		*24%*	*26%*	*34%*	*45%*	*52%*	*59%*	*60%*	
D = Difference In Installed Base + Prior Year Replacement	**Estimated Cobot Shipments By Region**									
	Europe		7,449	4,535	7,026	12,000	19,602	33,599	54,361	Assuming 2% annual replacement of prior year installed base, lower than the 4-6% generally seen in industrial robots given younger base
	North America		4,138	2,486	3,845	6,560	10,710	18,350	29,682	
	Asia		4,138	12,958	21,379	38,053	62,814	107,755	172,469	
	Other		828	2,100	3,515	6,347	10,677	18,654	30,488	
	Global	18,049	16,553	22,079	35,765	62,960	103,803	178,357	287,000	
	y/y % change			*33%*	*62%*	*76%*	*65%*	*72%*	*61%*	
E	**Average Selling Price**	$22,500	$23,625	$24,806	$26,047	$27,349	$28,716	$30,152	$31,660	Rising price assumes trends towards more robust, larger solutions (TER ASP $20-50k)
F = D x E	**Estimated Total Market By Region**									
	Europe		$176	$113	$183	$328	$563	$1,013	$1,721	
	North America		$98	$62	$100	$179	$308	$553	$940	
	Asia		$98	$321	$557	$1,041	$1,804	$3,249	$5,460	
	Other		$20	$52	$92	$174	$307	$562	$965	
	Global	**$406**	**$391**	**$548**	**$932**	**$1,722**	**$2,981**	**$5,378**	**$9,086**	
	y/y % change			*40%*	*70%*	*85%*	*73%*	*80%*	*69%*	

Market Sensitivity To Relative Density And ASP

		2026 Cobot Density As % of Non-Auto Density				
	$9,086	**20%**	**30%**	**40%**	**50%**	**60%**
Annual ASP Change	**-5%**	$1,994	$3,252	$4,510	$5,767	$7,025
	0%	$2,856	$4,657	$6,457	$8,258	$10,059
	5%	$4,019	$6,552	**$9,086**	$11,620	$14,154
	10%	$5,566	$9,075	$12,584	$16,093	$19,602
	15%	$7,597	$12,387	$17,177	$21,967	$26,757

Source: World Robotics, Company reports, Cowen and Company

Quick Walk-Through Of Our Methodology

The starting point for our analysis was density – the number of robots deployed per 10,000 manufacturing workers. We relied on World Robotics data for regional and end-market density for traditional robotics and estimated cobot density based on TER regional sales (~45% Europe, ~25% US, ~25% Asia, ~5% Other). Density varies dramatically by region and by application (auto by far the most penetrated).

Figure 5 Cobot Density Still In Nascent Stages

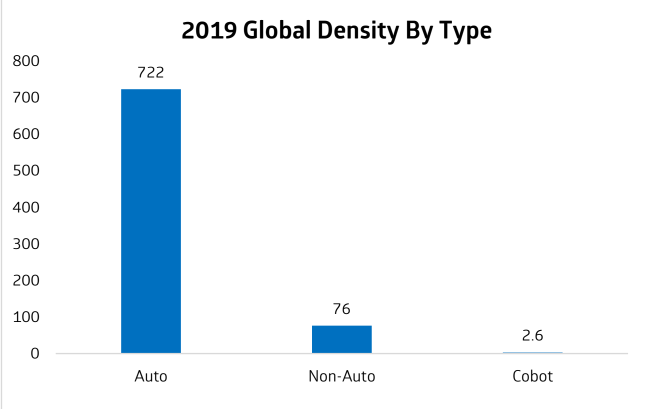
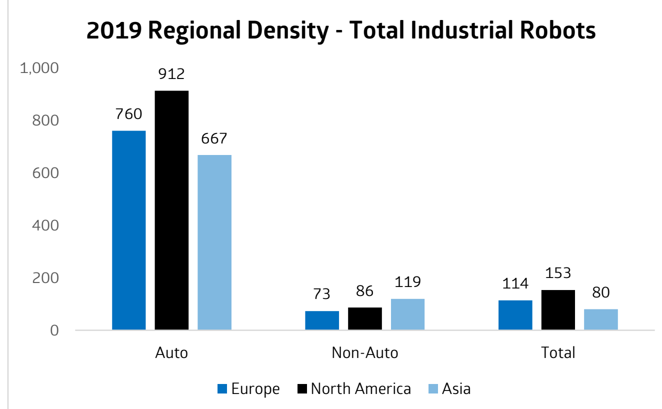


Figure 6 Regional Density Trends Similar Directionally By Application



Source: World Robotics, Company reports, Cowen and Company

We then made assumptions for growth in the manufacturing workforce by region based on recent trends and assumed that average selling price moved higher by 5% annually to account for a trend toward larger and more robust applications (our starting point in 2019 is near the low bound of current pricing ranges). We also assumed that each year, in addition to incremental demand ~2% of the prior year existing installed base would need to be replaced (typically that figure was ~4-6% for industrial robots – we are using a lower assumption given the younger age of the base).

To drive our 2026 estimates, we assume that cobot density by region would reach 40% of the non-auto density observed in 2019. We model an accelerating pace to reach that target. Those inputs imply a market exceeding $9B by 2026 on shipments of nearly 300k.

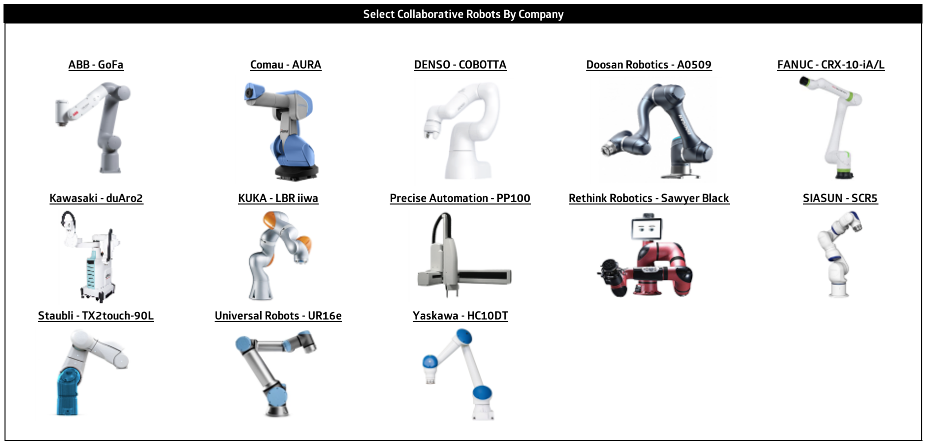
The Race Is On – Manufacturers Beefing Up Offerings

A widening application set paired with clear customer interest is having an impact on the supply side, and we are seeing clear movement from existing robotics players and new start-ups.

Figure 7 Select Collaborative Robots And Specifications By Manufacturer

Collaborative Robot Manufacturers		
ABB	Hanwha	Niryo
Aubo	Hitbot	Pilz
Automata	HRG Robotics	Precise Automation
Bosch	Hyundai	Productive Robotics
Comau	Inovo Robotics	Rainbow Robotics
Denso	ISYBOT	Rethink Robotics (HAHN Group)
Dobot	JAKA Robotics	Rokae
Doosan Robotics	Kassow Robots	Rozum Robotics
Elephant Robotics	Kawada Industries	SIASUN
Elite Robot	Kawasaki	ST Robotics
ESI	Kinetic Systems	Staubli
F&P Personal Robotics	Kinova	Techman Robot
Fanuc	KUKA	Tokyo Robotics
Festo	MABI	UFactory
Flexiv	Megarobo	Universal Robots
Franka Emika	Modbot	Yaskawa
Haddington Dynamics	Nachi Robotics	Yuanda
Han's Robots	Neuromeka	

Collaborative Robot Specifications					
Company	Model	Cobot Type	Payload	Range	Hand-Guided Teaching
ABB	GoFa	6-Axis Arm	5kg	950mm	✓
Comau	AURA	6-Axis Arm	170kg	2790mm	✓
DENSO	COBOTTA	6-Axis Arm	0.5kg	500mm	✓
Doosan Robotics	A0509	6-Axis Arm	5kg	900mm	✓
FANUC	CRX-10-iA/L	6-Axis Arm	10kg	1410mm	✓
Kawasaki	duAro2	Dual Arm SCARA	4kg	500mm	✓
KUKA	LBR iiwa	7-Axis Arm	7-14kg	800-820mm	✓
Precise Automation	PP100	Cartesian (2 or 3-axis)	2-3kg	500-1270mm	✓
Rethink Robotics	Sawyer Black	7-Axis Arm	4kg	1260mm	✓
SIASUN - SCR5	SCR5	7-Axis Arm	5kg	800mm	✓
Staubli	TX2touch-90L	6-Axis Arm	15kg	1200mm	
Universal Robots	UR16e	6-Axis Arm	16kg	900mm	✓
Yaskawa	HC10DT	6-Axis Arm	10kg	1200mm	✓



Source: ABB, Comau, Denso, Doosan, Fanuc, Kawasaki, Kuka, Precise Automation, Hanh Group, Siasun, Staubli, Universal Robots, Yaskawa, Cowen and Company

Universal Robots' UR5 brought robotic automation to small-to-medium sized manufacturers that previously saw robotics as too costly and complex to utilize. The lower price point (in terms of total deployment cost) and less intimidating cobot unlocked a wide variety of use cases in industries stretching beyond the automotive industry. Cobots are used in electronics production, food and beverage, medical and cosmetics, metal/machining, and plastics & polymer manufacturing. The list continues to expand as any industry that can benefit from higher output, better quality, and more consistent production processes is a prime candidate for future adoption. Given the higher level of flexibility of cobots (i.e., they can easily be moved and re-programmed and learn new workflows), the UR5 has been used during the Covid-19 pandemic to produce Personal Protective Equipment. For example, Hurco North America (a machine tool supplier) and EinsRobotics (a UR distributor) used the UR5 to produce N95 respirators and face shields, respectively. Additional detail and use cases can be found in our Primer HERE.

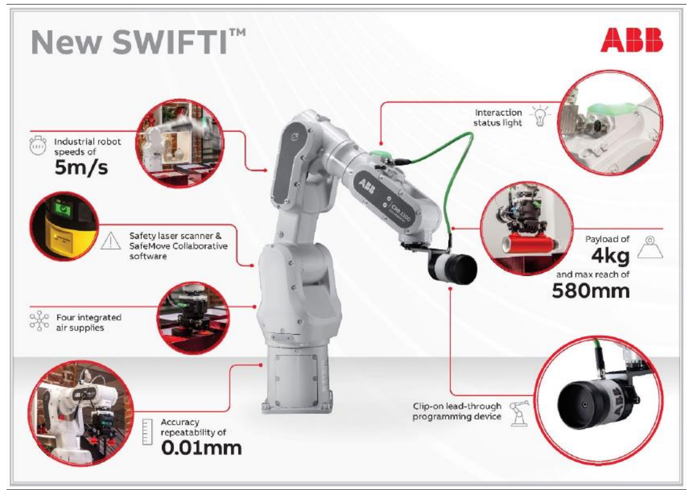
ABB Expands Cobot Offering, Launching The GoFa And SWIFTI In February 2021

ABB recently expanded its cobot offering by introducing two new products – GoFa and SWIFTI. Prior to this launch, ABB offered a single and double arm cobot called YuMi – first launched in 2015. The YuMi was a low payload (~0.5kg) cobot that was used for lab automation, assembly, screwdriving, and industrial testing applications. The YuMi was not suitable for material handling – hence the addition of GoFa and SWIFTI. Both are applicable to a wide variety of end-markets including manufacturing, automotive, food & beverage, logistics, retail, and health care. The newest ABB robots can be used by any industry that requires accurate repetitive tasks, human collaboration, and easy-to-deploy solutions.

ABB believes the addition of the GoFa and SWIFTI give them the most robust cobot offering on the market. ABB executives explained that varying customer needs required two new solutions – one set of customers might desire a robot arm that has a long reach and is suitable for close human/robot collaboration (GoFa), while others want high speed, short cycle times, high productivity and accuracy, with easy programing and no safety fences (SWIFTI).

Figure 8 ABB GoFa Collaborative Robot

Figure 9 ABB SWIFTI Collaborative Robot



Source: ABB

The GoFa is a 5kg payload cobot for material handling with the longest reach in its class at 950mm and designed for close human collaboration. The arm-side interface gives users a new and intuitive programming experience – a loop can be created by novice users in minutes. At the launch event, one of the program hosts learned how to create and program a simple picking application (that was successful) in under 5 minutes.

SWIFTI, as the name suggests, is 5x faster than traditional cobots currently on the market and bridges the gap between collaborative and industrial robots. The SWIFTI is designed for applications that require intermittent human collaboration, such as kitting, changing trays etc. SWIFTI uses an external safety sensor that sets three proximity zones (red, yellow, and green) that automatically adjust the speed of the robot depending on human proximity. When humans are at a safe distance, the robot operates at full industrial speed (green zone). When a human enters the yellow zone, the cobot will slow down to a safe speed, and it comes to a complete stop when a worker is in the red zone. We discussed this concept of applying collaborative functionality on traditional robot assets with start-ups **Veo Robotics**, **Realtime Robotics,** and **Humatics** last year HERE and HERE at our Industrial Tech, Robotics, & Sustainability Summit.

Beyond The Bot – UR+ Ecosystem Underscores The Broadening Of The Theme

UR+ is an ecosystem of EOAT (end-of-arm-tools), accessories, grippers, process end-effectors, and vision equipment. It was launched by Universal Robots in 2016, and by the end of the year they had a handful of products. In a little over 4 years the platform has meaningfully scaled to over 300 products. The structure allows partners to offer products that are compatible with UR's cobots and provides a wide variety of "application kits" that enable a customer to purchase a packaged solution to help accomplish a task. For example, if a customer needs a solution to weld components, an entire ready-to-deploy kit is available for purchase, further simplifying the deployment of cobot applications. It's a mutually beneficial relationship for UR, their partners, and ultimately, the end-users. UR benefits from their customers being able solve problems in a one-stop fashion, and partners don't need to rely on individual customers seeking them out specifically for a particular item/component.

Figure 10 UR+ Component Partner Overview

UR+ Components		
Category	**Products Available**	**Partners**
Vision	Part Location 2D, Part Location 3D, Inspection, and Metrology.	IFM Electronic GmbH, SICK, SOLOMON, Cognex, Datalogic, OMRON MICROSCAN, Micropsi Industries, OnRobot, Photoneo, Pick-It, Robotiq, Asyril SA, 3D Infotech, and SensoPart Industriesensorik GmbH.
Accessories	Cable Guidance, Feeders & Conveyors, Tool Changers	Haption, Vention, igus GmbH, Air Vise & Workholding, Blue Danube Robotics GmbH, Asyril SA, ATI Industrial Automation, Smartshift Robotics, Bagger-Nielsen, SCHUNK GmbH, Robotworld, Cobot Lift Aps, Robo-Gear, Dorner, EMI Corp, EasyRobotics, EVOTEC, Murrplastik Systemtechnik GmbH, FlexxBotics, Robotiq, OnRobot, Southie Automation, GIMATIC S.R.L, LEONI, Millibar, New Scale Robotics, Nordbo Robotics, REIKU, QC Conveyors, and Alumotion.
Handling Grippers	Electric, Pneumatic, Vacuum, Adaptive & Others	ZIMMER Group, OnRobot, Robotiq, SMC Corp, Bimba Manufacturing, Coval, CKD Corp, Soft Robotics, SCHUNK, EMI Corp, Festo SE, JOULIN, Weiss Robotics, HIWIN Technologies, Piab, GIMATIC, SMC Corp, VersaBuilt Robotics, PHD, New Scale Robotics, qbrobotics, and J. Schmalz.
Plug-Ins & Interfaces	Communication Protocol Interfaces, Data Collection & Monitoring.	AIRGATE, Hirebotics, BEHCO, Nutai, Olympus Controls, IXON, Nvidia, Mobile Industrial Robots, 4Each, Rocketfarm, Siemens, VersaBuilt Robotics, Robotiq, and WireTank.
Process End-Effectors	Screw Driving, Riveting, Sanding, Polishing, Cutting, Welding.	FerRobotics, Aim Robotics, ATI Industrial Automation, Dynabrade, Fancort Industries, American Hakko Products, FLEX TRIM, Mirka, Arc Specialties, Visumatic Industrial Products, and WireTank.
Software	Simulation Software, Path Generation and Planning, and Risk Assessment.	Vention, Energid Technologies, ArtiMinds Robotics, Autodesk, SolidSafe, OCTOPUZ, Native Robotics, RoboDK, and Hypertherm.

Source: Universal Robots, Cowen and Company

Figure 11 UR+ Application Kit Partner Overview

UR+ Application Kits		
Category	**Solution Kits Offered**	**Partners**
Assembly	Screwdriving, Nut Driving, Inserting.	WEBER Schaubautomaten GmbH, Atlas Copco.
Dispensing	Gluing, Painting, Sealing.	ROBATECH AG.
Finishing	Polishing, Sanding, Cleaning.	Reliabotics, Tantec, and Robotiq.
Machine Tending	CNC, Injection Molding, Press.	Vention and VersaBuilt.
Material Handling	Bin Picking, Palletizing, Packaging.	Columbia/Okura, Cross Robotics and Machine Automation, Robotiq, and Vention.
Quality Inspection	Mechanical, Optical, CMM.	New Scale Robotics.
Welding	Arc Welding, Brazing, Soldering.	Melton Machine & Control, Computech Manufacturing, Ultraflex Power Technologies, and Vectis Automation.

When UR+ was launched in 2016, the offering was primarily simple grippers. As UR worked to expand the capability of the Simulation Description Format (XML format that describes objects and environments for robot simulators, visualization, and control), their UR+ partners expanded the range of tasks they could accomplish. This truly collaborative partnership continues to drive simpler, more robust, higher value deployments for customers. In our discussions, UR likened the relationship to a group workout where each participant is pushing those around them to perform better. It ultimately shortens the innovation cycle of UR+ partners with end-customers ultimately reaping the benefit.

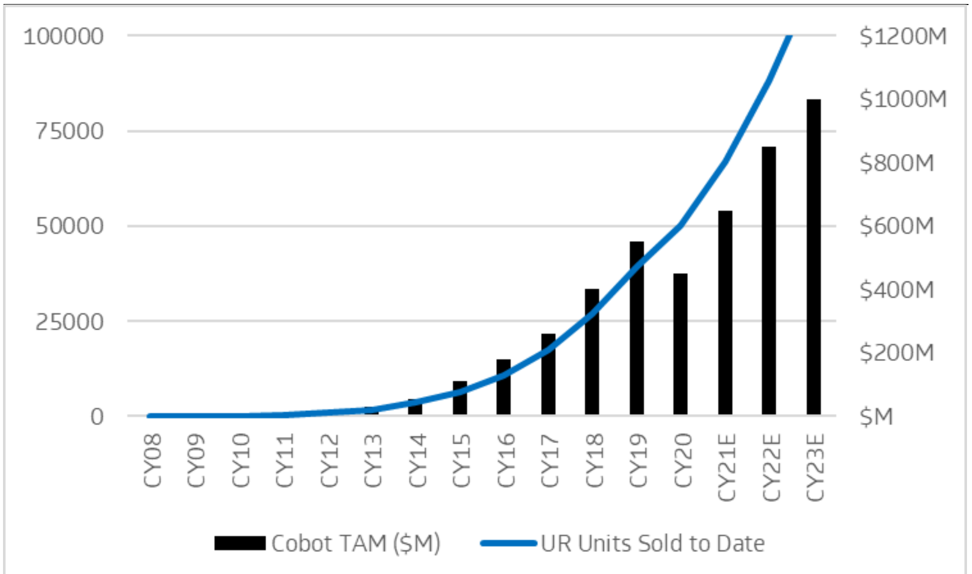
The UR+ community has brought more complex solutions to the market over the last few years. Today, partners like Vectis Automation and THG Automation offer welding application kits, while UR launched a new autonomous bin picking and placement offering called ActiNav. Introduced in early 2020, ActiNav can synchronously handle vision procession, collision-free motion planning, and autonomous real-time robot control.

The automotive industry has historically been the largest end-market for UR and has accounted for >40% of total unit sales in some years. Auto is expected to decline in % terms over time as other end-markets are growing at a faster rate. Electronics has been the fastest growing end-market, particularly in Asia. The most common use case for UR collaborative robots are machine tending and a variety of assembly applications. Screwdriving and welding are two tasks that have been rapidly expanding across a variety of end-markets. For context, the number of UR+ plug-and-play products for these applications have grown by 500% since 2018.

Favorable Long-Term Trends For Cobot Market After Year Of Digestion – Krish Sankar

Quantifying the cobot TAM: Universal Robots estimates that the company's market share is ~50%, which is broadly consistent with the~ 45% to 55% range over the past several years. We think UR's simple teach-to-program UI and fast deployment time remain industry benchmarks. Additional software innovations that also make its new ActiNav Bin Picking solution easy to deploy could further raise the bar and help it maintain 40%+ market share in the coming years. We estimate the cobot market grew from ~$100M in CY15 to ~$500M in CY18 (>60% 3Y CAGR) before cooling off starting in C2H19. With growth expectations reset, we expect the ~$400M-$600M Cobot market to grow at a ~35% 3Y CAGR, reaching a >$1B TAM by CY23+ (>100K UR cobot milestone CY23/24). Cobots are well suited for smaller scale (ROI, ease-of-use) operations such as bin/part picking in the industrial market and as a "manual labor" replacement in the automotive industry in areas prioritizing flexibility & precision such as screwdriving. Most importantly, cobots can be deployed quickly, easily and safely in work areas alongside humans.

Figure 12 Universal Robot to Date Units Sold and Cobot TAM ($M)



Source: Company reports, Cowen and Company

Key trends in the cobot market include: Both a strengthening industrial market and new automotive applications are driving near-term demand; long-term software innovation opens up new applications & addressable markets, low market penetration and secular trends in automation/supply chains/"social distancing" contribute to a sustained >35%E CAGR.

1) Disruption to the manufacturing status quo could benefit UR: Given the ongoing US China trade tensions and the disruption of supply chains due to COVID-19, we believe new attitudes could emerge from manufacturers regarding the re-shoring of manufacturing, especially in the US, as well as strategies to mitigate labor shortages and improve operational and cost efficiencies. In many of the case studies shown, the ROI across several light manufacturing applications was often less than 12 months. In addition to labor cost savings, the increase in manufacturing productivity from being able to add more work shifts and/or lower operating costs add further to the value proposition.

2) ActiNav autonomous bin picking could be disruptive: We continue to believe bin picking can be a disruptive application for cobots in the coming years. A key question is how total cobot solution pricing, including the vision and autonomous software subsystems, compares to current blended ASPs that are sub-$20K. We think UR's Autonomous Motion Module (AMM) that helps the cobot determine how to navigate into the bin to pick, move through the environment, and place the item into the destination machine could be a competitive advantage at this juncture given the level of abstraction it provides to allow easy programming by end users (no expertise needed).

An ActiNav application would only require 6 lines of software code for controlling the cobot whereas traditional programming-based methods could require 240-360 lines of code.

3) Potential services revenue stream from Service360 extended warranties: UR is increasingly offering an end-to-end experience for its cobots including a standard 12-month warranty, free software updates by application, regional support, UR Academy for end user training, and myUR for case/asset management tracking for online support. Post warranty, UR offers the Service360 Basic plan that adds an additional year of coverage and the Service360 Advanced plan that improves on the Basic by including remote and onsite diagnostics as well as free 2-week robot loaners to mitigate any downtime. Pricing is based on how many robots and type of model deployed by the customer. As the installed base grows, we think this could offer an interesting recurring revenue stream for UR.

Figure 13 Universal Robots, The Industry Standard & Future Market Trends

	Universal Robots Competitive Moat		Future Industry Trends
Software			
	Ease of Programing	UR academy; application builders	AI & Vision Recognition
	Flexibility	Application Builder; Tool Kits	Precise Grippers; 3D-Modeling
	Motion control	simple teach-to-program	Higher Payloads, Articulation and Balance
Ecosystem			
	Distributors	700+	New Market Entrants
	Developers/Integrators	400+ Devs; 245+ Certified Parts	Commoditization of Hardware
ROI			
	Low Cost, Quick-to-Market		ASP Pressure, Leasing Programs
Sales Model			
	Cobot Unit Sales ($15K-$20K)& UR Service360		Recurring Rev. Models (charge-per-productivity)

Source: Cowen and Company

Figure 14 Universal Robotics Sales ($M) vs. Y/Y Growth

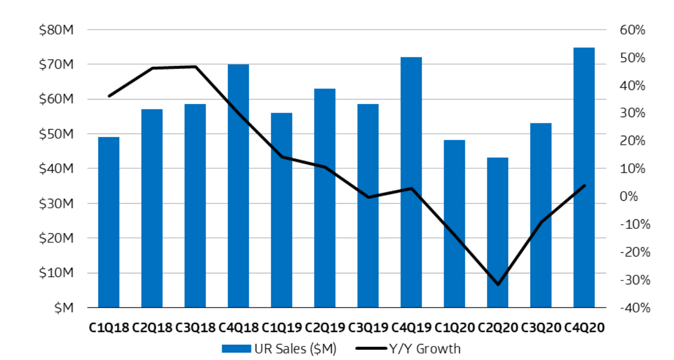
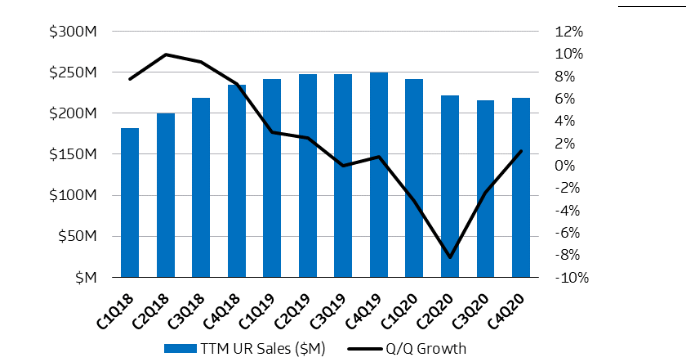


Figure 15 Trailing 12- Month UR Sales ($M) vs. Q/Q Growth



Source: Company Disclosures, Cowen and Company

One Step Further – From Working Together To Working As One – Joe Giordano

Additional background on exoskeletons can be found in our Primer HERE. Information on Sarcos Robotics is included HERE

*Exoskeletons are an extension of the collaborative robotics concept. Instead of working together in proximity, in an exoskeleton (particularly powered exoskeletons – our focus here) the robot actively supports human motion and augments characteristics like strength, stamina, durability, etc. We worked with **Sarcos Robotics** – a pioneer in the space – to develop a deeper understanding of this rapidly evolving and developing sector within the collaborative field. Based on those conversations, we believe the opportunity can exceed $10B by 2026.*

The concept of exoskeletons is not new, and we've seen deployment in applications such as health care/rehabilitation and in passive support functions (like devices used to help workers hold tools overhead for extended periods, etc.). However, the prospects for powered exoskeletons are now coming into focus as advances in battery technology, reductions in component costs, and general acceptance of service-based business models make the prospects economic for both sides. Layering in an aging workforce and challenges to attract adequate new labor supply, these applications make increasing sense.

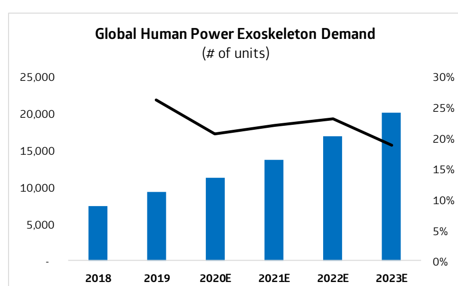
There Are Varying Views Of Market Size And Development – Timing Of The Unlock The Likely Difference

World Robotics sees the global exoskeleton market expanding from <$100MM in 2019 to nearly $300MM by 2023, and while that rate of growth is attractive, the gross size is fairly modest.

Figure 16 Global Human Exoskeleton Demand Expected To Expand To $271MM By 2023

Global Human Powered Exoskeleton Estimated Annual $ Value
(in $ '000)

	2018	2019	2020E	2021E	2022E	2023E
Powered Human Exoskeletons	$56,772	$82,827	$100,480	$125,984	$171,163	$271,687
y/y growth		*45.9%*	*21.3%*	*25.4%*	*35.9%*	*58.7%*



Source: IFR – World Robotics 2020, Cowen and Company

We believe that the advent and deployment of powered exoskeletons is a potential game changer that is not captured in the above analysis given suppliers of these products (like Sarcos) are just now reaching true commercialization.

In order to build out our market forecast we started with identifying sectors and jobs that require consistent heavy lifting and would therefore benefit from powered exoskeletons. Through discussions with Sarcos and using BLS employment data, we identified ~7.6MM jobs in the US that meet the qualification of potential benefit. The company believes that 1 powered exoskeleton for every 10 relevant workers is a fair base estimate for how many powered exoskeletons could be deployed into those markets. In our model we start with a 1 out of 20 ratio and move toward 1 out of 10.

Identifying the relevant worker population and the appropriate exoskeleton/worker ratio only helps form a potential market, as actual adoption rates, at least for several years, will likely remain quite low. From this starting point we assume a 5% initial penetration rate on top of the 1 machine per 20 relevant worker starting assumption. Over time we grow the deployment base by ~35%/year – similar to what we saw in the Chinese non-auto industrial market as robotic deployment ramped – which brings us to a ~15% adoption rate by 2026.

Through their own market analysis, Sarcos believes that typical customers across industries would pay between $100-150k per year for exoskeletons capable of lifting 100-200lbs. <u>At a price point within that range, our model suggests a market of over $10B by 2026. We acknowledge that the ramp to that target is steep even if the variables utilized seem reasonable. However, even if we assume that the potential market never expands beyond 1 out of 20 relevant workers and adoption rates in 2026 stay at only 5%, it still implies a $2B+ US market by 2026.</u>

Figure 17 See Market Opportunity Scaling To Potentially Over $10B By 2026

Exoskeleton Market Size Analysis

	2020E	2021E	2022E	2023E	2024E	2025E	2026E		Notes / Comments
Total Relevant Employees	7,612,420	7,634,542	7,656,728	7,678,979	7,701,295	7,723,675	7,746,121	A	Total US workers in applicable jobs in targeted end markets (logistics, manufacturing, maintenance, construction, etc) - based on BLS data and discussions with Sarcos mgmt.
Employment Growth Estimate		*0.3%*	*0.3%*	*0.3%*	*0.3%*	*0.3%*	*0.3%*		Average expected forward growth from BLS for logistics, mining, and construction sectors
% Of Relevant Workers To Potentially Utilize Exoskeleton	*5%*	*6%*	*7%*	*8%*	*9%*	*10%*	*10%*	B	Assumed potential market - % of applicable workers to utilize a powered exoskeleton
Total Potential Users	380,621	458,073	535,971	614,318	693,117	772,368	774,612	C = A x B	
Average Exoskeleton Price	*$125,000*	*$123,125*	*$121,278*	*$119,459*	*$117,667*	*$115,902*	*$114,164*	D	Expected value perceived by customers in the $100-$150k range based on company survey work. Assume initial cost largely in line with generated value and deflating over time.
Potential Market Size ($B)	$47.6	$56.4	$65.0	$73.4	$81.6	$89.5	$88.4	E = C x D	
Adoption Rate %	*5%*	*5.6%*	*6.5%*	*7.6%*	*9.1%*	*11.0%*	*14.9%*	F	Assumed rate of actual adoption of the potential market
Total Exoskeletons Deployed	19,031	25,692	34,684	46,824	63,212	85,336	115,203	G = C x F	
Y/Y Growth		*35.0%*	*35.0%*	*35.0%*	*35.0%*	*35.0%*	*35.0%*		Growth rate consistent with robotic scaling in China non-auto markets post 2009
Market Size ($B)	$2.4	$3.2	$4.2	$5.6	$7.4	$9.9	$13.2	H = G x D	

Market Sensitivity To Market Potential and Penetration Rate ($B)

Terminal Adoption Rate	Terminal % of Relevant Workers to Potentially Use Exoskeleton: 5%	8%	10%	12%	14%
5%	$2.2	$3.5	$4.4	$5.3	$6.2
10%	$4.4	$7.1	$8.8	$10.6	$12.4
15%	$6.6	$10.5	**$13.2**	$15.8	$18.4
20%	$8.8	$14.1	$17.7	$21.2	$24.8
25%	$11.1	$17.7	$22.1	$26.5	$31.0

Source: Bureau of Labor Statistics, Company reports, Cowen and Company

Poised To Unleash Power On The Market

World Robotics defines a powered exoskeleton as an "active mechanical device that is essentially anthropomorphic in nature, is 'worn' by an operator and fits closely to his or her body and works in concert with the operator's movements". Exoskeletons are viewed as a support structure to ease working conditions, especially in logistical operations in the face of demographic change. There are a wide range of applications for powered exoskeletons that have been demonstrated by prototypes and varying degrees of commercialization:

- **Rehabilitation** – This is currently the primary field of application addressed by today's powered exoskeletons. They can assist wearers recovering from spinal cord injuries or following a stroke, for example.

- **Performance Augmentation** – Various research programs are currently focused on using exoskeletons in defense, rescue, and disaster relief response.

- **Ergonomic Support** – Utilized to reduce lift loads on the spine, hips, shoulders when workers lift heavy objects at work. This is particularly relevant in manufacturing, logistics, and construction end-markets.

Rehabilitation is likely what comes to mind when exoskeletons are discussed; it is the primary field for today's powered exoskeletons. Several products have already received FDA approval for rehabilitation and handicap assistance – EksoNR (Ekso Bionics), Indego (Parker Hannifin), and Rewalk (ReWalk Robotics).

Figure 18 Select Exoskeleton Makers And Product Descriptions

Passive Exoskeletons		
Company	**Product**	**Description**
Comau	MATE	Passive exoskeleton that eases repetitive movements and relieves effort. The MATE replicates the users physiological shoulder movements to provide upper body support.
Cyber Human Systems	Aldak	Lumbar exoskeleton - lower back support when picking and lifting. Helps the wearer lift heavy objects or complete repetitive motions while providing proper ergonomic support.
	Besk G	Helps the wearer complete heavy duty tasks with ease by providing support to the forearms, lightening loads when arms are in an elevated position.
Ekso Bionics	EVO	Arm Support exoskeleton - Eases repetitive movements and relieves effort.
	EksoUE	Passive rehabilitation exoskeleton to help with upper body rehabilitation exercises - allowing the patient to tolerate higher therapy dosage for longer.
FM Logistics	Ergoskel	Passive "ergoskeleton" designed to help warehouse workers lift parcels while reducing physical strain on their bodies.
Herowear	Apex	The Apex is a back-assist exosuit that is designed to reduce strain on the back while fitting like a comfortable piece of clothing.
Hyundai	VEX	The VEX is designed primarily for production-line workers who need to work with their hands above their heads, usually on the underside of vehicles on the assembly line - the exoskeleton helps reduce fatigue in the wearer's arms and shoulders.
Innophys	Muscle Suit Every Muscle Suit Edge	Both the Muscle Suit Every and Edge are passive lumbar exoskeletons that help users lift heavy objects, provides support for demanding positions or completing repetitive motions while providing ergonomic support.
Lockheed Martin	FORTIS	FORTIS transfers loads through the exoskeleton to the ground in standing or kneeling positions and allows operators to use heavy tools as if they were weightless. An advanced ergonomic design moves naturally with the body and adapts to different body types and heights.
Ottobock	Paexo Back	The Paexo Back takes the load off the wearers shoulder while lifting and transfers force through the exoskeleton support structure to the thighs. The device stores energy force when bending and releases it again when lifting
	Paexo Shoulder	Passive shoulder support exoskeleton to assit workers who carry out physically demanding task with their arms raised on a daily basis. The device relieves strain on the shoulder joints and upper arms.
SuitX	ShoulderX	Enables the user to perform chest to ceiling level tasks for longer durations or with less effort. The ShoulderX supports the user's shoulder joint by transferring the load of the raised arm and tool to the wearer's hips.
	BackX	The BackX is a passive exoskeleton that helps decrease strain on the lower back. The device is intelligent enough to not impede natural movements, allowing the user to perform normal activities like walking, climbing stairs, and operating vehicles without restriction.
	LegX	The LegX supports the user's knees allowing them to squat repeatedly for prolonged periods of time with ease. The two modes allow the user to get assistance on the way down and up (smart mode), and can be used like a chair that can be adjusted to multiple heights (locking mode).

Powered Exoskeletons		
Company	**Product**	**Description**
ABLE Human Motion	ABLE	Lower body exoskeleton that enables spinal cord injured individuals to stand up from the wheelchair and walk again.
ADAGE	AGADEXO	Upperbody powered exoskeleton for lifting, and pick and place applications.
Atoun (Panasonic)	Model Y	Powered lumbar exoskeleton - assists with lifting and lower items. The motor reduces burden on he lower back when lifting and holding heavy objects.
	Model Y + kote	Same functionality as the Model Y, but also includes arm support system.
	NIO	Full body exoskeleton for heavy lifting - this product is still under development.
German Bionics	CrayX	The powered exoskeleton supports the wearer's lower back when lifting heavy loads by actively simulating and amplifying movements.
Ekso Bionics	EksoNR	Powered rehabilitation exoskeleton to assist patients to walk. The exoskeleton can also help patients with balance, weight shift, and squatting.
Indego (Parker Hannifin)	Indego Therapy	Allows clinicians to provide individualized gait, spinal cord and stroke therapy. Power is provided to motors in the knee and hip joints that enable gait impaired individuals to stand and walk again.
	Indego Personal	Enables those with spinal cord injury a new level of functional independence and upright mobility in their home and community.
Innophys	Muscle Suit Power	Powered via compressed air, this lumbar exoskeleton helps users lift heavy objects, provides support for demanding positions or completing repetitive motions while providing ergonomic support.
	Muscle Upper	The Muscle Upper is a powered exoskeleton that uses compressed air as its "power source". The exoskeleton helps support the arms and upper back while lifting items up to ~78lbs.
Myomo	MyoPro Orthosis	Powered arm and hand brace that helps restore function to the wearer's paralyzed or weakened upper extremities. This helps the user perform actions and daily activities that might not otherwise be possible.
ReWalk	ReWalk Personal 6.0	The battery-powered exoskeleton controls movement using changes in the wearer's center of gravity. A forward tilt of the upper body is sensed by the system and initiates the first step. Repeated body shifting generates a sequence of steps which mimics a functional natural gait of the legs.
Sarcos Robotics	Guardian XO	Full body powered exoskeleton. The XO can be used for a wide variety of material handling tasks. The exoskeleton moves in tandem with the person, augmenting their strength by a factor of 20x; meaning a person can lift 100lbs and feel like they are lifting 5lb.

ReWalk Personal 6.0

Sarcos Guardian XO

Comau MATE

Innophys Muscle Suit Edge

Source: Comau, Sarcos, ReWalk, Innophys, Company reports, Cowen and Company

The majority of solutions currently available for industrial use are partial exoskeletons (back, arm, or leg support) and very few are powered. While these solutions help reduce worker fatigue and assist with lifting items, they do not exponentially increase the strength of the wearer.

Sarcos Is Making A Viable Powered Exoskeleton A Reality For Applications Outside Of Rehabilitation/Military

Between 1965 and 1971, General Electric, the U.S. Army, and the U.S. Navy attempted to collaborate in order to build a practical powered exoskeleton called the Hardiman. The goal was to build a powered exoskeleton that could "amplify" human strength by a factor of 25 – lifting 1500lbs would feel like lifting 60lbs to the wearer. The project sponsors aimed to create a machine that could move heavy cargo and equipment. The exoskeleton itself weighed 1500lbs and was two suits – an internal skeleton attached to the wearer and an exterior suit that carried objects. The Hardiman never made it past the prototype stage due to its lack of stability and power supply issues. Even though the project was unsuccessful, it was the first attempt to build a powered human-machine interface.

The goal of human-machine interface didn't die with the Hardiman. In 2000, Sarcos (now Sarcos Robotics) accepted a grant from DARPA to design a powered exoskeleton for military applications. DARPA reviewed 14 design submissions and selected the one from Sarcos in 2006. In 2007, the company was purchased by Raytheon and until 2014 was focused exclusively on developing technologies for U.S. governmental agencies. The company was a division of Raytheon until 2015 when Sarcos President and Mission Center Executive Dr. Fraser Smith and technology entrepreneur Ben Wolff led a consortium that took the business private.

Figure 19 GE's Hardiman Exoskeleton Project 1965-1971

Source: Museum of Innovation and Science, Schenectady

Figure 20 Sarcos Robotics Guardian XO Exoskeleton

Source: Sarcos Robotics

After years of development, Sarcos started to ship commercialized version of the Guardian XO full-body exoskeleton to pilot sites. The Guardian XO is the world's first battery-powered industrial robot that combines human intelligence, instinct, and judgement with the power, endurance, and precision of machines. The exoskeleton can transform the way work is conducted – it augments the operator's own strength without restricting freedom of movement, which boosts productivity while simultaneously reducing injuries. The XO amplifies the operator's strength by a factor of up to 20x with a maximum payload of 200lbs. Each arm can lift up to 100lbs each or 50lb per arm when lifting at full extension.

The Guardian XO is designed for use in industries where lifting and manipulation of heavy materials or awkwardly shaped objects is required and can't be accomplished using traditional lift / conveyance equipment. More importantly, given tight labor market conditions, the XO has the potential to level the playing field in terms of physical capabilities. By enhancing the operator's strength and endurance, solutions such as these likely widen the pool of potential candidates to fill physically taxing roles.

In January 2020, Delta Air Lines announced a partnership with Sarcos Robotics to explore new employee technology – Delta is the first company whose frontline employees have worked directly with Sarcos to determine potential operational uses for the Guardian XO. We highlighted in September (HERE) comments by FedEx discussing necessary solutions from the robotics industry to deal with movement of bulky, heavy, and awkward items – typically referred to as "nonconveyable". Such items fit well with the operating profile of powered exoskeletons (among other potential solutions).

Technology And Battery Density Advances Helped Enable The Guardian XO

A wide variety of internal technological advances alongside availability of more affordable components enabled Sarcos' Guardian XO to become a reality. The first iteration of the Guardian XO, the XOS-1, was hydraulically powered and consumed roughly 6,800 watts of energy – roughly equivalent to one-hour use of two 3-ton air conditioners. Today's XO is untethered, battery operated and consumes ~500 watts of electricity, one-hour usage of two 40' HDTVs, a >90% decrease.

Sarcos has made significant internal advancements in proprietary power modulation and control systems. Availability of affordable, critical components like battery cells, actuators, servo-valves, and sensors has also helped make the Guardian XO a more cost-viable solution. Our conversations with industry experts over the last year have yielded similar findings – lower component costs have enabled the proliferation of a wider variety of advanced robotics solutions. The lower component costs have been enabled by advances in, among other things, electric vehicle production and continued progress toward autonomous driving – both of which utilize enabling technologies that are relevant to robotics and help bring production to scale.

Unmanned, AI And Robotics Are DoD Priorities – Roman Schweizer, Cowen Washington Research Group

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The unmanned and robotic revolution is underway at DoD and being driven by the development of crucial "enabling" technologies such as artificial intelligence/machine learning, advanced processors, increased communications bandwidth, better batteries and other subsystems. There is another compelling factor that is pushing DoD – one that hasn't been present for two to three decades – capable and well-funded competitors such as China and Russia have joined the arms race in this and other areas and are pushing DoD to quickly adapt and adopt, or lose. Those countries are also developing competing unmanned and robotic systems as well.

Note From Joseph Giordano:

Teledyne (TDY) is our preferred way within our coverage to play the themes highlighted in this section, with the pending **FLIR** acquisition bringing land exposure in addition to existing air/marine expertise**. APH** is also well positioned to capitalize broadly on a more tech focused military approach given their broad exposure profile there.

There is little question today that advanced unmanned systems, robotics, and artificial intelligence are at the top of the developmental wish list for the Pentagon. These broad technical areas are focusing on science and technology, research and development, and even procurement programs, but they are in varying stages of maturity within the departments of the Army, Air Force and Navy/Marine Corps. Moreover, they span several different categories (air, sea and ground), different systems (vehicles, robots, and cobots), and different missions (combat, maintenance and logistics).

Over the last several decades, unmanned aerial systems or drones have played important roles in U.S. airpower in the form of intelligence collection, reconnaissance and even weapon strikes. And newer generations of airborne drones are taking shape today. Ground and maritime drones and robotics have lagged (with some exceptions, of course) but the Army and Navy have now committed significant amounts of money into developing and fielding unmanned/autonomous systems. The Army is experimenting with prototype "Robotic Combat Vehicles" that come in a variety of sizes. Field testing is underway to develop operations concepts and to set requirements for full-fledged acquisition programs. The Navy is experimenting with its first generations of unmanned ships and submarines that will operate independently for days or months on end and have ranges of thousands of miles. The Navy has ambitious plans to spend billions over the next five years to buy unmanned ships and submarines.

These new systems are also creating change and shaking up the calcified “platform” market structure that has been locked in for decades. Small-to-midsize upstarts, non-traditional suppliers and even technology firms are playing key roles and winning contracts that would normally go to the two or three big players in each segment. These systems are also changing the way DoD thinks about its platforms. Aircraft, ships and ground vehicles – all increasingly driven by software and electronics – may be “optionally” manned in some cases, meaning they might operation with a human crew or might not, depending on the mission and risk.

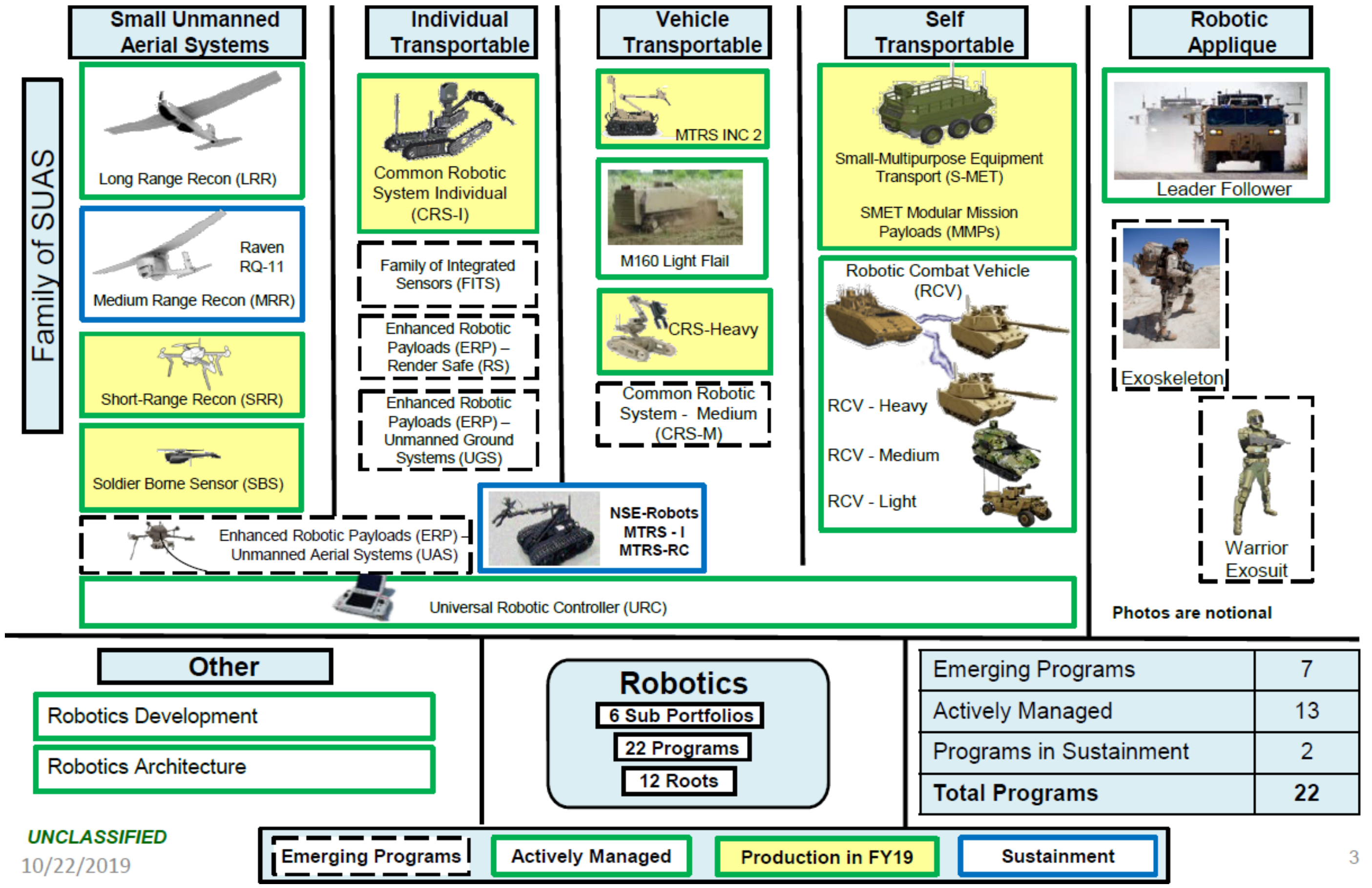
There are important practical and theoretical discussions about the morality and legality of using robots on the battlefield and the use of fully autonomous AI in the U.S. military. The U.S. military and U.S. government would always plan to keep a man in the loop, particularly whenever there was a firing decision or weapon involved. There is concern, however, that some of the U.S.’s more technologically advanced rivals, such as Russia and China won't be constrained by such thinking, and could perhaps field advanced autonomous “killing machines.”

For the purposes of this report, we’ve decided to exclude the DoD’s unmanned aerial systems and the Navy’s unmanned ships and submarines. We’re going to focus on the Army’s unmanned and ground robotics programs and add some discussion where the Navy/Marine Corps and Air Force have also participated. The Army will be the biggest market for ground robotics in DoD and its plans and requirements will play an important role in developing and shaping the market. It appears to be very serious about fielding various types of robotic vehicles and systems and is spending hundreds of millions of dollars annually on R&D and has billions of dollars in procurement planned over the next five years.

Army Unmanned And Robotic Systems

The Army, for its part, will have the biggest impact long term on the adoption of robotic vehicles and humanoid robotic systems. In the near term, it is focused on unmanned ground vehicles, ranging from large tank-sized vehicles down to small backpack-sized vehicles that can perform different roles and missions on the battlefield. We believe the Army is focused on adding unmanned and robotic systems that can increase combat power in the near term. Over the last several decades, it has fielded small robotic systems that help with reconnaissance and ordnance disposal. Those systems are going through generational upgrades and improvements, and even expanding their mission sets. According to the Army, robotics funding just five years ago was about $20M/yr but it has since grown to about $300M/yr. Army procurement for small robotic systems is expected to grow from about $35M in GFY19 to $255M in GFY25. For GFY21, the service asked Congress for $180M to by 2,380 robotic systems and small drones.

Figure 21 U.S. Army Robotics Portfolio Overview



Source: U.S. Army

The Army's main thrust right now in the unmanned vehicle category is centered on two platforms designed to carry weapons and fight in combat. The Robotic Combat Vehicle - Medium, a prototype system made by **Textron**, is a small light tank with a 30mm cannon. The company has produced and delivered four prototypes to the Army for tests and experiments. These systems will be used to develop requirements for a follow-on system to be acquired through another full-and-open competition to be held at a later date. Based on Textron's designs and videos of its “Ripsaw” concept, which utilizes not only ground vehicles, but carries integrated smaller ground vehicles and unmanned air vehicles like a mothership, suggests there could be a quite formidable use case for this kind of system. R&D spending in the RCV has accelerated quickly in recently years going from $70M in FY19 to $121M in FY21. Spending is expected to increase to about ~$145M per year between FY22-FY25.

Figure 22 Robotic Combat Vehicle – Medium (Textron)

Source: U.S. Army / Textron

Another vehicle being designed is the Robotic Combat Vehicle - Light. The U.K.-firm **QinetiQ** is the prime along with Pratt Miller (since acquired by **Oshkosh**). It has developed prototypes and delivered them to the Army for similar testing and a follow-on procurement like the RCV-M. The first RCV-L was delivered to the Army in November 2020. The agreement includes the delivery and support of four RCV-L platforms with procurement options for up to 16 additional RCV-L systems.

Figure 23 Robotic Combat Vehicle – Light (QinetiQ/Oshkosh-Pratt Miller)

Source: QinetiQ

The Army appears to be using a lengthy and methodical development and experimentation process, and it could be some time before significant amounts of money are spent on acquiring this these systems and they're fielded in large numbers. Based on Army funding documents, it appears the earliest formal procurement program for either the RCV-M or RCV-L may not occur until FY24.

Still, there is a new robotic vehicle that is being purchased and is planned to be fielded rather quickly. It is an unarmored support vehicle for infantry squads. Last year, the Army awarded a contract for its first Small Mechanized Equipment Transporter, essentially a robotic "mule" that will carry equipment, ammunition, and other supplies for infantry squads. The Army plans to spend $250M to buy 624 of the **General Dynamics**-built six-wheeled vehicles through 2H2024. SMET is designed to be unmanned or optionally manned, carry up to 1,000 pounds, operate 60+ miles for 72 hours and generate power to charge equipment and batteries.

Figure 24 SMET - Multipurpose Equipment Transport (General Dynamics)

Source: U.S. Army

While the Army is going slow with RCVs, it has used robotic vehicles in important ways since Afghanistan and Iraq for support missions such as reconnaissance and explosive ordnance disposal. These small robots have articulating arms and cameras for tele-operation to inspect tunnels, disarm/activate roadside bombs and provide reconnaissance. The Army is experimenting with a new Common Robotic System – Heavy, built by **FLIR Systems/Teledyne**, and is buying a smaller version, called the Common Robotic System – Individual, built by QinetiQ. It also has an older EOD program called the Man Transportable Robotic System Increment 2, built by FLIR, that is being fielded now.

Figure 25 Man Transportable Robotic System Inc 2 (FLIR Systems)

Source: U.S. Army

Figure 26 Common Robotic System – Heavy (FLIR Systems)

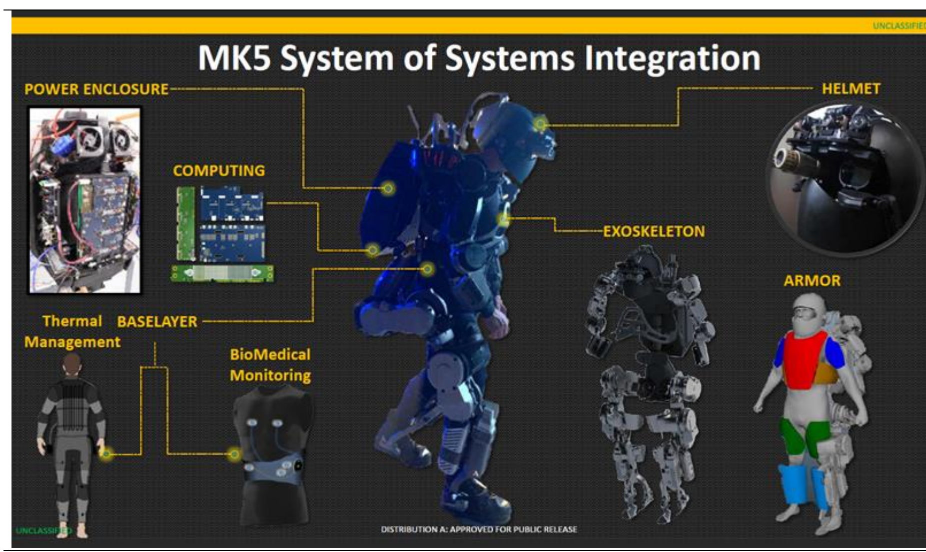
Source: U.S. Army

Figure 27 Common Robotic System – Individual (QinetiQ North America)

Source: U.S. Army

The Army appears to be taking a slower, more deliberate approach on cobots and exoskeletons. While it is funding small levels of R&D (a few $M/yr), we're not aware of any formal acquisition plans for any system. We think the Army is certainly taking a cautious approach, particularly after the failure of a high-profile developmental program at U.S. Special Operations Command. SOCOM tried to build the Tactical Assault Light Operator Suit – dubbed the "Iron Man" suit – but it ended in disappointment.

Figure 28 U.S. SOCOM's Mk 5 TALOS Suit Concept



Source: U.S. SOCOM

We did note, however, that the Army recently released a broad "request for information" to industry for ideas about exoskeletons. The Army is looking for industry to invest and is certainly looking at the best commercial/industrial technology that is available today or will be available in the near future.

> *"The U.S. Army Combat Capabilities Development Command Solder Center (DEVCOM SC) is conducting a market survey to identify sources of supply for exoskeleton technologies. The Army seeks to canvass technologies that can improve Soldier performance during repetitive tasks during logistics support or*

> *movement and maneuver operations. Exoskeletons are viewed by the Army as a promising approach to enable Soldiers to maintain peak performance when designed to improve strength, endurance and ergonomics while maintaining user safety and reducing physical injury risk during various occupational tasks, loads, or repetitive motion.*—U.S. Army RFI February 8, 2021

The Army is admittedly taking "a crawl, walk, run" approach to the development of "Soldier Robotics." We think these technologies will take much longer to field than the vehicles or systems mentioned above. We believe the Army thinks there needs to be longer battery life, perhaps as long as 72 hours, for missions in the field and away from bases. The Army, from what we understand, does not want to be limited to tethered power supplies for operations, whereas that type of system might work in some other cases where the Navy, Marine Corps and Air Force are focused.

The Army continues to look at some robotic systems to augment human performance. These include "soldier touchpoint" exercises at Fort Drum, New York, in 2018 that included the **Dephy** Exo Boot and **Lockheed Martin** ONYX, both of which are lower-body exoskeletons designed to reduce fatigue and offset heavy loads. We are unaware of any plans to field them. According to Lockheed Martin, "ONYX is a lower body exoskeleton designed to improve the strength and endurance of its users. Powered by technology from B-TEMIA Inc., ONYX combines rigid and flexible structures that conform to the human body. Sensors distributed on the exoskeleton report speed, direction, and angle of movement to an on-board artificial intelligence computer that drives electro-mechanical actuators at the knees." A company product sheet says ONYX "is being upgraded to use military-specification batteries that are approved for infantry use, to ruggedize and improve ergonomics, and to incorporate faster actuators that generate more torque at higher speeds."

Figure 29 Lockheed Martin ONYX Lower Body Exoskeleton

Source: Lockheed Martin

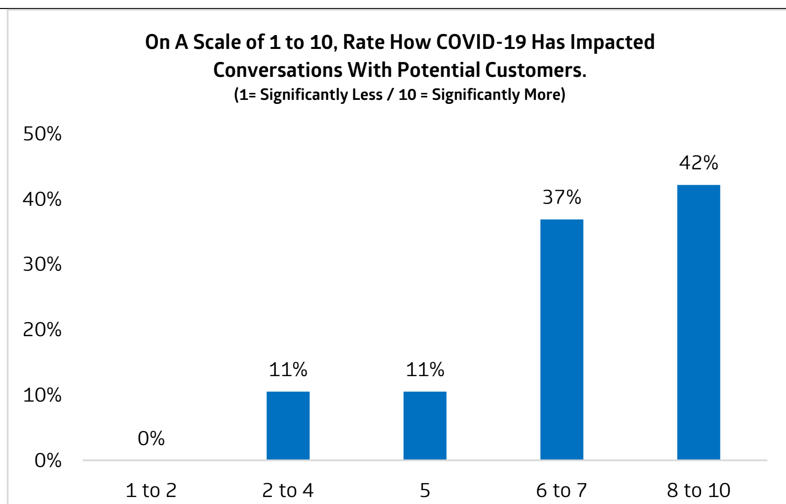
While the Army has taken a more limited approach to individual soldier robots and exoskeletons, the Air Force, Navy and Marine Corps have each in recent years agreed to test **Sarcos** systems. In 2019 the Navy's Puget Sound Naval Shipyard (PSNS) & Intermediate Maintenance Facility (IMF) agreed to evaluate and deploy full-body, powered exoskeletons and man-portable inspection robots, for use in naval shipyards. The Navy said it would evaluate Sarcos' Guardian XO battery-powered full-body exoskeleton and Guardian S inspection robot for use across a wide variety of unstructured, challenging work environments and tasks, including use of heavy items, power tools and inspection of confined spaces. Around the same time, Sarcos announced an agreement with the Air Force for the XO system. In August 2020, the company also received a contract from the Marine Corp for testing with logistics systems. Even more recently the company has won contracts with the Navy to develop a remote-controlled variant of the XO. According to the company, "The new, platform-agnostic, upper-body variant will be adapted to attach to a variety of mobile bases, such as wheeled or tracked vehicles that can operate at height. These include boom lifts, scissor lifts, and bucket trucks to address maintenance and logistics needs." And it has received a contract from the Air Force to develop an artificial intelligence-driven XO upper body that can be taught by hum operators to perform tasks.

MassRobotics And Cowen 2021 Robot Manufacturer And User Survey Results – Joe Giordano

Please see our Covid-related call series HERE

Covid as an accelerant is a theme that has been widely explored, but one that is particularly impactful to a sector like next-generation robotics, which is likely at a tipping point. Nearly 80% of surveyed robot manufacturers suggested they are seeing a spike in customer conversations as a result of the pandemic, with over half of that group categorizing it as substantial. Overall we found 4 main takeaways from our survey work: **1)** End-users are prepared to deploy quickly and increase spend; **2)** manufacturers and users are fairly well aligned on where the puck is moving (toward collaborative applications); **3)** there still is a mismatch in terms of perceived hurdles to clear; and **4)** talent remains a potential bottleneck to scale.

Figure 30 Conversations With Potential Customers Have Increased For Nearly 80% Of Our Participants



Source: MassRobotics and Cowen and Company Robotic Survey March 2021, n=27

End users are clearly looking to deploy and ramp spending – 75% of those surveyed expect robotic deployment in 2 years or less and all participants expected to increase robotics/automation as a % of spend over the next 2-3 years. Nearly 90% expect the increase to be 10+%.

Figure 31 End-Users Looking To Deploy Robotic Tech Quickly…

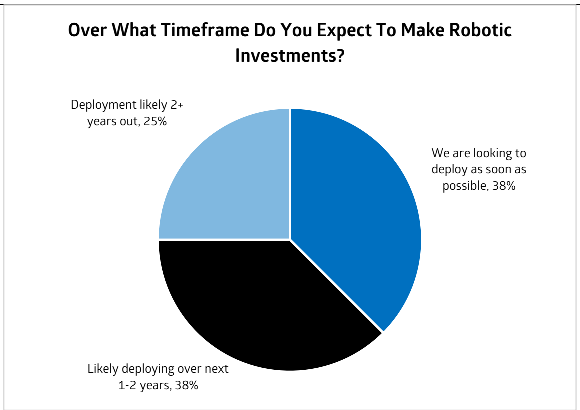
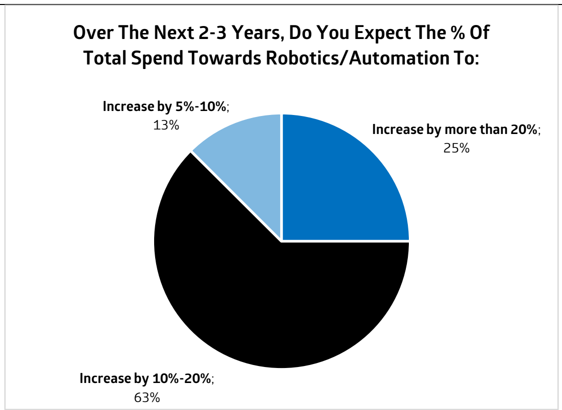


Figure 32 …And Increase Spending In % Terms On These Applications



Source: MassRobotics and Cowen and Company Robotic Survey March 2021, n=27

Over half the manufacturers surveyed have adjusted their offerings as a result of the pandemic, generally toward collaborative applications. End-users were largely on the same page in terms of desired solutions, with telepresence being a potential opportunity.

Figure 33 Manufacturers Cite New Interest In Collaborative Solutions Not Previously Offered…

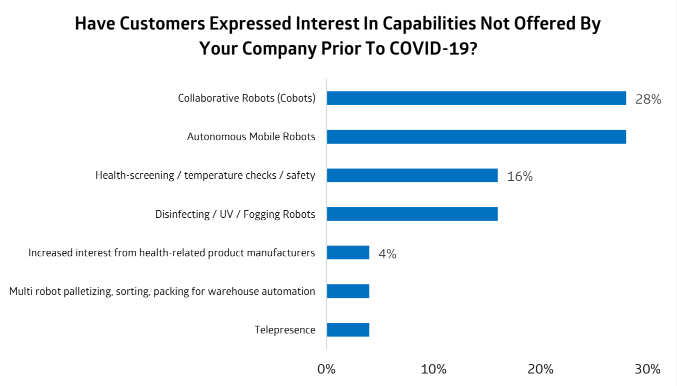
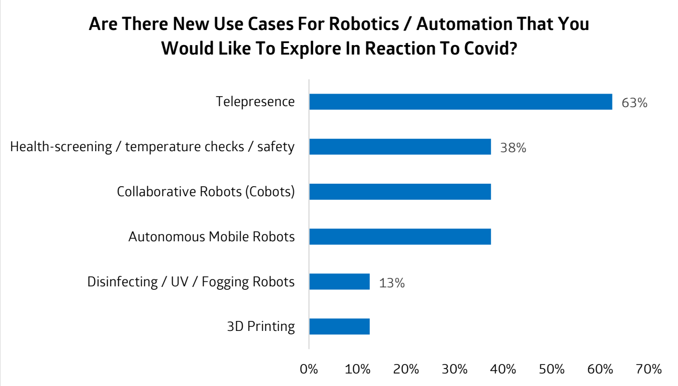


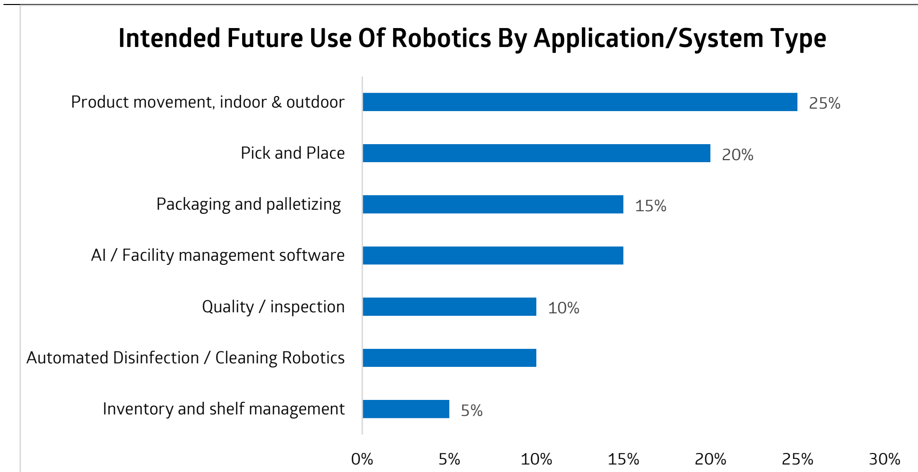
Figure 34 …End-User Results Consistent Though Suggest Potential Opportunity In Telepresence



Source: MassRobotics and Cowen and Company Robotic Survey March 2021, n=27

In terms of the actual applications, logistics-type tasks are clearly in high demand.

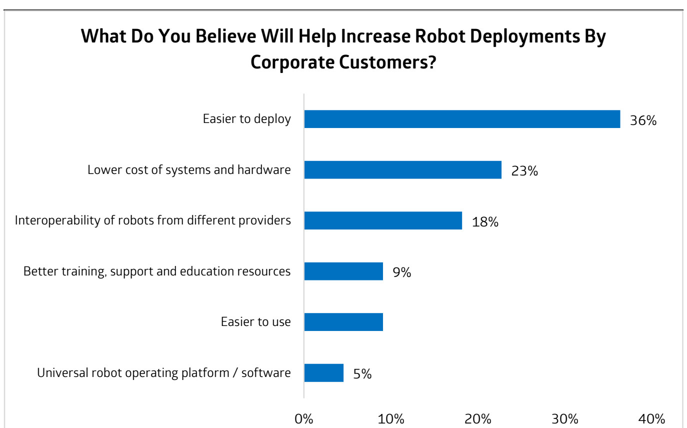
Figure 35 End-Users Clearly Looking To Automate Logistics Facing Functions



Source: MassRobotics and Cowen and Company Robotic Survey March 2021, n=27

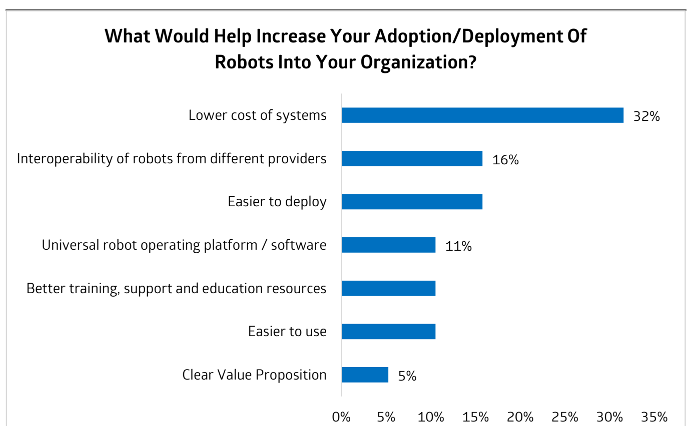
We highlighted in Part II of our series that there appeared to be a bit of a mismatch between what manufacturers view as primary deployment hurdles and what end-users believe. We saw that again in our survey this time. Manufacturers see deployment challenges as the number 1 obstacle toward increased adoption, whereas end-users overwhelmingly cite cost. This sets the industry up well – costs have been and continue to fall, and emerging acceptance of robots-as-a-service (RaaS) business models should make deployment less and less capital intensive.

Figure 36 Manufacturers See Deployment Challenges As Most Significant Adoption Challenge...



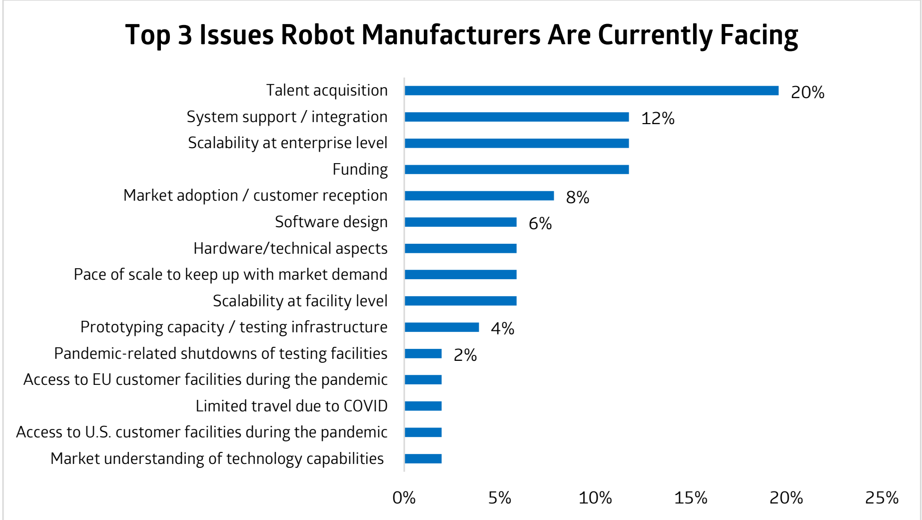
Source: MassRobotics and Cowen and Company Robotic Survey March 2021, n=27

Figure 37 ...While End-Users Cite Cost 2-To-1 As Largest Issue



While we view the mismatch above as wholly solvable given the trend lower in costs, the talent bottleneck could linger as an issue. Manufacturers cited talent acquisition as the single largest issue they are currently facing within their organizations. Given the amount of start-up activity, we'd expect the available labor pool to remain tight.

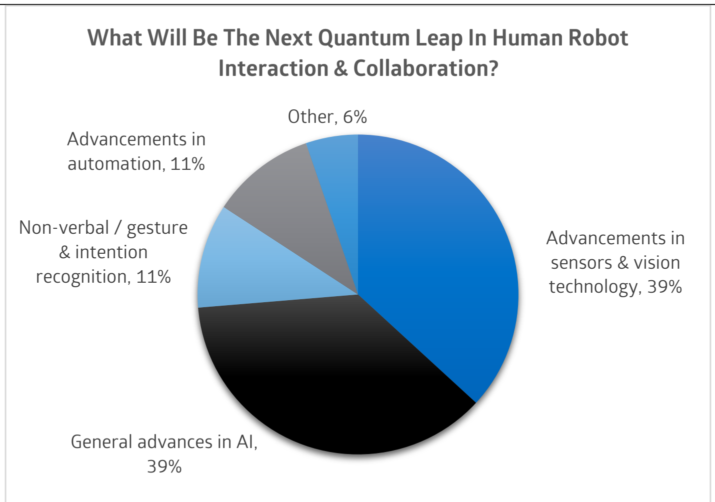
Figure 38 Talent Availability Remains An Industry-Wide Issue



Source: MassRobotics and Cowen and Company Robotic Survey March 2021, n=27

When asked about technologies that are critical to the advancement of the sector, manufacturers skewed heavily toward sensors/vision and AI – at nearly 80% of answers.

Figure 39 Manufacturers Were Clear On What Technologies Will Support Future Advancement



Source: MassRobotics and Cowen and Company Robotic Survey March 2021, n=27

MHI Survey Shows Robotics/Automation Viewed As Most Likely To Positively Disrupt The Manufacturing And Supply Chain Industry

MHI released its annual industry report for 2020 that focused on "Embracing the Digital Mindset". The Survey asked 1000+ participants from the manufacturing and supply chain industries a wide variety of questions surrounding disruptive technologies, adoption trends, challenges the industry currently faces, etc. Talent shortages in the supply chain industry have been magnified by accelerated adoption of digital technologies. 80% of MHI survey respondents believe digital supply chain models will become predominant by 2025.

Robotics & automation was seen as the top disruptive technology force in digital supply chains - 67% of respondents believe it has the potential to disrupt or create a competitive advantage (up from 64% in 2019). Sensors & Automatic Identification was ranked the second area that has disruptive potential. The current penetration rate of robotics & automation was cited at ~39% (up from 32% in 2019) and is expected to reach 58% in the next 1-2 years (vs 51% in 2019), and 73% over the next 3-5 years (vs 71% in 2019), while sensors & automatic identification is currently used by 42% of respondents and expected to reach 82% in 5-years (vs 86% in 2019).

Similar to our own takeaways, talent acquisition remains the biggest issue for respondents, 71% rated finding talent as extremely or somewhat challenging, followed by hiring talent (68%) and retaining talent (59%). The next biggest challenge is offering top performing workers a compelling career progression (57%). Investment for supply chain technologies over the next two years is expected to be over $1MM according to 50% of respondents. Of that group, 25% plan to spend >$5MM and 5% plan to spend >$50MM.

In this survey, like many others, there is concern that robots will displace workers – more so with older generations vs Millennials. We addressed this issue in both Part I and Part II, and we believe that many times the missing part of the analysis is that a combination of robots and humans is <u>required</u> to satisfy demand shifts that the market cannot fulfill with humans alone. The cobot dynamic speaks specifically to the age question/concern posed by the MHI survey. Collaborative applications by nature can help to minimize the age constraint on tasks. Workers can focus on the precision task and allow collaborative robots to do things like lift and place heavy objects. They effectively lengthen the potential career of skilled labor.

The U.S. Remains The Innovation Hub Of A Largely Private, Fragmented Landscape – Investment Dollars Continue To Ramp Despite Covid-19

While collaborative and exoskeleton subsets continue to mature, it remains early stage. The majority of the players are private, and leaders that have emerged have, in most cases, been acquired by large companies looking to gain a competitive technological advantage or expand their robotics platform (Amazon, Shopify, Teradyne). Appetite from private capital is clear, and we've seen annual investment dollars (based on Pitchbook data) expand from <$1B to ~$9B (avg of 2018-2020) over the last 6 years. Based on mid-February data (13% through 2021), private investment has already reached nearly 30% of total 2020 spend.

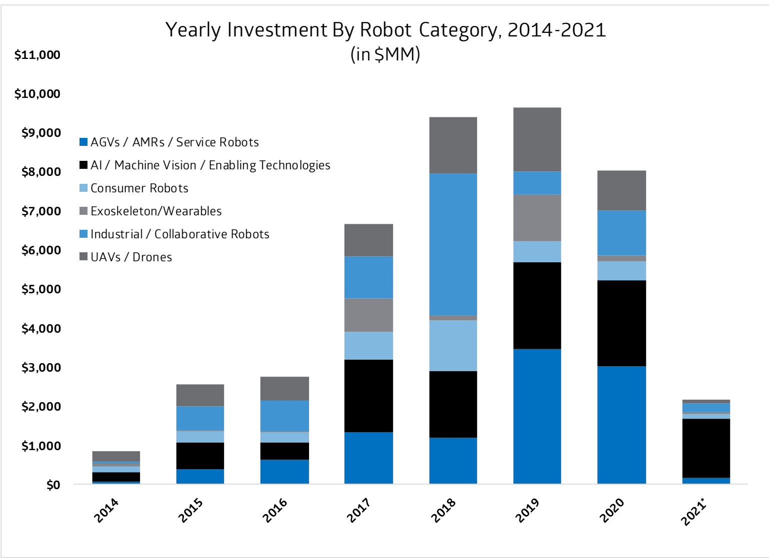
The majority of investment was directed toward North America, which accounted for 51% of all investment spend during 2014-2021 (when we exclude autonomous vehicles, medical, and defense robotics), while Europe accounted for 18%, Asia Pacific ~28%, and Rest of the World ~4%. This is a marked change from the traditional robotics paradigm, where large companies in Europe and Asia (Japan most notably) dominate and represent ~80% of global supply. Incumbents in traditional robotics include ABB, Kuka, Fanuc, Omron, Yaskawa, Kawasaki Heavy Industries, and Saisun.

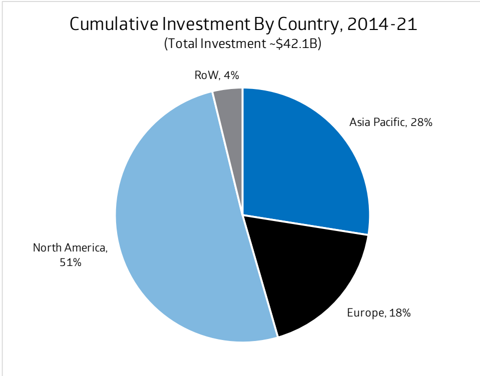
The most significant portion of investment growth has been directed toward the following areas: Enabling technologies, which includes AI, Deep Learning, Machine Vision and LiDAR (26% of spend or ~$10.9B); AGVs/AMRs/Service Robots (24% of spend or ~$10.3B); and Industrial/Collaborative Robots (19% of spend or ~$8.2B). Collectively these groups represent 70% of total investment in robotics during 2014-2021.

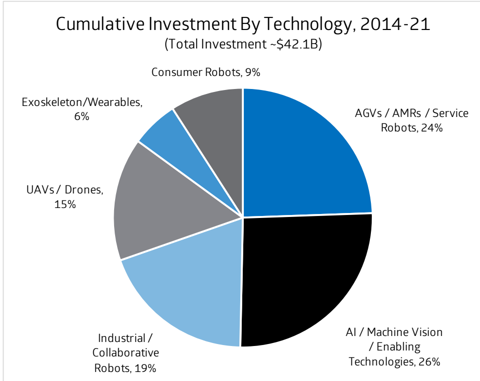
Figure 40 Significant Investment Growth In Robotics Over The Last 7 Years - AGVs/AMRs, Enabling Technologies, And Industrial/Collaborative Robots Have Received the Majority Of Investment Dollars. Fastest Growth From AGVs/AMRs and Industrial/Collaborative Robots.

(in $MM)	2014	2015	2016	2017	2018	2019	2020	2021*	6yr CAGR
AGVs / AMRs / Service Robots	$61	$391	$634	$1,341	$1,202	$3,460	$3,038	$176	92%
AI / Machine Vision / Enabling Technologies	$263	$674	$439	$1,847	$1,713	$2,243	$2,196	$1,521	42%
Consumer Robots	$135	$302	$263	$720	$1,279	$534	$490	$112	24%
Exoskeleton/Wearables	$76	$26	$30	$847	$128	$1,188	$135	$42	10%
Industrial / Collaborative Robots	$46	$621	$794	$1,076	$3,643	$594	$1,143	$233	71%
UAVs / Drones	$283	$546	$609	$832	$1,432	$1,639	$1,046	$91	24%
Total Investment	**$865**	**$2,560**	**$2,768**	**$6,662**	**$9,397**	**$9,657**	**$8,046**	**$2,175**	

*YTD as of mid-February 2021







Source: Pitchbook, Cowen and Company

Looking closer at the country investment for our two subject segments of robotics (exoskeletons and industrial/collaborative robotics), we found that North America accounts for the majority of investment into exoskeletons (57% or ~$1.4B) and slightly trails Europe in industrial/collaborative robot investment (North America ~38% or ~$3.1B vs Europe 40% or ~$3.3B).

It's worth nothing that investment in North American industrial/collaborative robotics significantly outpaced investment from all other regions during 2020 and accounted for nearly 70% of total spend for this category of robotics. We find a similar dynamic in exoskeletons/wearables, as North America accounted for >80% of spend during 2019-2021.

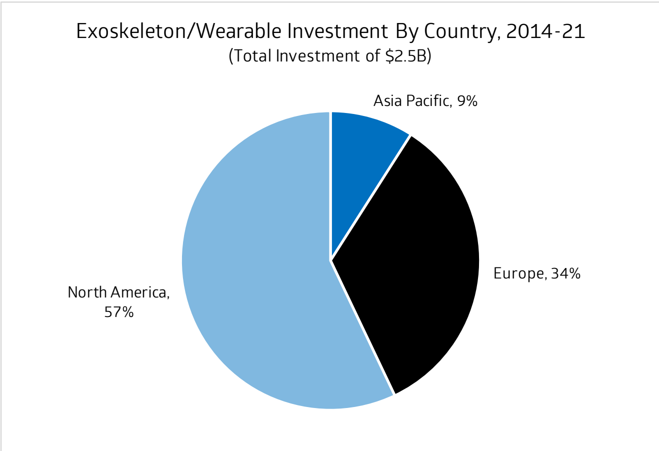
Figure 41 North American Investment In Industrial/Collaborative And Exoskeletons/Wearable Robotics Far Exceeds Rest Of The World During 2019-21

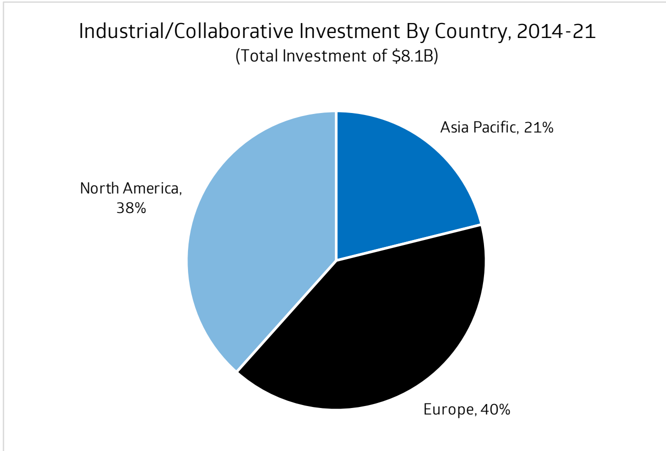
Exoskeleton / Wearable Annual Investment By Country

	2014	2015	2016	2017	2018	2019	2020	2021	Total
Asia Pacific	$21	$7	$2	$7	$23	$145	$18	$0	**$223**
Europe	$0	$4	$0	$762	$7	$7	$56	$0	**$838**
North America	$55	$15	$27	$78	$97	$1,036	$60	$42	**$1,410**

Industrial / Collaborative Robots Annual Investment By Country

	2014	2015	2016	2017	2018	2019	2020	2021	Total
Asia Pacific	$21	$159	$233	$471	$375	$141	$227	$96	**$1,722**
Europe	$2	$340	$504	$107	$1,844	$231	$141	$130	**$3,299**
North America	$24	$122	$58	$499	$1,424	$221	$774	$7	**$3,130**





Source: Pitchbook, Cowen and Company

Primer – Collaborative Robots, Use Cases, And Enabling Technologies

Collaborative Robots (cobots) at their core are designed to operate seamlessly and safely next to human workers. The first Collaborative Robot was sold in 2008, the UR5 designed and built by Universal Robots. The buyer was Linatex, a Danish supplier of technical plastics and rubber for industrial applications, to automate CNC machine tending. It was the first time a robot was deployed directly alongside the employees and the company was able to program the robot on their own using a touch screen, and with no prior programming experience. The total experience was a significant departure from that of traditional industrial robots.

Cobots differ from industrial robots in their design and specs in a variety of ways. Cobots move more slowly and are designed to stop when they come in close contact with a human with the use of force sensors. Industrial robots, by contrast, are faster and more precise in their motion but require safety cages and are not designed to be in close contact with humans. Cobots are flexible in their deployment given the ease of programming and can be taught by example. They are also not fixed in their location or application and can be easily redeployed as needed. Industrial robots typically are fixed in a location, have their own programming language, and require a trained programmer or integrator to be installed.

Figure 42 - Cobots Versus Traditional Industrial Robots

Attribute	Collaborative Robots	Industrial Robots (Articulated)
Motion	Slower but easier to use	Fast and precise
Price	Low total deployment cost, though bots generally more expensive on per payload basis ($10-50K)	High total deployment cost (typically more than $100K) but higher payload potential
Flexibility	Highly flexbile, can be redeployed	Higly inflexible, fixed once installed
Ease of Installation	Easy to install, hours or days	Hard to install, weeks to months
Programming	No programming experience required, can be setup manually or with a tablet	Need programming experience, training or an integrator/company representative
Integrator required	No, in most cases	Yes, in most cases
Safety	Designed to work safely alongside humans, stops when it comes in close contact	Requires cages or cells, safety precautions have to be taken, may not stop when humans approach it

Source: Cowen and Company

For background on Sarcos Robotics see **HERE**

Exoskeletons are a specific sub-segment of collaborative robots given that they directly augment human capabilities and are operated by humans as opposed to being preprogrammed and aware of surroundings like cobots. Exoskeletons can be thought of as “augmentation robots” and represent different types of wearable robotic suits. The two main types of exoskeletons are passive and powered. There are also various form factors that are fitted to different body parts (upper, lower, full body, extremities) and each is designed for different tasks and use cases. Exoskeletons offer autonomous power, mobility, superior maneuverability, dexterity, and endurance.

Powered exoskeletons amplify the user’s physical abilities by combining human intelligence, judgment, and intuition with the strength and precision of the robot. They are either tethered (connected via wire to a power source) or untethered (battery powered) and most are full-body suits. They work well in structured and unstructured environments and help workers complete difficult tasks such as lifting heavy payload objects. Full-powered exoskeletons have seen significant advancements recently in capabilities, packaging, and commercial viability.

Passive exoskeletons are non-powered, partial-body robots designed to reduce the physical strain that comes from tedious repetitive tasks by distributing the force throughout the frame using dampers, springs and other materials to transfer, store, and release the transferred energy from the specific task.

Examination Of Use Cases

Manufacturing encompasses a broad range of industries and products, including automotive, electronics, metals, chemicals, and food & beverage. Collectively, these industries tend to have high adoption of automation solutions and robotics, especially the automotive and electronics industries. More recently, these trends have accelerated even more as more companies embrace automation to accommodate faster production and delivery times, customized solutions, varying batch sizes, lower costs, and more frequent model changes. Cobots provide a lower total cost solution to the more traditional fixed assembly line and industrial robot solutions.

These trends have been accelerated by the recent Covid-19 pandemic, which highlighted limitations to the current supply chain architecture and the importance of having flexibility and social distancing in place. As a result, many companies have adopted (or are actively considering adopting) a more flexible and automated manufacturing system.

Cobots are a key enabling technology of flexible manufacturing and Industry 4.0. They are lower cost compared to large industrial and articulated robots (in terms of total deployment cost not on a per payload basis), more flexible (can be redeployed for multiple use-cases), easier to install as they don't require an integrator or programmer, and can be installed without interrupting existing setups. Workplace safety is also enhanced by letting robots handle the repetitive, sometimes dangerous, tasks while allowing human workers to focus on more value-add activities.

Cobots can help companies achieve a Flexible Manufacturing System (FMS) by working closely with human workers. An FMS is a highly automated technology machine cell consisting of one or more processing stations, interconnected automated material handling and storage systems, and controlled by a DCS. FMS is suited for mid-variety and mid-volume production. It's considered flexible because it can process different parts and styles simultaneously, design and quantities of production can be adjusted to suit demand, and it can react to changes in product specifications. In a world of lower volumes and higher customization, FMS is particularly attractive.

Collaborative robots can provide support in many industrial and manufacturing applications such as pick & place, material handling, assembly, coating, and quality inspection while also avoiding fencing and caging.

Use Cases In Manufacturing:

- **Assembly** such as screwdriving, parts placement, and insertion, which can reduce assembly times, increase production speed and efficiency. Cobots can work alongside human workers and speed up the process of assembly by performing strenuous and harder to do tasks while freeing up workers to perform more value-add jobs. These are tasks that workers typically don't like to do and, in some cases, can be dangerous.

- **Welding** including Arc, TIG, laser, MIG, ultrasonic as well as soldering and brazing. Advantages include reduced production downtime, less wasted material given higher precision, and increased safety. Many welding cobots can be trained by a welder by simply guiding the robot manually. Cobots also have the benefit that they can weld for extended periods of time without fatigue becoming a factor.

- **Dispensing** such as gluing, sealing, and painting. Cobots offer built-in force and torque sensing for precise placement of fluid and reduction of waste.
- **Machine Tending** such as CNC, injection molding, ICT. This relieves machine operators from physically demanding and repetitive work and at the same time increases workplace safety by reducing injuries.
- **Quality Inspection** such as testing, inspecting, and measuring. Cobots can integrate vision cameras such as CGNX products and have the flexibility to be placed at different stations.
- **Finishing** such as sanding and polishing, assuring the right force even in curved and uneven surfaces.

Figure 43 UR Cobot Used For Screwdriving In Auto Assembly Line

Figure 44 UR Cobot With An Integrated Cognex Camera

Source: Universal Robots

Heavy industry includes construction, metals, mining, and oil & gas. In most cases, the workplaces in these industries are unstructured, have uneven surfaces and contain obstacles and debris. This added layer of complexity has resulted in robotics adoption being slower since the technology required needs to be more advanced and complex. This segment represents the end-markets with the lowest robot penetration, at less than 1% of market share. It will likely remain slower in its adaptation but also represents the largest growth potential as newer technologies show promise for efficiency and productivity improvements and companies realize the potential.

The construction industry is ripe for robotics penetration because productivity hasn't increased in the past decades, while others like manufacturing and retail have seen 1500% increases. It's also very manual-labor intensive, unsafe in many cases, and robot deployment is extremely low. Increases in safety, reduction of injuries, and mitigation of labor shortages were identified as opportunities where robotics can help. Exoskeletons, both passive and powered, allow workers to carry more weight and work longer and safer. For more detailed information, see our takeaways from our MassRobotics Construction Robotics Conference here.

Use Cases In Construction & Heavy Industry:

- **Pre-fabrication** of walls, floor panels and other components. This is similar to how manufacturing lines operate, increasing efficiency and lowering construction time and cost.
- **Automated welding** of roof decking – autonomous welding machines could be programmed to traverse the roof and drop spot welds every few feet as decking is put into place manually.
- **Site surveying**, mapping and progress monitoring using outdoor AMRs equipped with vision sensors that can help assist with site scanning. These can also be used to paint layouts using 3D CAD models on foundations more accurately than humans.
- **Dry wall installation** using industrial robot arms with specialized end-of-arm tools.
- **Brick Laying,** companies such as *Construction Robotics* offer a brick laying robot for onsite masonry construction.
- **Carrying heavy pieces or equipment** with the use of exoskeletons such as *Sarcos*.

Logistics and eCommerce can benefit from the use of cobots in various material handling applications. The sector has the combination of a tight labor market and high injury rate (4.8 per 100 workers, compared to national average of 2.8) which makes it particularly attractive for automation and robotics deployment. Last year we examined the sector more closely and particularly the use of AGV/AMRs here. Cobots can help relieve workers from repetitive and arduous tasks in logistics, such as lifting large and heavy packages. Additionally, they can help address labor problems like shortages and typical seasonality.

More recently, behavioral shifts as a result of Covid-19 have only served to accelerate the trends for eCommerce share of total retail spend, as consumers flocked to online channels to purchase all type of goods. Newly implemented social distancing standards likely skew the percentage of "work" needed to be done by robots (as opposed to traditional labor) to comply and maintain a given amount of output. According to the U.S. Census Bureau, in 4Q20 eCommerce accounted for 15.7% of retail sales, a significant increase from 11% in 2019 and a 32% increase versus 4Q19. Expectations are for this share trend to continue, as these actions likely turned into habits given the length of the pandemic and lockdowns, so the pressure for companies to automate will persist.

Use Cases In Logistics/eCommerce

Material Handling

- **Bin Picking** is where a specific order selection typically takes place and requires the combination of grippers, machine learning, and vision systems to be performed satisfactorily. For large orders, products can be picked and aggregated.
- **Packaging and Palletizing** includes picking up finished products and placing them inside packages, as well as moving the packages to pallets.
- **Kitting** is the process of combining multiple SKUs into a single package, by aggregating orders into a single one, and creating a new SKU. It allows the

warehouse to reduce costs, streamline packaging and shipping, and improve inventory management.

- **Labelling** refers to placing labels with barcode and identification information on a package in order to identify the products inside the package effectively.
- **Material handling** workers can be relieved of physical strain and repetitive tasks by using exoskeletons for carrying large objects.

Medical and Lab applications include using cobots to increase productivity in testing, sampling, research, and pharmaceutical manufacturing. By automating repetitive tasks such as placing samples in testing machines and tube racks, scientists can focus on more important activities and aspects of their research. It's important that cobots in the medical and lab research fields have high precision, given smaller size of the objects, and size of the cobot is also important given that labs are not typically large environments. They also have to be designed to work in a variety of temperature and hygienic environments.

Figure 45 – A Cobot Used In A Lab For Testing Blood Samples

Source: Universal Robots

Enabling Technologies That Help Make Industrial Robots Human Friendly

Outside of collaborative robots that are purpose built to be human friendly – companies are working on a wide variety of solutions to make industrial robots safer and remove them from fenced off areas of manufacturing/production lines. Technologies range from sensor skins to trip-wire type barriers that will stop or slow down an industrial robot when a worker crosses into an "unsafe" area. We explore these technologies in greater detail below.

Microlocation is an important enabling technology of collaborative robots because of the required precision for certain tasks as well as the need for operating safely alongside human workers. Microlocation uses a combination of software, sensors, and

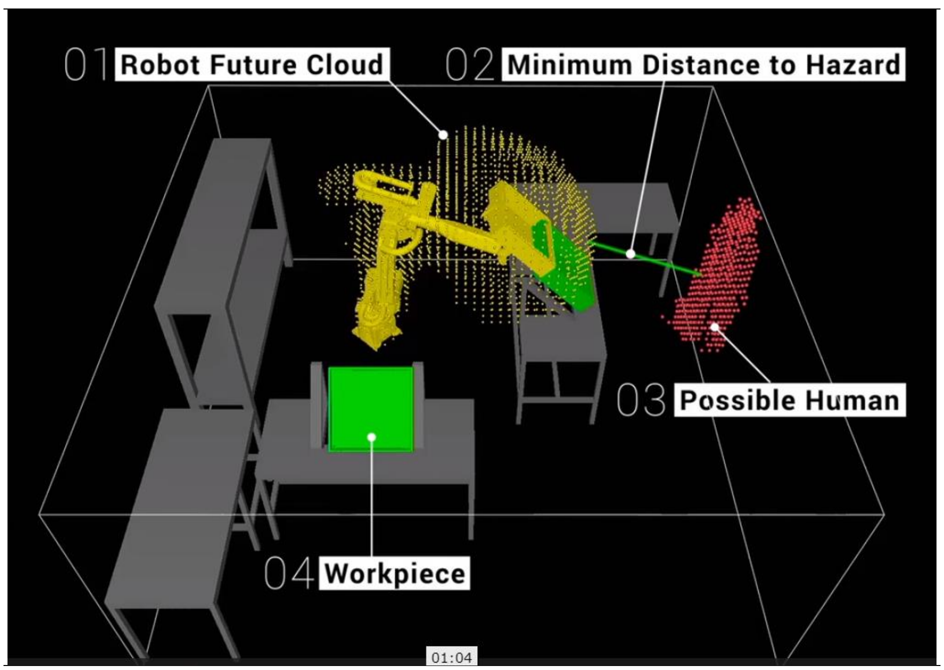
AI to locate something on a scale of meters to millimeters. Companies like Humatics, Realtime Robotics and Veo Robotics are focused on this application in various aspects.

Humatics offers a solution called Milo Microlocation System, which uses a base station and a collection of transponders to determine the exact location of objects in relation to each other and provide seamless coordination between people, machines, robots and infrastructure using real-time precision positioning. The information is aggregated and transmitted to a PLC, robot controller, or a human worker with visualization tools. We note, however, that Humatics has shifted its primary focus for its technology toward rail/subway assets that are challenging to monitor accurately in real time given physical obstacles.

Realtime Robotics is platform for automation that is simple and extensible and has interlocking features that enable customers and system integrators to apply flexible robot control technology to broader applications. The technology is a combination of proprietary software and hardware that enables real-time motion planning. The company enables robotics and automation through a combination of improved basic sensorimotor capabilities, ease of programming and design and safe human-robot collaboration.

Veo Robotics offers Free Move, a 3D comprehensive safeguarding solution. It makes the workplace of human and robot collaboration safer, easier to design, more flexible, and integrated. It uses custom 3D time-of-flight sensors positioned on the periphery of the work cell, capturing image data of the entire space including the human, robot, and workpiece. If the system detects that a human is closer to the robot than a predetermined distance, it signals the robot to stop and restart once it is safe again.

Figure 46 – Veo Robotics' Free Move Allows Workers To Enter Industrial Robot Work Cells Safely



Source: Veo Robotics

Sensors are an important enabler of robot collaboration as they measure or detect certain information which then gets processed for a specific use. This includes vision cameras (such as CGNX), radars, LiDAR, laser, temperature, pressure, and others. For example, a very important feature in collaborative robots is safety, especially the various safety-stop methods that can be accomplished using sensors such as laser scanners, force sensors, relays, light, switches and mats. This helps humans work safely around robots and quickly stop in cases where a human is approaching a dangerous distance to a moving robot.

SICK offers safety relays, stops and laser scanners with different field ranges and easy and flexible installation options, including stationary and mobile. The sensors use time-of-flight measurement to scan their surroundings and measure distances. An integrated rotating mirror allows the defined protection areas to be monitored in two dimensions.

Figure 47 SICK Sensors Can Help Enable Cooperation ...

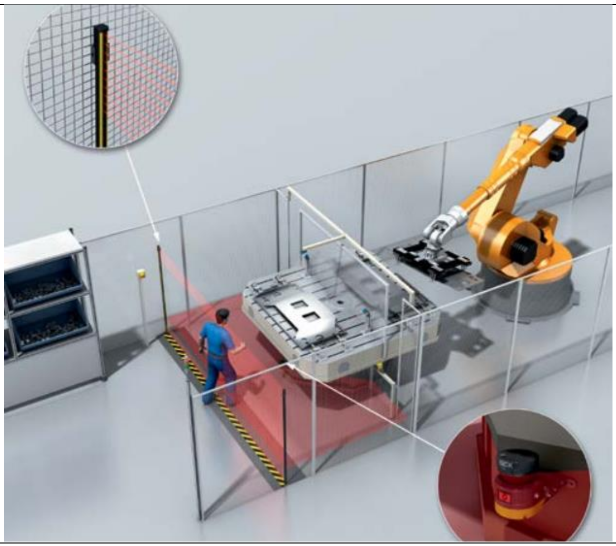


Figure 48 ... As Well As Collaboration

Source: SICK AG

Sensor skins are distributed sensors over a certain surface that provide proprioception (awareness of position and movement of body), tactile and environmental feedback, akin to human skin. Sensor cells can measure pressure, temperature, acceleration, and proximity. These skins are especially valuable in applications such as assistive care, where robots interacting directly with humans need to control the amount of force and pressure being exerted on humans.

Blue Danube offers Airskin, which is a pressure sensitive pad that detects air as a sensing medium to avoid collisions. The technology is used in robots so they can stop when they come close into contact with humans, but before actually being in physical contact or in a collision.

Hand-guided teaching is key enabling technology and important attribute for collaborative robots. This allows non-technical workers to program robots for specific tasks by simply manually guiding them through the steps that need to be taken. The robot programs itself after this process, using embedded encoders. It also allows for greater flexibility as that same robot can be redeployed to other uses if it is no longer needed in that specific task and be quickly reprogrammed.

End-of-arm tooling (EOAT) refers to the hardware and equipment that can be placed at the end of the arm of a cobot for specific applications and interact directly with components. Examples are screwdrivers, welding torches and grippers. This gives the robot its specific functionality and can be changed to fit different applications, giving the cobot an additional layer of flexibility (the other one being physical placement and programming ease).

Grippers and Piece Picking have been among the most complicated challenges in robotics over the last decades. How does a robot determine how to pick different shapes, forms, or textures? An egg, an avocado, a round piece of metal, a plastic bag of clothes? While intuitive to humans, this presents programming challenges for picking applications. Machine learning has dramatically advanced gripping capabilities in relatively short order, with new solutions capable of combining grip techniques at varying forces interchangeably and seamlessly. This is a large market. Within the UR+ ecosystem alone there are over 20 providers including: ZIMMER Group, OnRobot, Robotiq, SMC Corp, Bimba Manufacturing, Coval, CKD Corp, Soft Robotics, SCHUNK, EMI Corp, Festo SE, JOULIN, Weiss Robotics, HIWIN Technologies, Piab, GIMATIC, SMC Corp, VersaBuilt Robotics, PHD, New Scale Robotics, qbrobotics, and J. Schmalz. We've hosted companies such as RightHand Robotics on relevant panels on the topic as well.

Sarcos Robotics – Company Overview

Founded over 25 years ago, Sarcos Robotics designs and manufactures wearable and teleoperated industrial robotics, also known as exoskeletons. The company is the market leader and looks to be the only provider of full body, battery powered exoskeletons. Exoskeletons are designed to master the world's most dangerous, physically strenuous and unpredictable environments and tasks. In order to make the offering more affordable to a wider variety of potential customers, Sarcos plans to offer their exoskeleton as a Robot as a Service model (RaaS).

Exoskeletons provide the labor force with unparalleled strength, durability, and flexibility in industrial environments. The suit helps augment rather than replace humans for jobs that cannot be automated. As manual labor forces continue to age in developed nations, an exoskeleton can help extend a worker's useful life and help fill gaps in jobs that cannot be completely automated and need some level of human dexterity.

There are a wide range of end-markets and tasks that could benefit from exoskeletons: Aerospace (maintenance & repair, assembly support), Automotive (ship/receive, assembly), Logistics (non-conveyable goods, bulky/heavy items), Defense (non-destructive testing, logistics, maintenance & repair), O&G (maintenance & diagnostics, construct/destruct), Power & Utilities (line & transformer repair, infrastructure inspection), Construction (build & repair, material transportation), and Manufacturing (move & manipulate, assembly). Sarcos offers several robotic solutions – Guardian S, Guardian GT, Guardian XO, Guardian XT.

Figure 49 Guardian S For Surveillance And Inspection Applications

Source: Sarcos Robotics

Figure 50 Guardian GT – Leveraging Human Capabilities

The **Guardian S** is a surveillance and inspection tool used for uneven surfaces and challenging terrain and facilitates two-way real time video, voice, and data communication. Use cases include public safety applications such as situation awareness, detecting hazardous materials, HAZMAT applications to keep first responders out of harm and inspection applications such as entering areas previously considered inaccessible for a range of industrial and infrastructure applications.

Guardian GT is a force multiplying dexterous robotic system with an option of one or two arms mounted on a wheeled base. The robot is teleoperated and can be used for tasks such as heavy lifting, welding, joining, offering operators dexterity and strength. Industries that have common use cases for this robot are nuclear reactors, petroleum, construction, heavy equipment manufacturing, disaster recovery and humanitarian applications. The robotic arms act as a natural extension of the operators' real-time arm movements, with minimal training required. Its 7-foot arm offers 7 degrees of freedom, plus a task set-specific end effector which allows the operator to reach objects four feet in front of the mobile platform.

Figure 51 Guardian XO Exoskeleton – The Future Flagship

Source: Sarcos Robotics

Figure 52 Guardian XT Teleoperated Dexterous Robot

Guardian XO is a full body powered exoskeleton that provides responsive, fluid, and intuitive movement while carrying 100% weight of load, relieving human workers from the taxing elements of extensive physical activity. Pricing is designed to roughly equate to the cost of an employee (depending on the experience, etc.) and the solution provides capabilities of 3x-10x human workers. Use-cases include manufacturing, assembly, construction, field service, and warehouse/logistics. It increases worker productivity while reducing the risk of occupational injury.

Guardian XT is a teleoperated dexterous robot that can perform intricate and dangerous tasks requiring human-like skill while keeping the operator at a safe distance. It uses Virtual Reality and can lift and manipulate up to 200 lbs. It has force feedback to control precision and can mount to a variety of mobile and telescoping bases for both indoor and outdoor use. Applications include non-destructive test & asset inspections, live wire repair, steam pipe repair, etc. Industries include construction, manufacturing, maritime, network maintenance, petrochemical, aerospace, and mining.

Figure 53 Companies Mentioned In This Report (priced as of March 12, 2021)

Stock	Current Price	Rating	Analyst
ABB	$30.79	Outperform	Giordano
APH	$64.09	Outperform	Giordano
TER	$112.83	Market Perform	Sankar
TDY	$395.04	Outperform	Giordano

Source: Cowen and Company

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VALUATION METHODOLOGY AND RISKS

Valuation Methodology

Diversified Industrials, Automation & Robotics:

We utilize multiple analysis and discounted cash flow (DCF) analysis to value companies under coverage. We employ both EV/EBITDA and P/E multiple analysis and look at historical valuation multiples (typically 5- and 10-year averages) as well as current and historical multiples for competitor or representative companies. We evaluate the subject company independently and in terms of its comp group. In certain instances, we may look at current/recent transaction multiples to evaluate the subject company. When utilizing DCF analysis, we include a sensitivity table to both discount and terminal growth rates.

Investment Risks

Diversified Industrials, Automation & Robotics:

A general decline in the industrial production index, coupled with a global decrease in automation spending as a percentage of total capex could negatively impact the sector and the implied industry growth rate as well as leading to additional project delays.

Sustained pressure in emerging markets (especially countries with lower labor wages) could cause delays in automation implementation in several sectors, including general industrial, automotive, logistics, medical, and aerospace as factory upgrades are delayed.

Significant, lasting changes in the prices of key commodities, such as oil and natural gas could have material impact on upstream, midstream, and downstream applications. For example, a sharp increase in domestic natural gas projects could make LNG export facilities in the US less attractive and cause delays or cancellations of planned domestic chemical facilities. Sharp declines in oil and gas prices could lead to reduced production activity and therefore reduce demand for midstream logistics and downstream processing applications.

ADDENDUM

Stocks Mentioned In Important Disclosures

Ticker	Company Name
ABB	ABB Ltd
APH	Amphenol Corporation
TDY	Teledyne Technologies
TER	Teradyne

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Assumption: The expected total return calculation includes anticipated dividend yield

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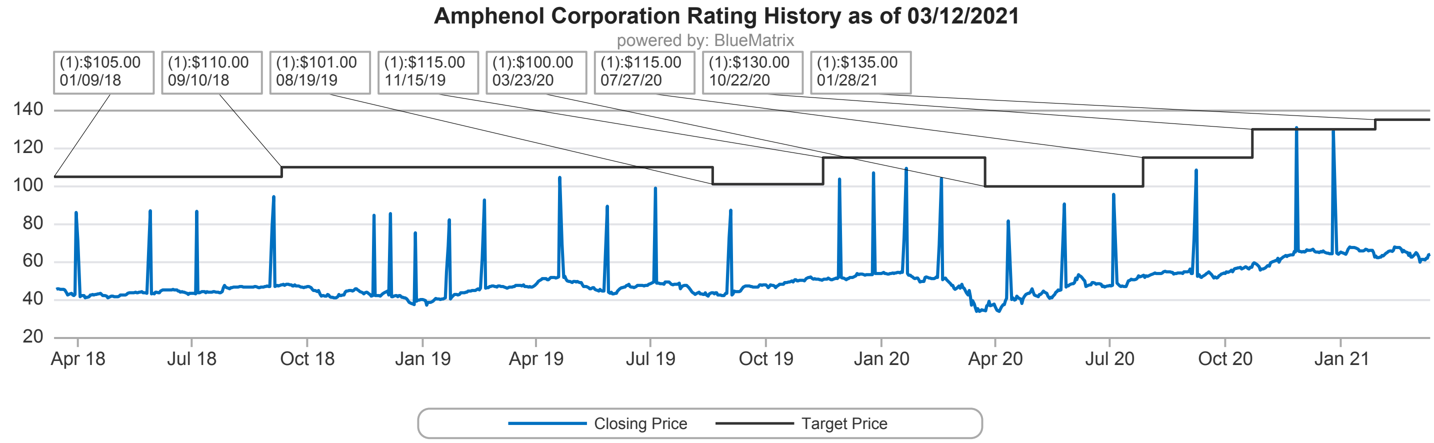
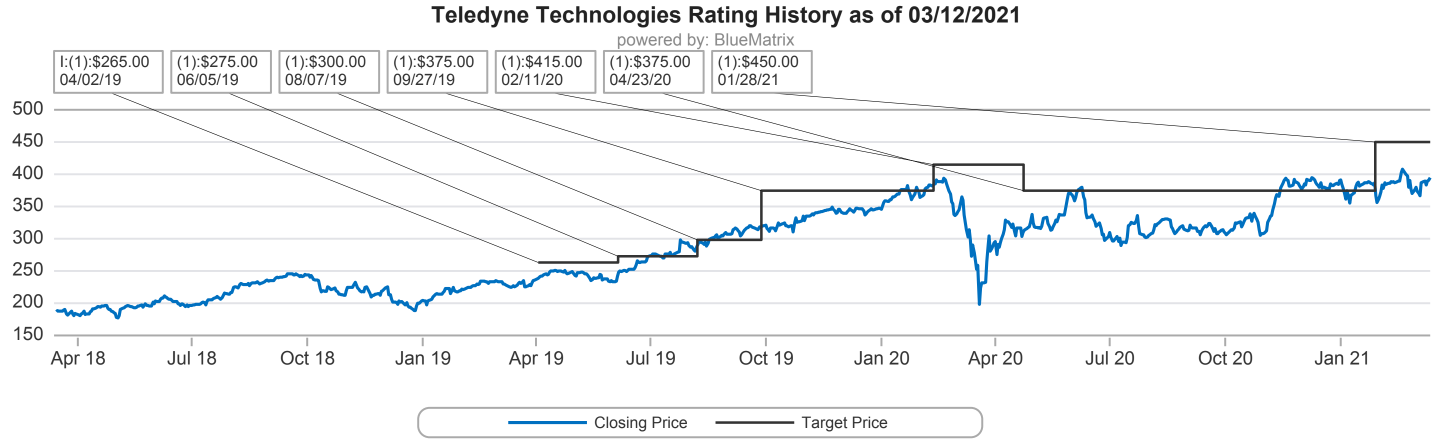
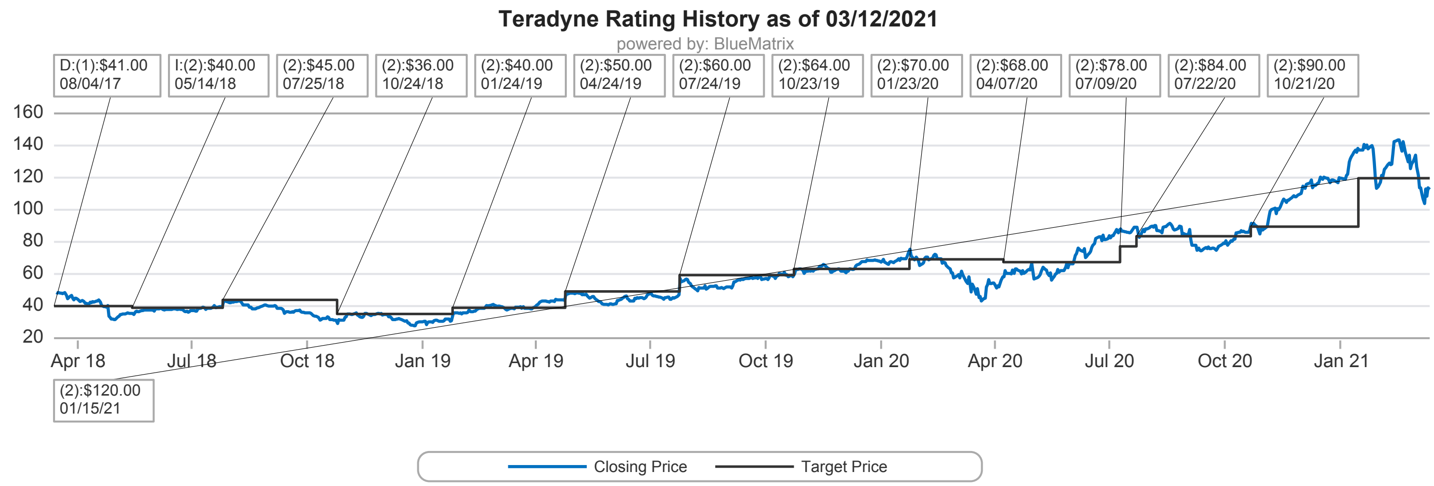
Rating	Count	Ratings Distribution	Count	IB Services/Past 12 Months
Buy (a)	538	67.17%	156	29.00%
Hold (b)	258	32.21%	19	7.36%
Sell (c)	5	0.62%	0	0.00%

(a) Corresponds to "Outperform" rated stocks as defined in Cowen and Company, LLC's equity research rating definitions. (b) Corresponds to "Market Perform" as defined in Cowen and Company, LLC's equity research ratings definitions. (c) Corresponds to "Underperform" as defined in Cowen and Company, LLC's equity research ratings definitions. Cowen and Company Equity Research Rating Distribution Table does not include any company for which the equity research rating is currently suspended or any debt security followed by Cowen Credit Research and Trading.

Note: "Buy", "Hold" and "Sell" are not terms that Cowen and Company, LLC uses in its ratings system and should not be construed as investment options. Rather, these ratings terms are used illustratively to comply with FINRA regulation.







Legend for Price Chart:

I = Initiation | 1 = Outperform | 2 = Market Perform | 3 = Underperform | UR = Price Target Under Review | T = Terminated Coverage | $xx = Price Target | NA = Not Available | S=Suspended

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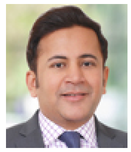

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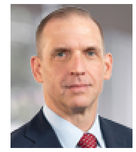

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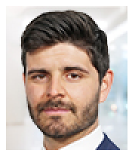

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