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Collaborative Insights
TMT
Industrial Automation & Robotics

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AHEAD OF THE CURVE® SERIES

LIVIN' ON THE EDGE, PART 5: ENABLING & EMPOWERING LOCALLY

MAY 22, 2020

The deployment of edge computing resources explored in Parts 1-4 of our series will change the way we think about manufacturing, mobility, infrastructure, and our daily lives.

The definition of edge broadens here and can be viewed as the means to enable new capabilities or the end itself as edge devices proliferate.

Edge computing will open new capabilities, accelerate adoption rates and help shape future use cases in markets like industrial automation & robotics, autonomous vehicles, smart cities, consumer devices, IT services, and video games.

In this report we examine diverse markets and opportunities, with the common thread being the further blurring of the lines between man and machine.

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COLLABORATIVE INSIGHTS

May 22, 2020

VIDEO

Multi-Sector

MULTI-SECTOR

LIVIN' ON THE EDGE, PART 5: ENABLING & EMPOWERING LOCALLY -AHEAD OF CURVE +VIDEO

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THE COWEN INSIGHT

The next wave of computing is coming to the edge. Just as the cloud moved processing, networking, storage, memory, and software into centralized locations, edge computing will bring these resources back closer to the devices consuming them. Enabled by an increasingly holistic approach to technology, edge computing will have wide-ranging implications across both hardware and software.

The Cowen Research team has created a five-part Ahead of the Curve series focused on Edge Computing structured by subsector. In this collaborative series of reports, we define, analyze, and project this disruptive trend to understand which companies are best positioned to capitalize as tech expands both figuratively and literally.

Subsector Focus: End-Devices & Services Enabled By The Edge: The first 4 reports in our Edge Computing Ahead of the Curve Series dealt largely with development and deployment of edge capability - what was required to bring the edge to fruition. If this series is a large-scale feast, parts 1-4 covered the cultivation of the ingredients, the preparation, and the execution. In this 5th and final installment - we eat. This report explores the wide-ranging implications of edge capability on our world - from more intuitive and adaptable factory automation, to smarter, more collaborative robotics. From smart cities to the autonomous vehicles that will navigate them. From smartphones and PCs to the always connected and AI/ML enhanced smart devices in our everyday lives. From intelligent digital product design & implementation to proprietary IoT platforms that support IT/OT integration within consulting and IT Services. From state-of-the-art video games on any screen to the virtual platforms that will provide them. While specific impacts in this sense are more challenging to quantify than the infrastructure resources required to enable them, they are certain to be profound as decentralized, distributed high power compute becomes readily available.

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Livin' On The Edge: Cowen's Edge Computing Ahead Of The Curve Series

The Cowen Research team has created a five part Ahead of the Curve series focused on Edge Cloud Computing structured by subsector. The next wave of computing is coming to the edge. Just as the cloud moved processing, networking, storage, memory, and software into centralized locations, edge computing will bring these resources back closer to the devices consuming them, driven by the need for low-latency access to cloud-scale computing and data. Catalyzed by artificial intelligence/5G and enabled by an increasingly holistic approach to technology, edge computing will have wide-ranging implications across both hardware and software. In this collaborative series of reports, we define, analyze, and project this disruptive trend to understand which companies are best positioned to capitalize as tech expands both figuratively and literally.

Part 1: Evolving Tomorrow's Internet

Subsectors: Communications Services & Cloud/Internet

Authors: Colby Synesael, Jon Blackledge, Jeff Osborne, Gregory Williams, Nick Yako

Part 2: The Brains and Nervous System of the Edge

Subsectors: Computing & Memory

Authors: Matt Ramsay, Karl Ackerman, Jeff Osborne, Krish Sankar

Part 3: Storage & Networking

Subsectors: Storage & Networking

Authors: Karl Ackerman, Paul Silverstein

Part 4: Bringing Software Logic to Edge Compute

Subsectors: Software & Security

Authors: Derrick Wood, Nick Yako

Part 5: Enabling & Empowering Locally

Subsectors: Industrial Automation & Robotics, Autonomous & Connected Vehicles, Smart Cities, Consumer Edge Devices, IT Services, Video Games

Authors: Joseph Giordano, Jeff Osborne, Krish Sankar, Brian Bergin, Doug Creutz

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LIVIN' ON THE EDGE PART 5: END-DEVICES & SERVICES SUBSECTOR IMPLICATIONS

Executive Summary: Enabling & Empowering Locally

Cowen Insight: The first 4 reports in our Edge Computing Ahead of the Curve Series dealt largely with development and deployment of edge capability - what was required to bring the edge to fruition. If this series is a large-scale feast, parts 1-4 covered the cultivation of the ingredients, the preparation, and the execution. In this 5th and final installment - we eat. This report explores the wide-ranging implications of edge capability on our world - from more intuitive and adaptable factory automation, to smarter, more collaborative robotics. From smart cities to the autonomous vehicles that will navigate them. From smartphones and PCs to the always connected and AI/ML enhanced smart devices in our everyday lives. From intelligent digital product design & implementation to proprietary IoT platforms that support IT/OT integration within consulting and IT Services. From state-of-the-art video games on any screen to the virtual platforms that will provide them. While specific impacts in this sense are more challenging to quantify than the infrastructure resources required to enable them, they are certain to be profound as decentralized, distributed high power compute becomes readily available.

Six Key Points By Subsector:

1. **Industrial Automation & Robotics (Joe Giordano)**: Deployment of distributed power through the edge is both a means and an end itself as it relates to industrials. Faster compute with low latency opens up new control applications and provides for robust real-time analysis while also unlocking robots themselves as intelligent, edge devices. To gain insights into edge implications we interviewed and received feedback from leaders across the automation and robotics industries and highlight 5 primary use cases that are likely to benefit going forward that we explore in detail in this report: **1)** Digital Twins; **2)** Augmented Reality; **3)** Robotics; **4)** Machine Learning; and **5)** Machine Vision.

2. **Autonomous & Connected Vehicles (Jeffrey Osborne):** Edge computing already plays a critical role in connected vehicles and autonomous driving applications, and is a key enabler of these technologies that Aptiv sees scaling from a ~$2bn addressable market in 2018 to ~$30bn by 2025. Within our coverage, APTV, LEA, and TSLA are the most exposed to utilizing edge computing for connected cars, and both APTV and TSLA are most exposed for autonomous driving. In the report, we discuss some of the fundamental problems being solved within the vehicle architecture and for domain controllers by Aptiv to enable connected and autonomous vehicles, the Xevo (acquired by Lear) and Otonomo (investment by Aptiv) as a connected car platforms, and Tesla's early use of OTAs and strategy to build autonomous vehicles via a neural network of connected vehicles.

3. **Smart Cities (Jeffrey Osborne):** Cities consume ~67% of all energy generated and produce around ¾ of all carbon dioxide emission, according to the Intergovernmental Panel on Climate Change. Governments, municipalities, and utilities are increasingly looking at smart infrastructure to address the challenges of rising pollution, overcrowding, and dwindling resources. These smart city deployments look to better utilize existing assets, improve energy

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efficiency, decrease emissions, reduce unplanned maintenance cost, strengthening grid resiliency, and provide new insights into city planning. Smart city providers and their customers are beginning to leverage higher degrees of edge computing in order to better digest and analyze the massive influx of data generated by these smart IoT installations as well as take action based on the analysis. This should help to create more robust full featured solutions at the cost of low bandwidth and ultimately provide new economic use cases to improve the value of smart city deployments to governments, utilities, and municipalities. Within our coverage we see Itron (ITRI) and Landis+Gyr (LAND.SW) as uniquely positioned to capitalized on this theme over the next decade given their initiatives in the smart meter and smart city markets.

4. **Consumer Devices (Krish Sankar):** Within the consumer edge device market, we view the rollout of 5G wireless cellular technology and growth in edge computing resources as beneficial to smartphones and the fast-growing smart devices category. We believe the new 5G wireless standard can be a catalyst for smartphone device demand as consumers view it as a material upgrade from existing wireless technology, thus driving a replacement / upgrade cycle over the next 2 to 3 years. Greater access to cloud computing resources and expected growth in AI/ML computing algorithms is expected to complement or underpin the growing utility of smart home devices. On a go-forward basis, the diversity of sensors and the quality of data captured by smart thermostats, security cameras/doorbells, and speakers, etc. is likely to improve the end user experience even more in terms of level of transparency and remote control capabilities of the device.

5. **IT Services (Bryan Bergin):** Edge Computing and Industry 4.0 potential presents massive Services opportunity through the horizontal integration of operational technology and information technology, and the development and support of clients' new products, business models and services. Combined, corporate spend across the global engineering R&D (ER&D) and digital product engineering is projected to nearly double by 2025 to over $2 trillion; we see the outsourced component rising to 50% over this period, to $1+ trillion yielding an attractive ~20% CAGR. Despite its scale, the nascence of the Edge and Industry 4.0 markets yields a landscape with only few definitive market leaders; we highlight ACN as most visible in IoT franchise development, IBM, ATOS.FR & NTT Data addressing broad server & services needs; CAP.FR building formidable mix via its Altran consolidation, and digital product engineering provider EPAM for its software engineering depth and building physical product design/consultancy.

6. **Video Games (Doug Creutz):** If video game streaming is to succeed as a mass-market consumer product, we expect edge computing to play a very important role. In order for the core gaming audience to be willing to switch to virtualized streamed game platforms, they will need to be convinced that the fidelity of the service will be at least as good as those on their existing console/PC hardware devices. We believe edge computing will be a necessary component of that, in order to maintain consistent connection quality between the game servers and the player's screen. To whatever extent video game streaming does contribute to market growth, we would expect all of our covered core gaming names (EA, TTWO, ATVI, and UBI.FP) to benefit more or less equally.

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Companies Best Positioned For Edge Cloud: End-Devices & Services

Cognex (CGNX, Outperform) – Giordano

CGNX is in an interesting position to benefit from edge capability both through machine learning and vision. The beauty of CGNX's offering is its ease of use, and improved edge capability should hasten the ability to deploy more robust deep learning offerings (through ViDi, SUALAB, etc.) in an integrated way. COVID-19 response is likely to push the industry more toward vision based (rather than human) inspection, and edge enables deep learning to open to capabilities that weren't possible in a "definition" based inspection world.

Amphenol (APH, Outperform) – Giordano

APH is a multi-faceted way to play edge deployment, first through content on infrastructure deployment (in the mobile equipment, in the datacenters) and ultimately through leveraging edge capability in sectors like auto, consumer devices, etc. Amphenol's exposure base here is wide and comprehensive, with products designed to ensure power, data, and signal is transmitted safely and quickly.

Itron (ITRI, Outperform) – Osborne

Itron has made substantial progress with its smart city efforts, following the acquisition of Silver Spring Networks. This is in addition to acquisitions like Comverge, which increased the company's big data capabilities. The company has leveraged its smart grid business to provide distribution automation features, and the streetlight business from Silver Spring puts it in good position to drive more distributed intelligence through its smart infrastructure installations. Over the longer term we expect a greater portion of the company's profitability to be derived from its Outcomes business with focus on grid edge analytics and solutions.

Landis+Gyr (LAND.SW, Outperform) – Osborne

Landis+Gyr is focused on expanding its partnership ecosystem that leverages grid edge intelligence as highlighted by its Revelo meter and Gridstream Connect App ecosystem. Additionally, we remain constructive on the company's partnership with Sense and its agreement with Utilidata in August 2019. Landis+Gyr partnered with Utilidata, an industry leader in energy optimization software, to deploy Utilidata's edge applications on Landis+Gyr's smart meters. Leveraging real-time data and machine learning, Utilidata's applications strengthen Landis+Gyr's platform by adding grid visualization, dynamic monitoring of distribution circuits, and real-time fault detection capabilities to enable utilities to collect and synthesize data from an array of grid endpoints. The rollout of Landis+Gyr's smart meters embedded with Utilidata's software is initially planned for the North American market.

Apple (AAPL, Outperform) – Sankar

Our Outperform rating on Apple continues to be predicated on the Services business as a long-term growth driver for new recurring revenue streams that should drive the valuation multiple higher while the iPhone and other hardware businesses remains a steady cash flow generating annuity for the company. In the current COVID-19 affected demand environment, we view the stock as a defensive name given that the Services segment that continues to benefit from the 'work from home' environment, and a cash flow generating iPhone demand trajectory that should improve once we 'get out of home.' Looking into CY21, a 5G iPhone cycle coupled with further growth in Services is expected to drive a reacceleration in revenue and earnings. Reiterate Outperform and $335 price target.

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Universal Display (OLED, Outperform) – Sankar

UDC is the leading supplier of emitter materials for organic light emitting device (OLED) based display panel technology. We continue to view UDC's long-term growth prospects positively given secular growth in OLED display technologies, limited competition, and a strong balance sheet with net cash of $640M (~$14 / share). We expect smartphone demand and sector sentiment to improve into 2H20 and an expanding customer base for OLED TVs and industry production capacity are positives for driving the next phase of long-term revenue growth. Our Outperform rating is based on a price target of $200.

Accenture (ACN, Outperform) – Bergin

Accenture has been most visible in its IoT/smart connected products and services efforts, dubbed Industry X.0. The company clearly benefits from its overall scale across the consulting through SI and managed services value chain; however it has also been most visible in forward-looking investments. It's executed on high-value tuck-in M&A deals, developed internal IP and patent filings across IoT/robotics/and industrial applications (600+), and boasts over 10,000 Industry X.0 professionals. It has the most expansive network of physical facilities to co-innovate with its clients and work with broad technology partners, across 20+ strategically located sites in its global Industry X.0 Innovation network.

Capgemini (CAP.FR) – Bergin

Capgemini's recent acquisition of Altran for €3.7 billion is the largest bid to date and first major combination of a global IT Services provider and OT/ER&D firm. The combined scope of its Engineering and R&D services represent annual revenues ~€3.4 billion and 54,000 professionals. The combined base of industrial and manufacturing clients with a leading footprint in Europe position it in key areas as Intelligent Industry gains scale.

EPAM Systems (EPAM, Outperform) – Bergin

EPAM's pure-play expertise in both digital platform engineering services and integrated physical and digital design makes it a natural beneficiary of Industry 4.0. It's Made Real Labs via the Continuum acquisition, combined with EPAM Garages, yields a growing physical network for experiential prototyping. Through these and its heritage strength in software engineering for high-tech clients, EPAM boasts an end-to-end offering. Continued front-end investments are expected to broaden its consulting & design breadth.

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Edge Cloud Market Forecast: Early, But Cloud-Like Growth Potential

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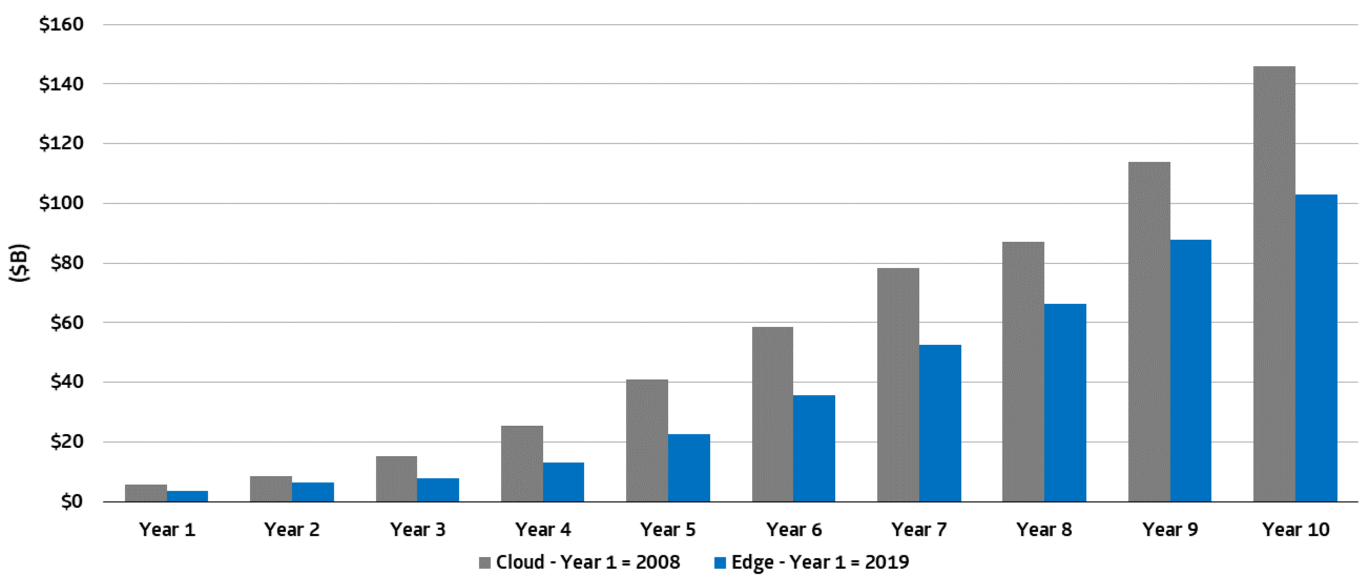
We cannot help but reminisce and compare initial forecasts to the early days of the cloud. In the mid-late 2000s, cloud computing was a concept driving limited actual dollar investment and investor focus. Conceptually, it showed promise but there was still plenty of pushback as those in the technology and investment community questioned the feasibility and value of a centralized and shared computing model. This first re-architecting of the Internet in its first few years admittedly seemed like a small market attracting limited capital investment and attention, but as shown in the figure below, cloud has grown at a 38% CAGR for more than a decade, from ~$6B in 2008 to ~$208B in 2019. We see edge cloud computing following a similar, potentially exponential, adoption curve, as the low-latency benefits for emerging autonomous technologies require this type of cloud-scale computing at the edge, ultimately crossing the $100B threshold through exponential growth in the coming decade. It's early, but we encourage investors to take notice now of what we view as a decade+ trend.

We also would note that while cloud computing has grown at and to this massive scale, it still only accounts for ~40% of the server market today (enterprise/government/ networking the remainder). While our initial edge computing forecast calls for only ~10% of cloud servers deployed in edge locations in eight years, the market remains in its infancy, and we would be unsurprised to see the forecast oscillate significantly (in either direction) over the coming years as the ecosystem matures. The net takeaway is that, yes, edge is likely a small market today, but investors need to be paying attention to the slope of the adoption curve relative to the cloud growth we've seen in the last decade. Finally, given the current COVID-19 pandemic, we concede near-term investment levels in edge/5G remain fluid, but we are confident in the long-term trend, and investment in edge infrastructure may accelerate out the back of the COVID crisis.

Figure 1 - Public Cloud Computing Market Size Versus Edge Computing Projections (Revenue)



Source: Cowen and Company, Statista, Tolaga Research

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Edge Computing Primer: Machines Are The New Cloud End Users (TMT Research Team)

Pages 12-26 Are Cowen's Edge Computing Primer. For End-Devices & Services Analysis, Please See Page 27 Here

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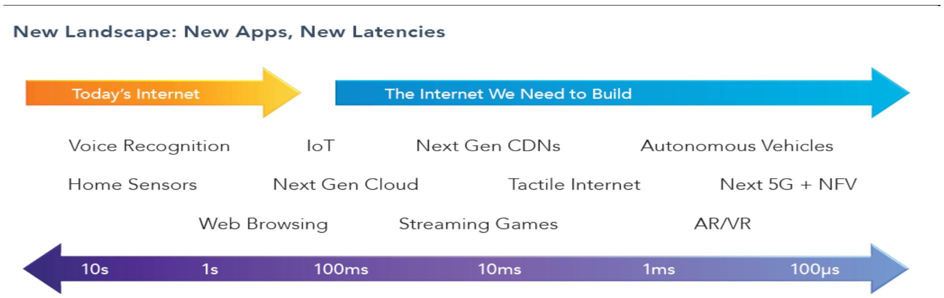
We define edge cloud computing as the trend of moving cloud-scale computing resources closer to the end devices utilizing them. This rearchitecting of the Internet promises not just to make current services/applications better, but more importantly, will enable a whole new set of use cases that utilize real-time analysis and are situationally aware/autonomous. The key difference in these applications, and the reason this rearchitecting is needed, is that they will be largely operated by machines, not humans, and thus require low-latency access to both compute and data at the edge.

Machines – Not People/Businesses – Will Become The New Cloud Computing End Users

Looking ahead, as machines increasingly become the "end user" of datacenter or network output, we believe demand for applications requiring significantly lower latency will increase. Whereas today's Internet has largely been built for human or business consumption (email, video/streaming, social media, websites) and grew up with the record once/stream many times model, we believe this new Internet will be built under the assumption that data and computing resources will both be generated and consumed by machines (drones, sensors, robots), and thus will need to be much faster and de-centralized for low latency. While many applications with low latency and lower compute horsepower requirements may be able to satisfy their compute needs with embedded processing that is connected to a network, we believe many emerging applications will also require cloud-scale computing horsepower or storage.

Figure 2 - Demand For Lower Latency To Drive Compute to the Edge



Source: Tolaga Research / The Linux Foundation "State of the Edge Report 2020"

For instance, enterprise digitization and increasing use of operational technology will continue to create massive amounts of data that will need to be processed and connected between enterprise locations. In many of these instances, power and resource constraints make it unlikely a high-performance processor can be supported in an embedded form factor, making a distributed model necessary. Further, edge cloud computing has potential security benefits as well. By limiting the transfer of data and sensitive information between the network edge and central datacenter, moving data to the edge inherently limits potential risks (as long as edge points are secured; more to come on that topic). Further, enterprises can physically disaggregate their data from other users by storing information in an isolated location at the network edge.

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Pulling this together, we see a confluence of factors driving demand for a computing model that is unable to be served by either current cloud, embedded, or on-premise datacenter computing models. While many of these use cases are in their infancy, early applications that fit these criteria are attracting a significant amount of interest and capital funding both within established companies and standalone/startup businesses.

While still nascent, applications that fit this model include: autonomous vehicles, factory automation, smart cities, augmented reality streaming gaming, and 5G network function virtualization (NFV). Given these demands, we expect a new computing model to evolve as an extension of the cloud with a unique challenge: edge computing.

Figure 3 - Edge Cloud Computing Potentially Solves Latency, Optimizes TCO, Protects Data, and Enhances/Enables New Applications

Source: Intel

Edge As A Natural Expansion/Extension Of The Cloud

From a high level, we view edge processing as a natural evolution of the cloud, the most important computing architecture change over the last 20 years. The cloud enabled the disaggregation of physical technology hardware from its consumers by allowing the virtualization and sharing of computing resources like CPUs, storage, networking, and software. In this type of architecture, most functions are implemented in software and placed via virtualization tools onto a common set of shared and interchangeable hardware housed at large mega datacenters.

This model worked perfectly for most applications given the end devices utilizing these compute resources have largely been PCs and smartphones. This architecture rapidly grew in prominence to drive datacenter utilization and efficiency and to optimize Total Cost of Ownership (TCO) as computing/storage resources were placed where both land and power are less expensive commodities. Having a centralized location for compute and storage resources allowed for massive scaling and pooling of resources, including data, that greatly lowered the overall cost of computing and allowed for a massive leap forward across the technology landscape.

For most applications, particularly anything human-facing, cloud-based computing latency is likely “good enough,” even unnoticeable to the end user or application, as often throughput was optimized at scale. Moving these physical resources away from devices, however, inherently results in a delay for those computing or storage resources to be delivered or utilized by the end device or user, or latency.

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Jitter, or the variance in latency, also presents challenges to content delivery and end utilization from the disaggregation of IT hardware and end users. We have seen successful implementation of many of these applications where content for human consumption is moved outside a centralized datacenter through content delivery networks (CDNs). Human reaction time generally peaks at around 0.2 seconds, and thus any latency below this level for human applications is virtually unnoticeable.

Moving Back To Decentralized Architectures

We believe the edge cloud computing trend is a natural ebb and flow of resource allocation from centralized to decentralized locations to support end device applications. Computing began with centralized mainframes, where the idea was to centralize the vast computing/data resources into a single machine and to physically connect it to dumb terminals that were able to extract out information. This made sense given the significant cost to build a mainframe computer at the time and the significant physical space that they took up.

Then the PC and smartphone revolution allowed for mobility of computing in decentralized locations. This was driven by significant advancements in technology, including microprocessors, which both shrunk the form factor of a computer and reduced its price. As PCs and smartphones created a huge increase in data and compute needs, this created use cases demanding that resources move to centralized cloud, where resources could be shared.

This of course changed in the 2000s and early 2010s at first with the addition of CDNs and regionalized data centers and then with the advent of the cloud, which like the mainframe again aimed to centralize compute/data resources but on a more regionalized basis and on an open Internet architecture that created greater scale efficiencies.

Now new end device applications, many of which are enabled by AI-trained models in the cloud or require real-time access to both generate and consume data, are requiring these resources to move back to the edge. Edge computing promises to shift compute/data resources to a more localized architecture, but notably will continue to do so using an underlying cloud architecture. Simply, applications are not pulling for just computing at the edge, but cloud-scaled and AI-based computing at the edge. As numerous industry luminaries have noted, though, the edge today is like cloud in ~2010, meaning that while at a high-level we conceptually know what edge means, we have yet to fully flesh out the business opportunity and to understand the magnitude of the impact it will have on society as a whole. The path forward for edge cloud seems inevitable, but it is very early days.

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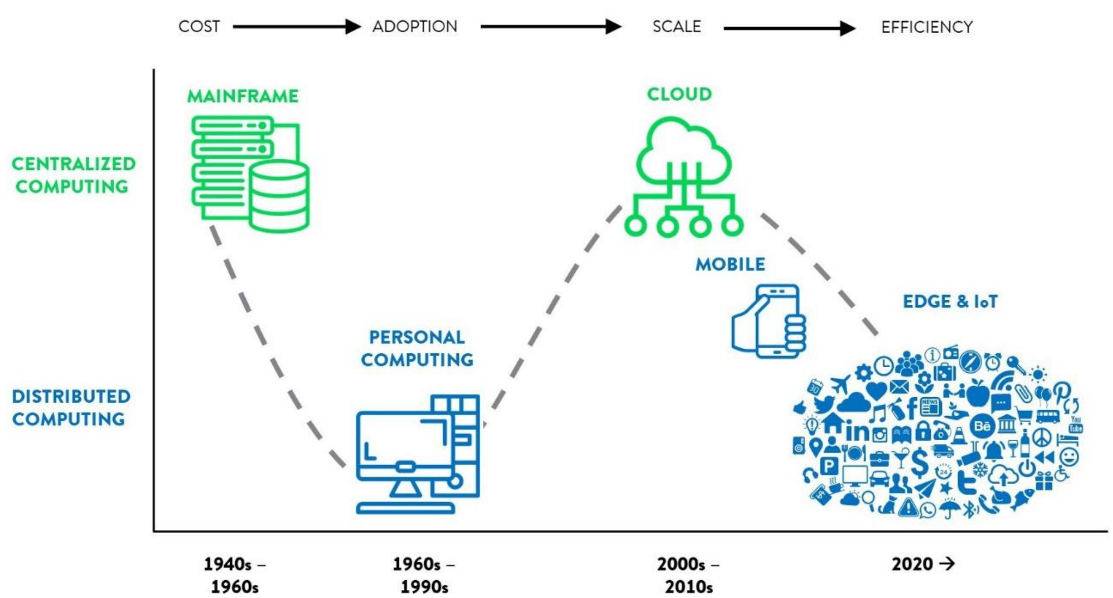
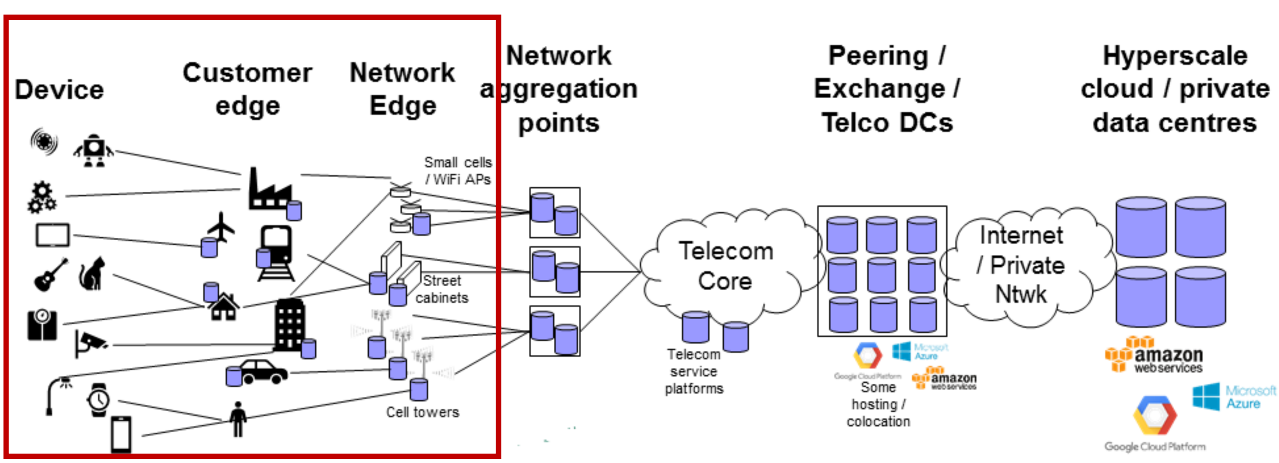
Figure 4 - Ebb and Flow of Centralized and Distributed Computing Over Time



Source: Cowen and Company

To be clear, we do not believe edge computing will replace or meaningfully cannibalize current cloud enabled applications, but rather will be required by new latency-sensitive markets. The sheer increase in data will not just drive demand for new edge data centers but in theory should drive demand for all data centers, recognizing that not all data will sit at the edge but instead will sit throughout the data center hierarchy. This would also suggest then that even the biggest data centers that sit in remote areas will see a significant step up in the level of data that sits in their facilities. Taking into consideration the concept of data gravity, this could also drive demand for the companies that own/control that data to have their own physical presence nearby where they can more (cost) effectively analyze this data.

Figure 5 - Edge Computing -> Resources Moving Back Toward Devices



Source: Disruptive Analysis Ltd 2017

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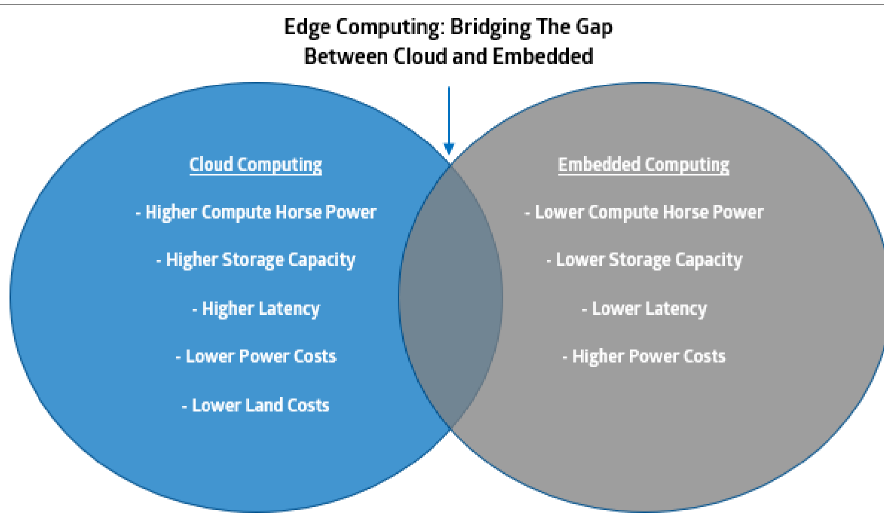
Instead, we believe they will work as complementary approaches to a broadening set of applications that are being disrupted by technology taking over responsibilities traditionally served by humans, such as smart cities, industrial & home automation, and intelligent/autonomous driving. In addition to those applications, we believe the edge cloud will serve to improve and compliment cloud computing by helping to offload and filter the enormous and growing volume of data being created at the edge.

Contrasting the edge trend with cloud, we see two methods by which edge computing can be implemented: either by moving datacenter-style resources closer to devices or by increasing the compute power of the devices themselves. In essence, edge hardware is defined by its location, on the edge of the network … not by its size, application, or architecture. We believe the vast majority of implementation will take on the former business model given size, power, and resource constraints in embedded devices.

Key verticals (such as in-vehicle autonomous computers or MCUs/FPGAs at the edge in embedded devices) will inevitably scale, but remain fragmented and likely smaller than overall edge infrastructure buildouts. We will therefore focus this series of reports primarily on edge servers/datacenters, given embedded compute is a more fragmented and likely smaller market for now. In contrast, the final report in this series focuses on examining a few key applications/markets enabled by edge cloud computing, while providing a framework for understanding the breadth of potential use cases and those most likely to benefit from the buildout of edge servers versus device-embedded compute processing power (which in many cases is already in place).

Figure 6 - Edge Computing – Bridging the Cloud and Embedded Computing Use Cases



Source: Cowen and Company

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Why Now? AI-infused Applications Demand Low Latency Compute As Investment Shifts From Training Models To Implementing Them

The Cowen TMT team believes that artificial intelligence (AI) is the key driver of demand for edge computing by disrupting multiple industries and changing their respective IT demands. Following the last years of investment in AI-training, **the industry is ready to put artificial intelligence models to work** and shift investment to the next phase: inference. This dynamic is a critical driver of edge computing, as inference applications see latency as a critical gating factor. This will inherently push compute resources toward the edge of the network in order to satisfy the near-zero latency requirements of new AI-enabled (often near-autonomous) applications. Simply put, offloading these calculations required for AI-inferencing to a cloud environment will not cut it from a latency perspective, and **investment in resources is needed at edge locations.**

How We Got Here And What It Means For the Future: Artificial Intelligence

Taking a step back, Artificial Intelligence is hardly a new phenomenon. It is simply intelligence exhibited by machines that can be traced to the earliest days of modern computing, or with a looser interpretation, devices like the abacus. Essentially, as machines continue to take more responsibility in applications traditionally done by humans, the hardware demands are increasing, including the latency and processing requirements, which are driving resources closer to their end implementation.

In our view, artificial intelligence innovation has accelerated due to two fundamental shifts in computing. First was shifting from binary variables to more flexible ones. This has driven what is commonly referred to as neural networks where computing systems logic chains function in a more similar manner to that of a human brain. The second technological innovation allowed AI systems to correct and adjust on their own, allowing machines to do programming instead of humans. This gave rise to *machine learning.*

Machine Learning accelerates artificial intelligence by dynamically adjusting its decision making for new data sets. Key to this advancement is the ability to learn from previous outcomes, and correct errors, in a compute intensive process called *training*. In machine learning, a compute engine uses algorithms to analyze data, adjusts that algorithm, and eventually makes predictions based on past inputs. This greatly speeds up development, allowing machines to learn from experiences without human interaction or adjustments.

AI Training Is Allowing Implementation … Shift To Inferencing Puts Trained Models Into Place, Driving Applications Demanding Low Latency Computing

The rise of machine learning has bifurcated artificial intelligence development and implementation into two distinct phases: training and inference. **Training** is when a compute engine is fed massive amounts of data, running simulations and self-correcting errors until it can answer AI problems at a sufficient confidence level. Training is highly compute intensive, as the more simulations a system can run, the more accurate it will be by understanding and correcting past errors. **Inference** puts what is learned in training into practice in the real world. This stage is inherently less compute intensive in the volume of calculations that must be run, and is instead focused on implementing what was learned during training.

Latency can be critical in inference depending where machines need to react based on already-trained models. But latency can also be so for training at the edge if machines are autonomous and required to learn from new data quicker than the round-trip latency back to the central cloud datacenter. This new requirement is what is pushing not just computing to the edge, but AI-based computing at scale.

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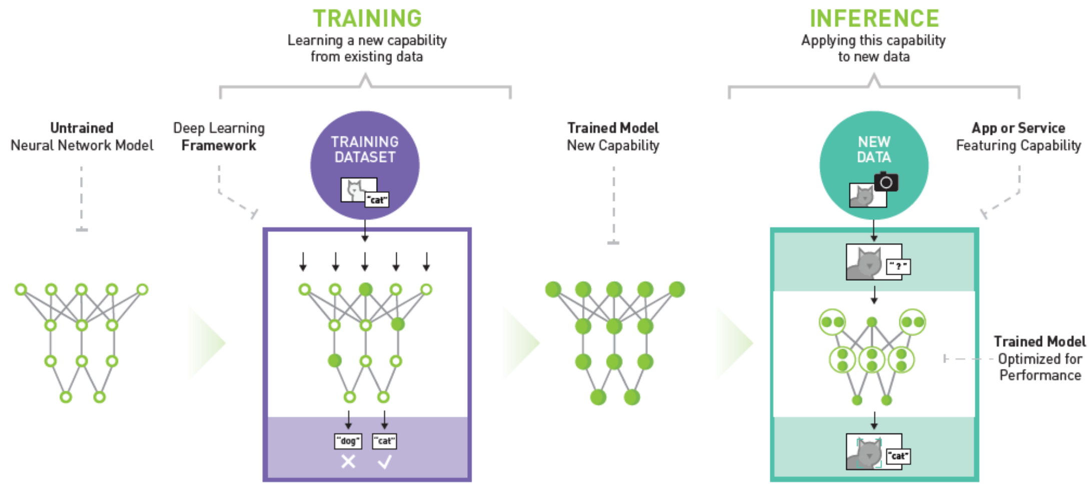
Figure 7 - Training A Neural Network For AI Versus Making Decisions Through Inference



Source: nVidia

What Is Allowing AI, And Edge Computing, To Take Off And Catalyze New Growth?

1) **Data explosion:** It is critical to understand that data is the fuel that feeds artificial intelligence innovation. Likewise, more and more of data capture and processing needs are taking place on the edge of the network. Each piece of data can essentially be used as a piece of evidence to improve a machine's decision-making functionality in artificial intelligence. Connectivity has allowed for an explosion of data creation and sharing from the edge of the network to the cloud, while memory bit growth and cost reductions have allowed this data to be managed efficiently.

   This increased connectivity has also enabled what the **Industrial Revolution 4.0 and IoT.** This fourth industrial revolution that is taking place today is characterized by physical machines, robots, and systems as well as IoT devices (phones, sensors) which generate immense amounts of data that can be used more effectively to provide real-time insights and autonomy. This can be done with the use of cognitive computing (AI and ML), simulation, and augmented reality. It has also led to the creation of cyber-physical systems where a machine exists not only in its physical form but also as an exact digital replica (a Digital Twin) that can behave in the same way to give users better insights.

2) **Hyperscale and public cloud has put computing power, data storage, and software developers under the same roof:** Data processing and storage has increasingly been dominated by a few large hyperscale cloud players. This allows better economics, and better data sets for artificial intelligence from hyperscale datacenter owners, and thus better AI-trained models. While we believe AI-at-the-edge will grow as inferencing puts AI into practice, initially the economics of cloud computing has allowed rapid advancements in AI hardware/software in cloud environments is serving as a catalyst for the industry.

3) **The "GPU's" application to AI:** While the cost of overall computing has continued to decline (albeit at a checked pace versus prior paces), perhaps the most important hardware change to artificial intelligence has been the advanced adoption of accelerators, primarily GPUs. CPUs, the primary compute engines in PCs and servers, can operate a broad array of complex tasks in succession, known as serial processing. GPUs (and other accelerators) are designed to do many simple tasks very quickly and simultaneously (parallel processing) given their original function was to manipulate many pixels on a monitor simultaneously.

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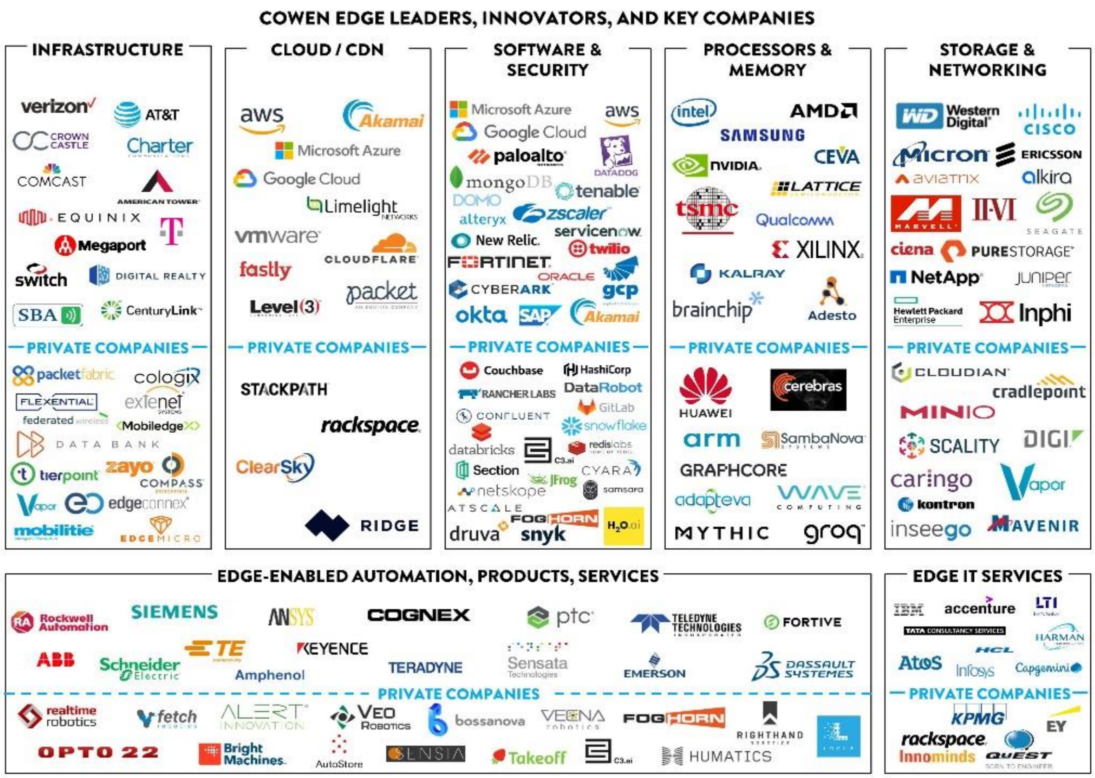
4) **Enterprise spending on AI is increasing:** Simply put, companies are realizing the value AI can bring to their businesses and investing in it, starting with hyperscale players but moving down to traditional enterprises. We believe it is the significant increase in enterprise investment, particularly by hyperscale cloud vendors, that has inflected growth.

5) **Last but NOT Least – Software:** The start of this rise in software investment should continue to unleash AI computing growth. Most notably, as Machine/Deep learning software development environments scale, Artificial intelligence innovation across the stack will benefit. We have seen and expect continued development from environments such as Google's TensorFlow, Caffe (started at Facebook), and multiple open-sourced environments. Similarly, improvements in virtualization and networking software (in addition to hardware) are allowing increased portability of computing frameworks, allowing them to move to or be implemented in edge environments.

What Will Edge Look Like: Co-opetition Between CSPs And Hyperscalers

While the ecosystem is still in its infancy, one thing is clear about edge cloud computing: it will require close industry collaboration across hardware providers, software and applications companies, enterprises, communications service providers, and network infrastructure players. As discussed above, edge cloud computing describes a concept, not a form factor, as compute/storage increasingly occurs closer to the end-device it is serving to help reduce latency and transport costs.

Figure 8 Edge Leaders, Innovators, And Key Companies



Source: Cowen and Company

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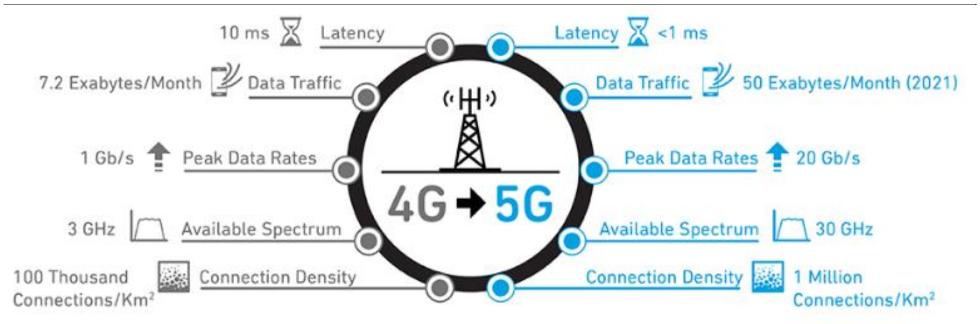
With a massive generational improvement in latency, we also believe 5G will play a crucial role both creating use cases that require edge computing, and helping deliver these computing and storage resources to their end devices. For more details on 5G including its role in edge computing, we recommend investors look at Cowen's Ahead of the Curve Report **One Vision, Many Paths; Defining "True" 5G**.

Ultimately, the needs of specific use cases will drive the debate around latency and cost. Said another way, dictating what will get computed/stored and where will be based on (1) law of economics (costs), (2) law of physics (latency), and (3) law of the land (ex: GDPR), requirements. Because of this, we believe edge will play a critical role in true 5G architecture.

Figure 9 - 4G -> 5G Comparison



Source: Qorvo

Key Conclusion: While true 5G will be dependent on the edge, the edge will not necessarily be dependent on true 5G.

Consequently, we believe a convergence of wireless infrastructure suppliers and hyperscale cloud players will need to materialize given (1) hyperscale cloud providers are often the current suppliers of compute and storage resources; and (2) wired and wireless infrastructure players are tasked with delivering not just data, but also often these cloud resources to the end device. For the purpose of edge computing, the question of whether these computing resources are delivered via a wireless or wired connection is almost irrelevant. It is instead moving the supporting computing resources closer to their end device/delivery point that is critical. Said differently, while true 5G will be dependent on the edge, the edge will not necessarily be dependent on true 5G.

How Will The Edge Cloud Be Monetized?

While we conceptually understand what the edge cloud is/will be and there are some conceptual themes that continue to be referenced, including autonomous vehicles, AR/VR solutions, and robotics, even in these cases it's not yet clear what the end solution/model will look like. What we do know is that the end solution/model will leverage the key attributes that the edge enables that did not previously exist before including lower latency, lower cost, and data sovereignty, and in many cases will align with the key attributes that 5G enables, including not just latency, but also faster speeds and the ability to connect an almost unlimited number of devices to the network.

Bringing this to fruition will be challenging, however, and differs from previous evolutions considering 5G/edge have less to do with technological advancement but more with a change in the network topology, which essentially requires a significant amount of new investment and orchestration across a number of constituents, including edge operators, real-estate owners, network providers, cloud companies, tower operators, equipment vendors, software companies, and installers/construction.

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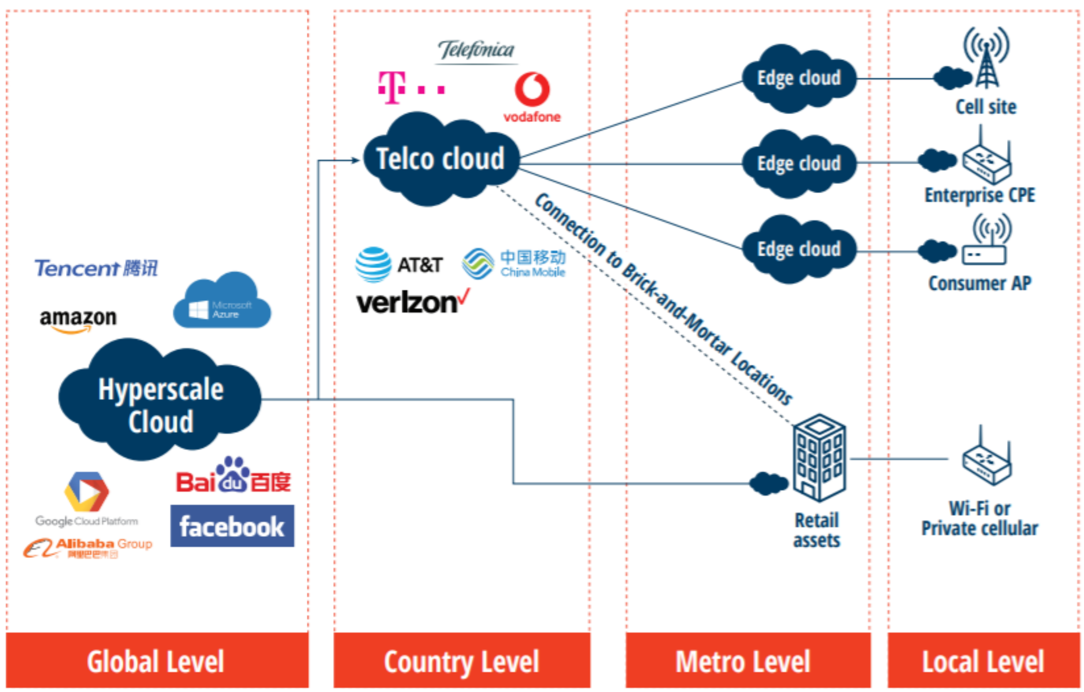
Early on, the majority of edge infrastructure deployments will be augmentations of current/proven business models such as (1) predominantly using regional data centers for regional enterprise deployments but carving out some portion of capacity for edge deployments, or (2) building fiber networks to macro towers and C-RAN aggregation hubs to support 5G phone-oriented use cases but then also connecting an edge location. This, however, will be complemented by a handful of start-up/pure-play providers that will build edge-specific infrastructure that hopes to establish a first-mover advantage. For these early pioneers there is fortunately already significant interest from cloud and cloud-oriented providers that are already eager to expand their own physical footprints.

It's likely that the earliest edge solutions will be one-off/customized solutions where the infrastructure edge is (1) owned by the customer (services, devices, etc.), (2) deployed on premise, and (3) connected to end devices over a private network. This is largely because the edge infrastructure required to enable an end solution has yet to be deployed at scale.

Figure 10 - Edge Computing Domain Hierarchy



Source: Intel

Ultimately, we believe most edge locations will be owned/operated by third-party providers and that their customers will largely consist of cloud-oriented companies such as public cloud providers like AWS, private cloud providers like Packet, and CDN providers like Akamai. The difference, however, is that given the sheer number of edge locations that are expected to be created, and in some cases (particularly at access and pre-aggregation sites) it will be impractical for enterprise/third-party creators of end solutions to physically deploy their own infrastructure. Instead, we believe enterprise/third-party creators of end solutions that utilize an edge architecture will use the physical infrastructure that these cloud and cloud-oriented companies deploy. By doing so enterprise/third-party creators of end solutions alike will benefit from speed to market, a pay-as-you-go model, and the increasing number of locations these providers are located in.

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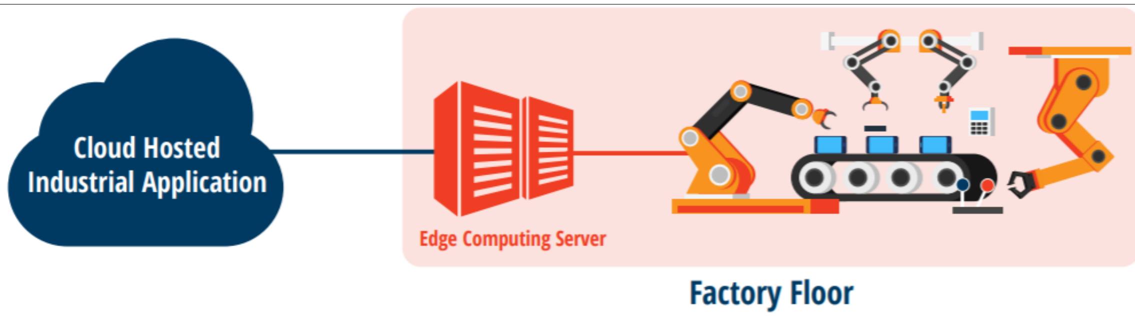
Moving down the supply chain, these established customers in particular will likely look to their network of hardware providers to implement custom/niche solutions during the initial build period, similar to that of a cellular network buildout ahead of a more scaled ramp when standards take over. On the hardware level, we believe there will be an important land grab as silicon providers, for instance, look to gain initial footprints and demonstrate TCO of installing their hardware in edge infrastructure.

Figure 11 - Edge Computing Model Servicing A Factory Floor

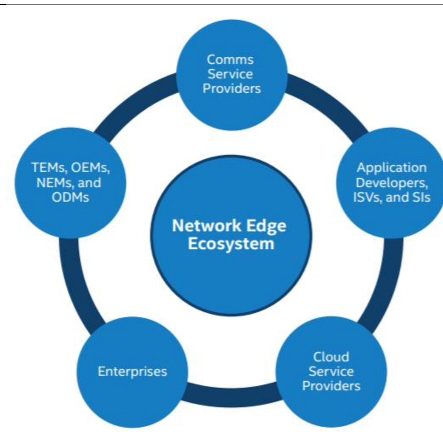


Source: ABI Research

Who Are The Key Players?

As discussed above, looking forward, we increasingly expect wireless and cloud convergence/collaboration to deliver edge computing. We expect 5G-enabled cloud services to become a significant driver of demand for cloud service providers (CSPs). While it may be too soon to tell, it will be interesting to monitor these CSPs and other tech/FAANG companies and specifically how far each will play up the stack on 5G-driven cloud and AI services. As an example, AT&T recently announced a partnership with Microsoft Azure for customers "to directly access a multitude of cloud options," including bringing the cloud to the edge for "low-latency cloud" and IoT solutions. AT&T and Microsoft are opening Network Edge Compute (NEC) technology, which weaves Microsoft Azure cloud services into AT&T network edge locations. This allows AT&T's software-defined and virtualized 5G core to deliver Azure cloud services for low latency applications.

Figure 12 - Edge Computing Requires TMT Industry Collaboration



Source: Intel

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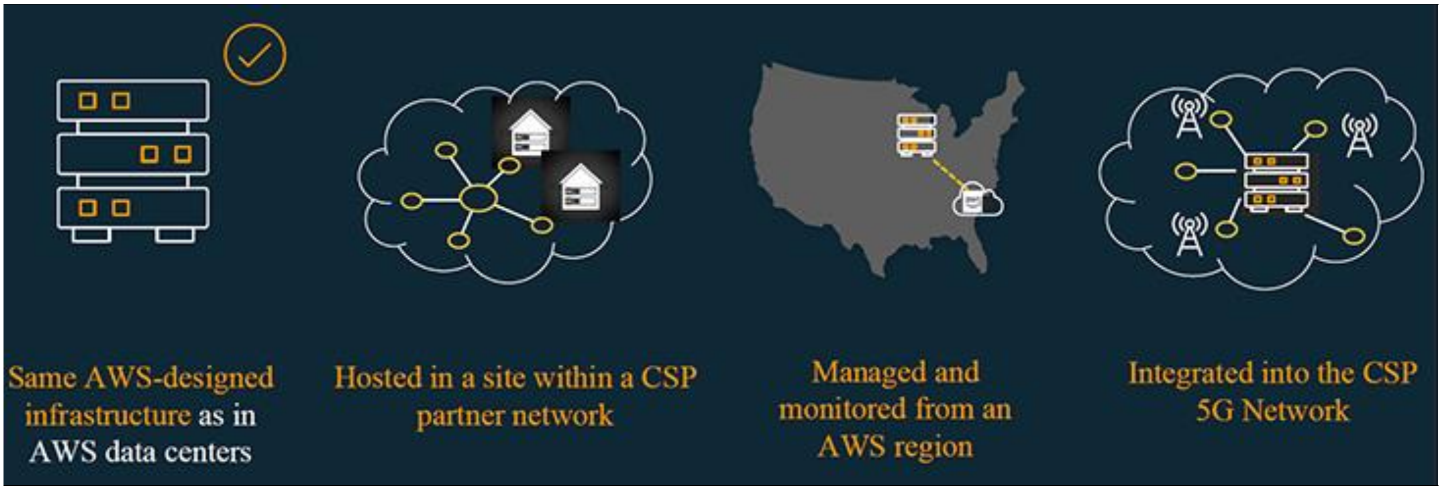
Some have suggested that Amazon's acquisition of Whole Foods was in part motivated to acquire real estate in dense US locations that can be used for edge servers. In December 2019 Verizon and AWS announced a 5G edge computing partnership. Verizon will be the first carrier to use AWS Wavelength, Amazon's platform to let developers build super-low-latency apps for 5G. The company's joint announcement highlighted the ability to bring native AWS environment features such as APIs, management console, and tools to the edge of the network to enable single-digit millisecond latency to mobile and connected devices.

- **Key quote from AWS / Verizon Edge Collaboration:** "In placing AWS compute and storage services at the edge of Verizon's 5G Ultra-Wideband network with AWS Wavelength, AWS and Verizon bring processing power and storage physically closer to 5G mobile users and wireless devices, and enable developers to build applications that can deliver enhanced user experiences like near real-time analytics for instant decision-making, immersive game streaming, and automated robotic systems in manufacturing facilities.

Figure 13 - Amazon Wavelength Extends Its Cloud Environment To The Network Edge To Deliver Low Latency Applications



Source: Amazon

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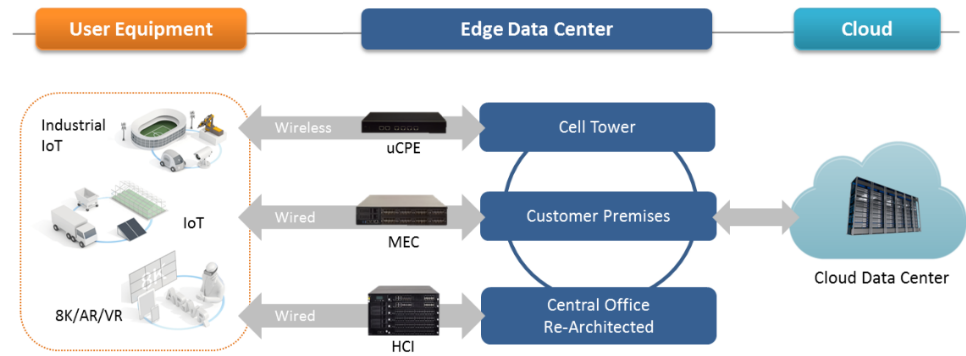
Key Considerations & Characteristics of Edge Hardware & Software

Ultimately, as compute and storage resources get pushed closer to the network edge, we see multiple ways resources can be delivered to the end user. As illustrated in the figure below, this can be via a wireless connection from a cell tower, on-premise datacenter, or wired connection to the emerging class of edge datacenters.

Figure 14 - Edge Compute Can Be Delivered In Multiple Ways



Source: Lanner Electronics

As such, we expect edge servers to be delivered in fragmented form factors in a variety of physical locations; essentially they will take on a variety of structures. These “micro datacenters” are often modular, minimize energy consumption and physical footprint, and can be standalone rack-level systems with all traditional datacenter components including cooling, networking, storage systems, and security. These smaller scale server installations can be located virtually anywhere that uninterrupted power supply can be deployed as long as these power, cooling, and ruggedness requirements are satisfied. Micro datacenter layouts, for instance, could include servers at the bottom of a basestation tower, or even a few servers placed virtually anywhere running a specific enterprise application such as a cloud hosted rack on a datacenter floor. They can range in size from a shipping container to a single server rack. While current micro datacenters are often shipped preassembled, we expect cloud and communications service providers will also install edge datacenters themselves where they need to be heavily customized for their specific customer workloads.

For analyzing the edge, we believe there are several key differences to traditional on-premise or hyperscale datacenters.

- **Location at the network edge, near devices –** Servers will need to inherently be installed closer to their end devices, and thus at the network edge. This requires a physical location that makes sense both from the networking perspective and the physical requirements described above. The diverse locations of these server locations will also help satisfy data locality and security regulations and standards.
- **Fewer servers per site –** Location will be limited, and the servers will be supporting inherently fewer end devices and thus will be smaller in scale. This changes the economics of the market. Gartner defines an enterprise datacenter as having 101-500 racks and operating a footprint of 5,000-15,000 square feet, while large datacenters are 500+ server racks and 15,000+ square feet. At typical datacenter rack has 42 slots, meaning any footprint >4,200 servers is considered an enterprise or large datacenter, a footprint which is not feasible in the majority of locations.

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- **Less controlled environment –** Servers are extremely sensitive to environmental factors such as heat, humidity and motion. Servers installed at the edge of a network will be inherently more difficult to control for these factors.
- **Power requirements –** Servers are power-hungry devices. Globally in 2018, data centers consumed an estimated 198-terawatt hours of electricity, or almost 1% of the total annual electricity demand. They will need access to a power source that is capable of delivering high voltages and is extremely reliable.
- **Secure –** One of the key benefits of edge computing is having data more secure by having it in a disaggregated environment, away from other servers. Edge servers will need to be in places where they cannot be tampered with – both physically and over the network.
- **Less data transit:** Sending large amounts of data over networks carries significant cost, especially for IoT/IIoT applications that produce a lot of data. With software business logic running at the edge, larger volumes of data can be processed locally, with intelligent gateways enabling low-value/ephemeral data to be used & discarded locally while only high-value data is sent back to the cloud, optimizing the use of overall network resources.
- **Higher throughput:** Near instant compute & analytics can be brought to the edge, reducing reliance on network bandwidth and lowering data processing latency. This is especially powerful for applications that rely on Machine Learning inference and/or need <100 milliseconds of throughput to execute tasks, including Smart applications (i.e., manufacturing, energy, surveillance), Autonomous applications (i.e., cars, drones) and Immersive applications (i.e., AR/VR, computer vision wearables).

Edge Computing & Enabling Technology From A Government & Policy Perspective (Washington Research Group)

The National Security Imperative Of Edge Tech (Schweizer)

Any portion of this report prepared by a member of Cowen Washington Research Group is intended as commentary on political, economic or market conditions and is not intended as a research report as defined by applicable regulation.

Technologies that enable edge – cloud/data storage, AI/machine learning, 5G – have been identified as critical in the geopolitical competition with China. These new technologies are considered vital to national and economic security. Government policies on export control, foreign investment, and intellectual property will factor in controlling China's access to these and other technologies.

DoD has taken the lead for USG policy and spending in these areas, although there are other national level efforts, military and civilian and classified and unclassified. DoD wants adopt/adapt commercial technology for both warfighting and business operations purposes. Other government agencies will do the same. The USG market, however, is not large enough to drive commercial R&D and innovation, but it is a significant niche market that major companies are pursuing.

Cautiously Positive Regulatory Outlook For AI And Edge Computing (Gallant)

As noted above, the Cowen TMT team believes AI is the key driver in stimulating demand for edge computing solutions. Later in the series, we address the outlook for U.S. and European policy to influence AI uptake. We believe U.S. and European policy will generally be supportive of AI development and thus edge computing. In particular, we believe Europe's desire to spark digital innovation – and "catch up" to the U.S. via AI-driven tech – may well restrain Europe's regulatory tendencies. In the U.S., we think the FTC is likely to continue its light-touch approach in tech policy that helped create U.S. global tech leadership. The main U.S. variable we see is whether Trump (good for AI/edge growth) or Biden (slightly riskier for AI) wins in November.

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Industrial Policy, The Breaker of Chains & The Digital Iron Curtain (Krueger)

The 30-year bipartisan consensus in Washington that trade and globalization was a net positive was already gone pre-COVID19. Regionalization is the new globalization with industrial policy, managed trade and national champion policy the new foundation of an alliance that has the GOP and their brethren in organized labor singing from the same hymnal. On the U.S.-China narrative: supply chains, investment restrictions, and export controls will be the primary fronts in 2020 and beyond – regardless of who is President and who controls Congress. U.S. companies will need to be aware of this as edge cloud is deployed at scale with de-centralized datacenters in more diverse physical locales.

**More to come as part of this series regarding government policy and regulation*

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PART 5:
ENABLING & EMPOWERING LOCALLY – POWER TO THE PEOPLE (AND THE ROBOTS)

Ok, so the edge is here. In the final part of our series, we explore what that actually means to our lives as devices leverage newly available power and speed, next generation applications that were previously impossible, inefficient, or not even thought of are developed, and we all rethink the barrier between man and machine. It's that last point – that convergence of human and machine interaction that links the seemingly disparate topics we explore here.

Our report spans 5 senior analysts / subsectors:

Industrial Automation & Robotics: Joe Giordano – HERE

Autonomous Vehicles & Smart Cities: Jeff Osborne – HERE

Consumer Edge Devices: Krish Sankar – HERE

IT Services: Bryan Bergin – HERE

Video Games: Doug Creutz – HERE

Industrial Automation & Robotics

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Edge computing will be a key enabling technology for the Industrial Automation market promising to bring digital enablement, connectivity and real-time data processing to the factory floor and into the hands of workers. Industrial applications where real-time decisions and high compute power can be used to improve operations, and increase productivity, asset utilization and safety should all benefit from the adoption of edge computing. **The technology itself serves both as a means and an end.** Added local power with low latency deepens the applications that traditional automation providers (like ROK, ABB, Siemens, Schneider Electric, etc.) can offer in real-time and allows mobile robots to act as intelligent edge enabled tools autonomously.

The trend toward automation is characterized by the application of information and communication between manufacturing technologies and processes that include cyber-physical systems (CPS), the industrial internet of things (IIoT), use of the cloud & edge computing and artificial intelligence. In other words, machines and sensors are connected to a system of high compute capabilities that can visualize production/tasks and use real-time data to make decisions on its own.

According to Allied Market Research, the total factory automation addressable market is estimated to be over ~$200B and is expected to grow 5-8% per year over the next 5 years. We expect the deployment and adoption of edge computing by manufacturers to serve as both a catalyst and accelerator for industrial automation as it becomes more attractive for many companies from an ROI perspective, makes the technology more user-friendly and viable, and brings new high-tech products and solutions to the market.

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Major Edge-enabled Industrial Automation use cases are: Simulation and Digital Twins, Augmented Reality, Robotics, Machine Learning, and Machine Vision

We identified five major Industrial Automation use cases that are enabled by edge computing. These include products and services where the minimum viable requirements to operate satisfactorily depends on an edge architecture to provide a combination of low latency, high computing power, high bandwidth capabilities (low data transmission costs), storage, and cybersecurity. Additionally, we included areas that have seen good adoption rates over the years and are likely to get an additional benefit as edge-computing capabilities come online.

Five Major edge-enabled Industrial Automation use cases:

1. Simulation and Digital Twins
2. Augmented Reality
3. Robotics
4. Machine Learning
5. Machine Vision

It's important to recognize that the Industrial automation market benefits from edge-computing are *a second-order effect*, meaning it's an adjacent market that will proliferate as a result of the adoption of this technology. In other words, it's an indirect outcome of edge computing. This therefore makes it inherently more difficult, if not impossible, to predict and forecast the total size of these markets given the various variables involved and wide range of potential outcomes. We instead adopt a more qualitative approach by recognizing which use cases are likely to grow as a result, looking at the requirements that edge computing will address for them. An appropriate analogy would be trying to estimate the growth and size of the ridesharing industry enabled by the introduction of smartphones and 4G Cellular networks back in the late-2000s, something not many people could foresee or recognize. As a result, we would also expect new technologies that we do not currently foresee coming to market as a result of edge computing, much like it has happened in past technological innovations.

The benefits of this more holistic approach is clear when thinking through impact to companies like APH and TEL. Our TMT team expects edge server demand to reach ~1.6MM units by 2028, roughly 10% of total servers. Strictly from a content standpoint, that likely equates to a TAM for edge servers of somewhere around $150MM (and the net impact is smaller when we consider potential cannibalization of other servers elsewhere). So, while both TEL and APH will gain some benefit from the infrastructure buildout, the larger impact will be felt through new capabilities their customers will deploy in markets like auto, consumer devices, industrial, medical, etc.

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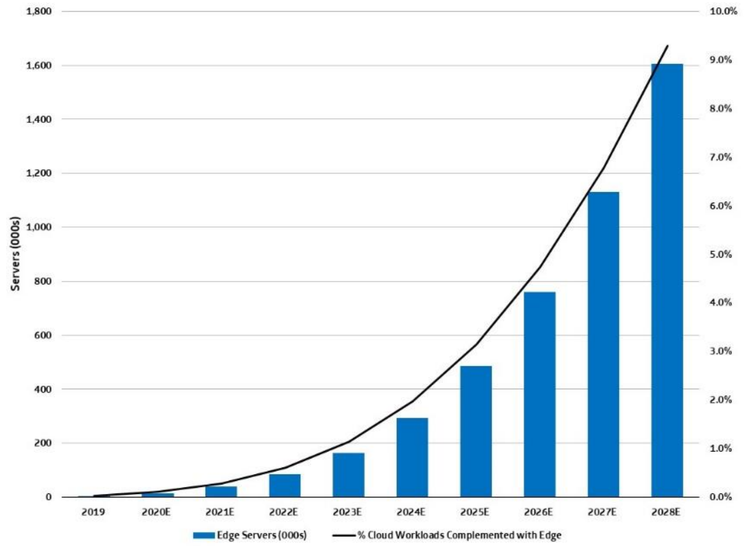
Figure 15 Edge Servers Expected To Ramp Quickly From Infancy To Nearly 10% Of Total Servers By 2028



Source: State of the Edge, Cowen and Company

Why Edge Computing Is Driving The Next Wave Of IIoT Adoption

"Our business goals require us to reduce the time between asking a question and getting an answer. How do you reduce time to insight when it comes to your data? You create your analysis as close to your data as possible."
-Marshall Daley, Tableau Software

By the year 2025, total data generated is expected to be 175 zettabytes (1 zettabyte equals 1 billion terabytes), a 10X increase from 2016. IoT devices alone are expected to generate 90 zettabytes, according to IDC. This almost incomprehensible amount of data will be catalyzed by four enabling technologies: IoT devices, 5G, Artificial Intelligence and edge computing. Naturally, all this data will need some sort of real-time action at the source.

Manufacturing plants also generate immense amounts of data that is not necessarily being used appropriately, or most effectively. According to IDC, a smart factory can generate up 1 Petabyte per day, coming from devices such as industrial computers, cameras, and sensors. The trend has certainly been toward leveraging this information to develop, for example, algorithms and statistical models that give them insight into where operations can be improved, and waste can be eliminated. What this lacks though, is a real-time capability and insights from data generated at specific moments in time. Edge computing can potentially push boundaries further and allow much more complex modeling and analysis to be done quickly on site.

Bridging The Gap Between OT And IT

One of the biggest challenges ahead is driving the convergence between Operational Technology and Information Technology.

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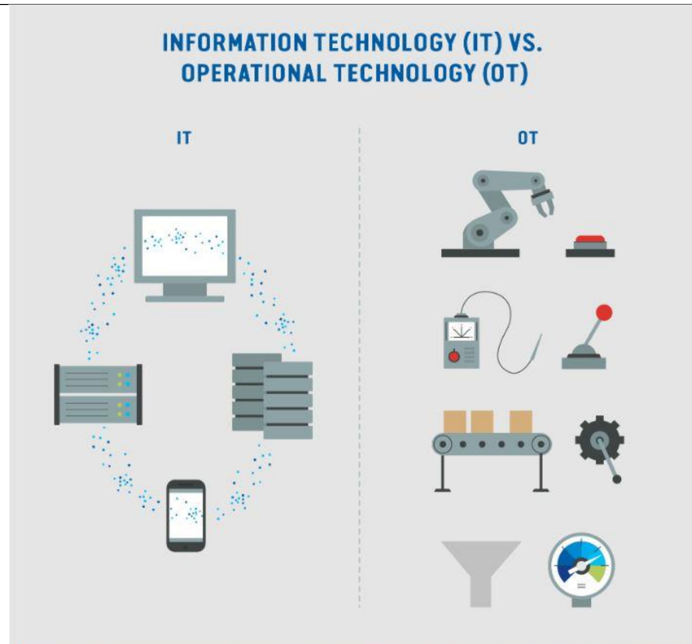
Figure 16 Linking IT And Operational Infrastructure A Key Focus for IIoT



Source: Coolfire Solutions

Historically, these two fields have operated separately. IT has relied more on programming, algorithms, and modeling to make decisions while also having a standard set of communication and networking protocols (such as ethernet). On the other hand, OT processes are heavily focused on a specific task, require more human oversight and in many cases, are not connected to the internet and rely on their own proprietary communication protocols. Nevertheless, in order to achieve the full potential of IIoT, this gap needs to be closed and the data generated by OT needs to be translated and standardized so IT can make sense of it and use it. Enterprises are interested in bringing these devices online to be able to apply the intelligence of IT, especially given all the data being generated. Another obstacle of converging these two fields is the importance of data privacy, when in many cases companies are reluctant to let data generated by OT machines be handled by the IT side.

Identifying The Playing Field

The spectrum of companies offering automation solutions is broad. There are large publicly traded established players in the space offering a full suite of automation solutions (PLCs, motion control, robotics, software, etc.) along with others that focus solely on one solution, such as Machine Vision or Simulation. On the private side, there are smaller companies and startups that are typically trying to solve a specific problem and in many cases offering newer technologies that are attempting to disrupt the existing market.

Companies offering a full-suite of solutions include the typical public large-scale players such as ABB, Rockwell, Emerson, Honeywell, Siemens and Schneider. These companies have historically focused on the motion control space (motors, drives, servos) as well as control systems and related products (PLCs, Distributed Control Systems). More recently they have embodied the IoT trend by building IoT platform architectures to include offerings in both the OT and IT world. The IT side includes software offerings,

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AI/ML initiatives, networking and servers (sometimes through partnerships with large-scale players like Cisco, HP, Dell, etc.).

On the other side of the spectrum are the focused companies, which typically offer one solution (or a combination) aimed at solving a specific problem in which they are the experts. Examples of this include Cognex and Keyence in Machine Vision, ANSYS in Simulation and PTC and Dassault in Product Lifecycle Management software (PLM). The web intertwining these companies with larger-scale providers gets more complicated almost daily.

Figure 17 Public Companies And Capabilities

Company (Ticker)	Traditional Automation (motion control, PLCs)	Sensors and Connectors	Simulation and Digital Twins	Augmented Reality	Predictive Diagnostics and Maintenance	Asset tracking	Machine Vision	Robotics	Machine Learning	Oscilloscopes and protocol analyzers
Amazon Robotics (AMZN)								✓	✓	
6 River Systems (SHOP)								✓	✓	
ABB (ABB)	✓		✓	✓	✓			✓	✓	
Amphenol (APH)		✓								
ANSYS (ANSS)			✓		✓				✓	
Cognex (CGNX)							✓		✓	
Dassault Systèmes (DAST.PA)			✓	✓	✓				✓	
Emerson (EMR)	✓	✓			✓	✓			✓	
Fanuc (6954.T)	✓				✓		✓	✓	✓	
Fortive (FTV)										✓
Honeywell (HON)	✓	✓	✓	✓	✓			✓	✓	
Keyence (6861.T)	✓	✓					✓			
Kuka (KU2G.DE)		✓					✓	✓	✓	
PTC (PTC)				✓	✓				✓	
Rockwell (ROK)	✓	✓	✓	✓	✓				✓	
Schneider (SCHN.PA)	✓	✓			✓	✓		✓	✓	
Sensata (ST)		✓				✓				
Siemens (SIE.FWB)	✓	✓	✓	✓	✓	✓			✓	
TE Connectivity (TEL)		✓								
Teledyne (TDY)							✓			✓
Teradyne (TER)			✓		✓			✓	✓	
Yaskawa (6506.T)	✓	✓						✓	✓	

Source: Cowen and Company, Company reports, websites and interviews

The private landscape includes startups that are also considered to be focused usually on solving a problem that hasn't been solved by the bigger, more established companies. These include Bright Machines and Opto22 in next-gen automation, FogHorn focuses on ML-driven edge software platform, Humatics for Asset Tracking and various mobile robotics companies we've covered before such as Fetch, Locus, 6 River (now a part of Shopify so no longer private) and Vecna.

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Figure 18 – Private Companies And Capabilities

Company	Next-gen Automation (3D, remote operations)	Robotics	Predictive Diagnostics and Maintenance	Asset tracking	AI/ML software
Bright Machines	✔	✔			✔
C3.ai					✔
Covariant					✔
Fetch		✔			✔
FogHorn			✔		✔
Humatics				✔	✔
Locus		✔			✔
Opto22	✔				
Realtime Robotics	✔	✔			✔
Sensia			✔		✔
Soft Robotics		✔			✔
Vecna		✔			✔
Veo Robotics		✔			✔

Source: Cowen and Company, Company Websites and Interviews

For a more comprehensive list of companies with exposure to edge-enabled technologies along with descriptions, please refer to a later section titled *List of Public and Private Company with Exposures HERE.*

Interview With Fran Wlodarczyk, Senior VP Of Architecture & Software At Rockwell Automation

To get a better grasp of how large-scale automated players are capitalizing and positioning themselves in the edge computing trend, we interviewed Fran Wlodarczyk, Senior VP of Architecture & Software at Rockwell Automation. Mr. Wlodarczyk highlighted that hardware cost and AI capability has improved meaningfully in recent years, and having scalable hardware where customers can deploy edge-based software is critical. 100% of Rockwell's products and solutions are considered edge-enabled, and ease of use (from the customer's view) is an area where suppliers can differentiate. Their biggest challenge has been doing consistent deployment across manufacturing plants, and they are addressing that by working on remote device management software as well as software containerization (deploying OS-level virtualization to run distributed applications instead of launching an entire virtual machine for each application).

Rockwell also agrees with our view that the "edge-enabled space" TAM is very hard to quantify, partly because the space itself is still being defined and relatively new. In terms of offerings that would benefit from a rise in compute power, they highlighted running complex physics-based models using Digital Twins through their partnership with ANSYS. This could help companies optimize production processes using real-time analytics.

Another trend we have noticed mentioned by Rockwell (as well as other companies we spoke with) is the importance of data privacy. Manufacturing customers tend to be very sensitive to how their data is being used and where it's stored. Therefore, solution providers like ROK have limited use of their customers data other than how it applies to application usage. For this reason, a lot of their customers have kept on-premise data servers instead of migrating a lot of workloads to the cloud. We think edge data centers have an opportunity here given their proximity gives them an advantage of safety (as well as latency and lower data transition costs) while still reaping the benefits of a traditional cloud architecture such as scalability.

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Industrial Automation Applications Enabled By Edge Computing

The range of industrial automation applications that are enabled by edge computing is diverse. Some use cases have been in place for decades, but the edge will open new capabilities for them, like Machine Vision and Robotics. Others, like Digital Twins and Augmented Reality, have seen more adoption recently and edge computing is likely to accelerate the rate as it makes the technologies more attractive and viable for end users.

To determine which industrial automation applications will be most benefited by edge computing, we ranked each use case by its specific requirements (from low to high) of each of the five characteristics that the edge provides: low latency, high bandwidth (i.e. lower data transmission costs), compute processing power, storage and cybersecurity & data privacy.

Figure 19 – Edge Requirements By Application (From Low To High Requirement)

Automation Technology	Low Latency*	Bandwidth	Compute Processing Power*	Storage	Cybersecurity & Data Privacy
Simulation & Digital Twins	High	High	High	High	High
Augmented Reality	High	High	High	Medium	High
AI & ML-based Software	High	Medium	High	High	High
Robotics (Industrial, AMR, Collaborative)	Medium	Medium	Medium	Medium	High
Machine Vision	Low	Medium	Medium	High	High

*As it relates to live data streamed or processed in nearby servers, Robotics and Machine vision also have on-board processing power.
Source: Cowen and Company

Simulation And Digital Twins

The next frontier in Simulation includes using Digital Twins during the operational process to make use of actionable real-time data

In industrial environments, simulation has been around for decades (ANSYS, a simulation software pioneer, was founded in 1970) and is used to design, test and engineer new products. With recent technological breakthroughs, simulation has become more important in the role of product testing. For example, in the production of batteries for electric cars, simulation software can be used to replicate the physical capabilities for materials testing, which reduces both costs and waste. The next frontier is being able to use simulation across the entire product life-cycle – known as pervasive simulation. This not only includes ideation, design, and manufacturing, but also during operations by utilizing **Digital Twins** to make use of real-time actionable data.

There are four stages in the product life cycle:

- Ideation: coming up with an idea for a product
- Design and Analysis: designing the product and prototyping it
- Manufacturing: making the product
- Operations: running the process, understand and optimizing the performance and maintaining it

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Figure 20 – The Product Life Cycle

Source: ANSYS

A **digital twin** is a simulated, virtual model of an actual working product in the field. The ability to take a virtual representation of how elements and the dynamics of a device operates come from sensors that are mounted on the physical product combined with the use of Machine Learning algorithms to develop highly complex "deep physics" simulation models to accurately predict how the asset behaves in various environments. With this information engineers can determine how the device works and lives throughout its life cycle as well as make informed choices for future design and improve the accuracy of simulations. When simulation is added to the digital twin ecosystem, conditions that would be normally impossible to see and analyze can be tested. Another important characteristic is the ability of digital twins to enable true predictive maintenance, helping companies act "just in time" to address any product issues that may come up, predicted by the digital twin with the help of sensor data.

ANSYS believes the Digital Twins market can be worth anywhere between $5.5-20B by 2030, or roughly a ~45% CAGR

Digital twins can be applied to a wide variety of systems such as aircraft engines, wind turbines, offshore oil platforms, office buildings and entire manufacturing operations. Digital twins have been a key advancement in simulation because they have expanded the simulation market from design and engineering to manufacturing and operations. According to a survey by Gartner, at least 50% of manufacturing companies with annual revenues of more than $5 billion plan to start at least one digital twin initiative by 2020. The potential size of the market is hard to determine, but ANSYS believes it can be anywhere from $5.5-20B total addressable market by 2030 or roughly a ~45% CAGR (from ~$100MM in 2018).

Digital Twins and Simulation require an edge architecture for various reasons. First, computing power is key given how advanced and process-heavy modelling has become, especially as it incorporates different physical and chemical properties when designing new products, testing them out and simulating a physical asset. Second, a lot of data can be generated from these models as well as sensors; therefore it becomes more cost efficient to transmit this data to a nearby edge data center rather than to the cloud. Third, for certain simulation applications like Digital Twins, latency is an important factor for aspects like predictive maintenance. A difference of milliseconds can mean the difference between acting proactively to fix an issue in hours versus having machine downtime for an extended period due to a longer repair.

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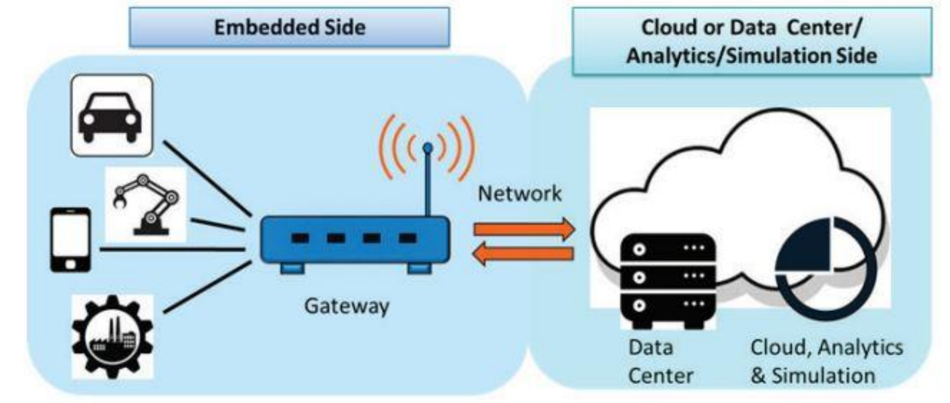
Figure 21 – Digital Twin Architecture



Source: ANSYS

Flowserve partnered with ANSYS and PTC to create the digital twin of a pump and test different conditions and operating environments. By creating and simulating different environments in the digital twin, they were able to improve uptime, predict where potential faults would occur, and source potential problems.

To test, a digital twin was used to simulate an environment of stress and predict accurately the source of the problem. An operator purposely introduced an anomaly in the pump by closing the suction valve from 100% to 50%. The embedded sensors instantly indicated that there was a problem, but they provided no information for diagnostics (you cannot *look* inside the physical product) or for determining what would happen if different actions were taken to address the problem. However, the digital twin can be used to leverage the same sensor information and apply it to simulation models. The model began exhibiting the same symptoms as its physical counterpart and enabled engineers to look inside the virtual product to see exactly what was going on. As they looked at the different anomalies, such as the formation of bubbles, implosion of voids and noise generated, the digital twin was used to evaluate the impact of adjusting the operating conditions and in effect determined that the issues were caused by the suction valve (which the operators stressed at the onset as the test), proving that the model can take a series of outcomes and determine the likely cause.

Digital twins can also be used across an entire manufacturing line (naturally requiring even more compute power) and can test out different operating environments. If an operator wanted to see if a particular process could run faster without disrupting the entire line, that condition can be simulated and evaluated off line and prevent real-world downtime or issues.

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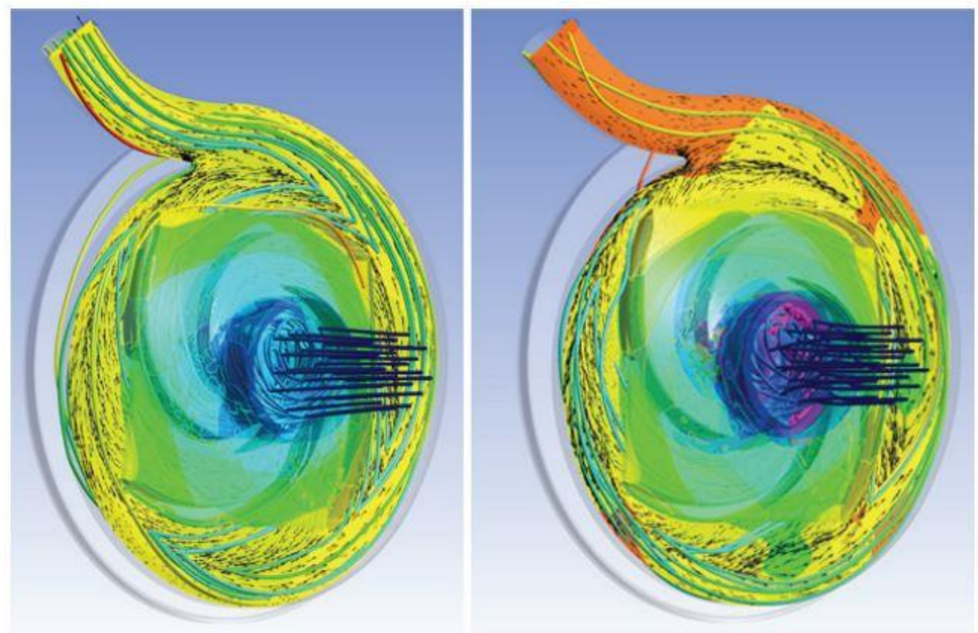
Figure 22 – A Digital Twin Version Of A Pump, Left Is Operating At Normal Conditions While Right Is Showing Signs Of Stress



Source: ANSYS, Flowserve

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Augmented Reality

Augmented reality (AR) refers to the use of software and hardware applications to provide users with digital information that is visually overlaid into their immediate surroundings. This is accomplished with the use of a device like a pair of smart glasses or a tablet. AR has the potential to change the way manufacturing plant employees work and interact with production lines and assets. Mobile devices and smart glasses can provide real-time direction, training, asset diagnostics, and analytics for plant operators using AR.

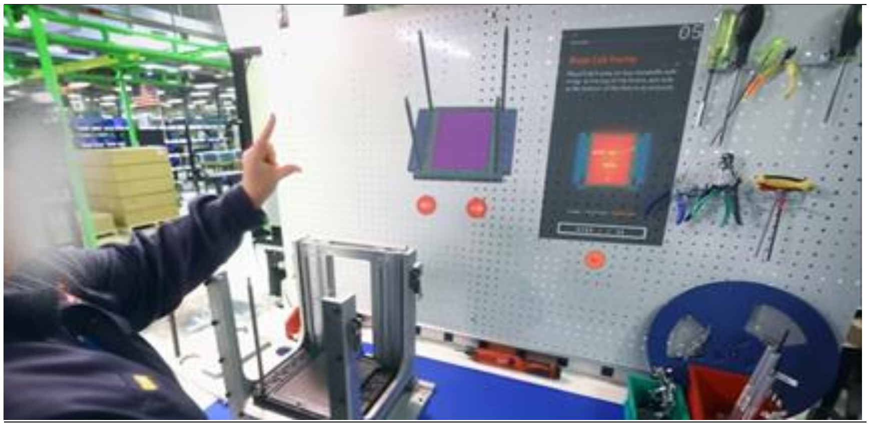
Edge computing is an ideal and necessary platform for AR given it requires *very* low latency and high compute power to operate effectively and at a user-acceptable level. Without the necessary computing power and latency, AR becomes impractical because it ceases to appear natural to the user – think about overlaying an instruction on top of a machine in a plant with smart glasses and the visual taking time to load or having delays then the user looks elsewhere. Various tests have been done where delays in real-time interaction and visualization leads to user acceptance issues (even dizziness), which affects the adoption of the product.

Another factor to consider is that given the high computing power required, for example for rendering algorithms, it would be too costly to depend heavily on a hyperscale cloud provider. Rather it becomes cheaper to transfer and process the data in a nearby edge data center. Given the high requirement of graphic intensive processing, it is likely an AR solution will also depend heavily on the edge to identify and analyze objects and display the processed information. It will also use Hyperscale cloud for longer-term storage of content and tweaking ML models.

Augmented Reality can be used in Industrial settings for direction, training, diagnostics, and analysis. BAE created interactive Mixed Reality experiences in hours that led to assembly times being cut in half.

Using PTC's ThingWorx Studio software, BAE created interactive Mixed Reality experiences for HoloLens (Microsoft) in hours and at a tenth of the cost. Using these guided step-by-step work instructions, first-line workers were able to assemble battery cells using 3D models in half the time usually needed, and the company was able to train new people 30-40% more efficiently.

Figure 23 – An Assembly Worker Of BAE Systems Uses Mixed Reality To Aid Her Battery Assembly Process



Source: PTC

Robotics – Industrial, Collaborative And AMR

Please see HERE for detail on our conversations on COVID impacts within the robotics industry.

The robotics space includes industrial, collaborative, and mobile robots. This industry has received wider attention recently as adoption has accelerated into new industries and geographies. Technology has improved meaningfully, costs have come down, and labor markets have become constrained, making adoption not only more attractive but increasingly essential. These trends have been accelerated due to the COVID-19 global pandemic, and ensuing supply chain disruptions have proved the importance of having automation in place for safety and social-distancing reasons. Our conversations with industry participants suggest incoming interest has rising in response.

Robotic deployment isn't necessarily edge dependent, it's the robots themselves that are essentially the edge devices. We spoke with leaders across the mobile robot space and found that the vast majority of compute sits on the robot itself (thanks in part to powerful GPU processors). This provides for minimal latency – a critical requirement in obstacle avoidance and important given collaboration with humans. In some cases (depending on architecture and design of the robot), data is sent from local servers to the robots in the form of simple commands or tasks - such as "Pickup item X"- while the robot's computer does the actual execution. Periodically, data is sent back to cloud data centers for orchestration, model tweaking and training, and location, navigation, and software updates.

It is likely that when edge-data centers come online at greater scale they will take share of the computing processing and storage from both the on-premise servers (for scale reasons) and the cloud (for cost reasons). An example of this would be when there needs to be a playback of a specific scenario where there was an issue or problem. In this case substantial amounts of data are sent from the robot to the cloud, and an edge server would prove to be a cheaper option to run this process. This may give customers

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yet another reason to deploy robots, especially those who find it too costly and complicated to run their own servers.

An interesting difference we noticed in our discussions with companies in preparation for this report is how industrial customers and retail/e-commerce customers handle the use of data differently. Customers in traditional manufacturing tend to be more sensitive with their data privacy and cybersecurity and therefore want to own the data generated from devices and use their own servers to process the data. They are also more sensitive to sending data to the cloud, other devices, and giving vendors (such as robot manufacturers) access to the data. This results in most manufacturing users relying more on on-prem servers versus the cloud for critical functions. Meanwhile, many of the e-commerce and logistics customers agree to allow the robotic supplier to collect robot data that is then used to improve operational capability across the customer base.

For a more in-depth look into Robotics, please see our reports on industrial robotics (HERE) and warehouse / logistics robots (HERE).

Machine Learning

Machine Learning is used to aggregate data generated by IIoT devices and generate real-time insights for condition-based monitoring, predictive maintenance, and asset optimization

Both Artificial Intelligence and Machine Learning are key components of the industrial automation use cases we have covered, which make use of these types of algorithms to perform some part of their broader function. ML-based software can also be thought of as a use case itself. Using data generated by the IIoT devices (sensors, PLCs, robots, drives, etc.), this type of software can aggregate, process, and analyze it to generate real-time insights such as condition-based monitoring, predictive analytics, and asset optimization.

Predictive Analytics uses the vast amount of data generated by industrial sensors to generate real-time insights, relying heavily on Machine Learning algorithms. This data can tell plant operators when a machine is required to have maintenance, when it's about to fail, or when it's not operating at optimal conditions. Historically, many manufacturers have used *historical* data to gain insights on their operations, but predictive maintenance is about using *real-time* data to generate actionable insights that reduce downtime and increase plant efficiency.

An edge architecture is important for ML software because real-time action is a requirement; a few seconds may mean the difference between a quick fix in a plant or a larger, longer repair (maybe even a full replacement) of a certain component or machine with costly associated downtime. There are also safety concerns as some operations deal with more dangerous tasks (material handling, boilers, flames, etc.) where latency becomes paramount for preventing accidents.

ML models must make use of both the hyperscale cloud and nearby edge servers to make the best use of each. Hyperscale cloud servers are best fit to train the models on a long-term basis with large amounts of new data generated by sensors and devices, but this data would be sent periodically and in batches, not constantly as it would be too costly. The actual models themselves would sit as near to the use cases as possible, with an edge data center being an ideal solution given that latency is a key attribute and decisions need to be made on a real-time basis. An example we're all familiar with to understand latency is the experience of the delay that happens when we speak to Alexa or Siri. This happens because the data is sent to a centralized data center, where a complex speech recognition model (known as natural language processing) and inference algorithms use dense computing resources to figure out what was said,

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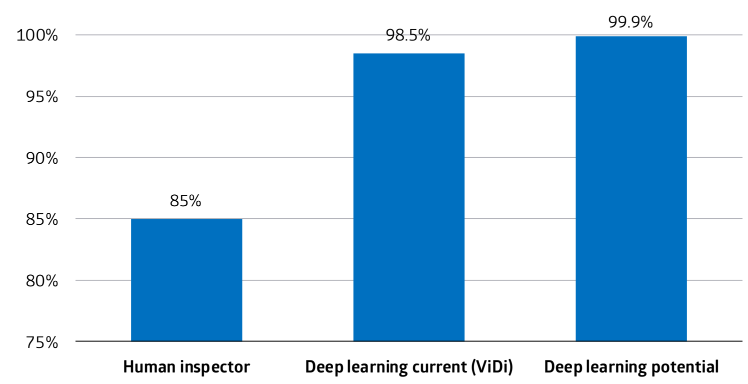
determine a response, and send it back to the user. The response is fast, but not instant, and certainly not fast enough for real-time industrial settings.

General Electric partnered with FogHorn to use their edge Intelligence software to detect early defects and improve capacitor production yield. GE was facing a multi-million-dollar scrap problem as they weren't using real-time insights in their production process. The production cycle included 30+ machines, which generated large amounts of RFID sensor data, which FogHorn was able to aggregate using an edge intelligence layer for real-time condition monitoring during the production process. Multiple challenges were addressed with their solution. First was to improve pack press monitoring – in the traditional statistical process control an operator needs to interpret and enter machine data, which is highly time consuming and error prone and relies on traditional cloud-based analysis and significant amounts of data transfer. FogHorn's solution automated the interpretation of the machine data and optimized processing between the edge and the Cloud. A second challenge involved having operators select which oil fill was required from two types, which depends on the capacitor design – again, another manual process. FogHorn also automated this process by using serial number discovery and streaming the correct oil type directly to the PLC. With this solution yields increased 8%, and because it ran at the edge, it required only a few percentage points of bandwidth versus a cloud-only architecture.

Machine Vision

Machine vision is used in industrial applications to gauge, inspect, guide, and identify parts and pieces in a wide variety of industrial processes. It aims to replace human inspection with cameras and algorithms that are more efficient at detecting a faulty product, measuring the size of a package, or picking a specific product based on a set of specifications. More recently, with Deep Learning capabilities, a new frontier has opened for Machine Vision applications in cases where identifying a characteristic is more subjective (such as in life-sciences applications – is this cell abnormal?). Traditional machine vision could not tackle the kinds of problems because it's almost impossible to program all the required attributes. Deep Learning models can be trained to learn exactly what it is they are looking for, and the more data is fed into the system, the better it becomes at the task.

Figure 24 – Increasing Efficiency From Human Inspectors To Deep Learning



Source: Cowen and Company, Cognex

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We consider Machine vision an edge beneficiary since it is a market that has been around for a long time and has consistently benefited from adoption rates (Cognex was founded in 1981) across a wide variety of industries (most notably semiconductors, consumer electronics, automotive and recently logistics). In its true sense, Machine Vision has always depended on and used some sort of edge architecture as the processing algorithm sits very close (or at the device-level) to the camera that generates the data. Going forward, the technology is likely to see benefits from nearby edge servers most likely within their Deep Learning solutions as the heavy data processing and storage (such as for model tweaking and storing big data) can take place closer to those devices that wouldn't necessarily be able to do the processing themselves. Machine vision can benefit from making the best use of the different parts of the edge network stack and optimize for each. The camera generates data, which itself (or a nearby computer) processes to make a decision (such as pass/fail) using a local software algorithm. The Hyperscale Cloud can be used for longer-term storing of big data and retraining and fine-tuning the Deep learning models, which is not as time sensitive.

Given the speed at which they operate, machine vision cameras generate immense amounts of data, much of which wasn't historically leveraged beyond what was needed to make the on-site decision. The devices were used to perform their specific on-site function (make a determination about the object it was looking at) but not to gain broader insights into the entire operation. Companies like Cognex are looking now at new technologies using edge gateway products to take advantage of data that is already being generated (potentially reaping a new, recurring revenue streams). These products, while more common elsewhere, are still early stage as they relate to machine vision cameras but seem like a logical extension.

An often-overlooked advantage of Deep Learning applications is the importance of scale in terms of data. Having larger sets of data than your competitor likely results in a superior algorithm given that it has benefitted from better input, training, and feedback data. This may also mean that once a customer installs a certain deep learning software and starts to iterate to newer and improved versions (which have benefited from feedback data), switching costs rise and relationships become stickier.

List of Public And Private Company With Edge Exposure

Publicly Traded Companies

6 River Systems is a Boston-based startup founded by former Kiva employees and recently acquired by Shopify, the multi-channel eCommerce platform for small businesses, for $450MM. The company has estimated revenues of $30mm and expenses of $25mm, according to the Shopify press release. Its flagship robot, Chuck, is an AMR that works collaboratively with warehouse workers to accomplish fulfillment tasks by leading workers to items on the shelves, letting them know what quantity is needed, and carrying the selected items through the facility. It uses state of the art sensors, machine learning, and AI to move around and adjust to the environment. It can carry a maximum payload of 160 lbs. The company cites a 12-18-month payback.

ABB traces its roots to 1883 and focuses on manufacturing electrical equipment in the robotics and industrial automation space. ABB offers a full-suite of automation products, from PLCs and servo motors to industrial software and robotics. ABB offers digital twins through its parentship with Dassault Systems. The company also has an IoT platform, *ABB Ability* which is an open architecture, unified, cross-industry digital portfolio that extends from the device to the edge and cloud. The platform consists of over 160 solutions that utilize artificial intelligence and machine learning to improve efficiency and productivity, safety and reliability, and security of customer operations.

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ABB Ability spans the entire lifecycle of assets, from planning and building to performance management.

Amazon Robotics (formerly Kiva Systems): Amazon acquired AMR pioneer Kiva Systems in 2012 for $775 million and decided to use the robots exclusively in-house, letting all their third-party contracts expire. This gave them a significant first-mover advantage as there weren't many scaled alternatives in the market. The now ubiquitous orange robots known as "pods" are designed to move racks irrespective of size and shape. They are controlled by a centralized computer using a secured Wi-Fi network, use infrared technology to detect obstacles and cameras to read QR codes and determine location and direction. Additionally, the robots can self-adjust and learn from crowdsourcing that aggregates data from other pods. The company currently has over 200,000 deployed across its more than 300 fulfillment centers, a number which is expected to keep growing.

Amphenol was incorporated in 1987 and operates through two reporting segments: Interconnect Products and Assemblies, and Cable Products and Solutions. The Interconnect Products and Assemblies segment designs, manufactures, and markets connectors, antennas, and sensors used in a broad range of end markets and applications. Connectors facilitate transmission of power and signals when attached to an electrical, electronic or fiber optic cable, a printed circuit board or other device. The Cable Products and Solutions segment designs, manufactures, and markets cable and value-add products and components that are used mainly in the broadband communications and information technology markets.

ANSYS is a leader in engineering simulation. Founded in 1970, its software is used to design and test new products that turn new concepts into successful products. Its engineering simulation software is used to predict how product designs will behave in real-world environments, meaning it is capable of modelling multiphysics environments and various chemical properties in materials design. More recently, it has focused more on Digital Twins, which stand to benefit from edge computing architectures.

Cognex is the leading provider of vision systems, vision software, and vision sensors used in manufacturing automation and industrial ID reading. The company manufactures and sells modular vision systems and identification products. The company's products are used to automate the manufacture and tracking of discrete items, such as cellular phones, aspirin bottles and automobile wheels, by locating, identifying, inspecting, and measuring items during the manufacturing and distribution process. The company has more recently entered the deep learning space with two acquisitions, bringing new potential applications to their available markets that traditionally could only be done by humans.

Dassault Systèmes is a French software company founded in 1981 that develops 3D design, 3D digital mock-up, and product lifecycle management (PLM) software. The company also offers simulation software and augmented reality solutions. The purpose of the company is to provide business and people with a 3D experience universe.

Emerson Electric is a manufacturer of products and solutions that serves the industrial, commercial and consumer markets. Their Automation Solutions segment offers measurement and analytical instrumentation and process control software and systems. Emerson also offers an IoT platform called *Plantweb Digital Ecosystem* providing solutions such as remote monitoring using sensors, gateways, controllers, and software.

Fanuc is a Japanese company founded in 1972 that provides automation products and services such as robotics (mostly articulated) and computer numerical control systems

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(CNC). It is one of the largest makers of industrial robots in the world, and the name is an acronym for Factory Automation Numeric Control.

Fortive was spun-off from Danaher in 2016 and it houses the Test & Measurement and Industrial Technology segments as well as Retail petroleum platform. Most of the businesses play in niche markets and are leading brands in their sectors. Specific to edge computing and networking, under its Tektronix brand Fortive makes oscilloscopes that measure complex electronic signals. Many of the company's products are also communication enabled to leverage generated data.

Honeywell is a multinational conglomerate that operates its businesses through four segments: Aerospace, Building Technologies, Performance Materials and Safety & Productivity Solutions. The company offers process technologies and automation solutions, sensors, motors, controls, industrial software and an IoT platform called *Honeywell Forge*.

Keyence is a Japanese company that develops and manufactures automation sensors, vision systems, barcode readers, laser markers, measuring instruments, and digital microscopes.

KUKA is a German manufacturer of industrial robots and solutions for factory automation. It offers everything from a single-source to a fully automated system. Most customers are in the general industrial and automotive industries. It is owned by the Chinese company Midea Group.

PTC is a global software and services company that aims to drive a digital transformation for industrial companies. They have four technology platforms consisting of 3D modelling (CAD), lifecycle management (PLM), data orchestration (IIoT) and experience creation (AR). PTC has a partnership with Rockwell, which also made a $1B equity investment in the company representing an 8.4% equity interest.

Rockwell Automation provides a full spectrum of automation capabilities, motion control, and information products and solutions to a globally diverse customer base spanning a wide range of end markets. Products include Programmable logic controllers (PLC), drives, Human Machine Interfaces (HMI), motion control, and industrial sensors. We spoke to ROK's Fran Wlodarczyk, SVP of Architecture & Software, regarding their edge capabilities and they said 100% of their products are considered "edge enabled" and they see opportunities in the future specifically in enterprise risk management, digital twins, remote device management and predictive maintenance. Rockwell differentiates themselves by focusing of ease-of use, scalability and compatibility. The company also has partnerships with PTC, ANSYS, and Schlumberger (SENSIA). More recently, the company acquired ASEM, which offers a complete range of industrial PCs as well as hardware HMI hardware and software, remote access capabilities and secure industrial IoT gateway solutions.

Schneider Electric specializes in electrical equipment offering products for automation in buildings, homes, and factories as well as industrial control systems and electrical grids. Schneider offers an IoT platform called *EcoStruxure* which is open architecture and targeted for Homes, Buildings, Data Centers and Industries used for analytics and services.

Sensata Technologies is a global manufacturer of sensors and controls. The industrial technology company is incorporated in the Netherlands and sells its products and solutions in various end markets, though the automotive industry is by far its largest exposure. Sensata's products are mainly sensors that measure a physical phenomenon,

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such as pressure, temperature, or position, and translate it into electronic signals that can be used by control systems or microprocessors to regulate or give information to a process. The company's customers consist mainly of global automotive OEMs and their Tier 1 suppliers.

Siemens is a German conglomerate and one of the largest industrial manufacturing companies focusing on Industrial Automation, Energy, Healthcare, and Infrastructure. Siemens has an established Digital Industry initiative with the intention of driving Industry 4.0 forward. The company's *MindSphere* platform, a cloud-based open IoT operating system, connects products, plants, systems, and machines, enabling users to harness the data with advanced analytics.

TE Connectivity manufactures a wide array of connectors and sensors products that are reported in three segments including Transportation Solutions, Industrial Solutions, and Communication Solutions. Their products are designed for the automotive, commercial transportation, aerospace, defense, medical, oil & gas, energy, data & devices and appliances markets.

Teledyne is an industrial technology company that provides mission critical components and equipment for harsh environment applications in the digital imaging, instrumentation and A&D space. Specifically related to edge computing and communications, Teledyne makes oscilloscopes and high-speed protocol analyzers for communication links. Oscilloscopes are used to measure complex electronic signals. Protocol analyzers generate, capture and analyze high-speed communication traffic for existing and emerging communications standards such as Ethernet and USB.

Teradyne is a global supplier of Automatic Test Equipment used to test semiconductors, wireless products, data storage and complex electronic systems in the consumer, wireless, automotive, industrial, computing, and communications, and A&D industries. The company is also a leader in the sale of collaborative and industrial robots for manufacturing applications after acquiring Universal Robots and MiR (Mobile Industrial Robots).

Yaskawa is a Japanese manufacturer of servos, motion controllers, drives and industrial robots. The *Motoman* robots are heavy duty industrial robots used in welding, packaging, assembly coating and material handling.

Private Companies And Startups

Bright Machines is a software and robotics company whose applications focus on automation for the electronics manufacturing industry. The company develops software defined micro-factories enabling intelligent assembly and inspection as well as flexibility.

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Figure 25 – A Bright Machines Microfactory

Source: Bright Machines

C3.ai is a provider of a PaaS (platform-as-a-service) enterprise software intended to rapidly deploy big data, AI, and IoT applications. C3.ai delivers a comprehensive and proven set of capabilities for rapidly developing, deploying, and operating large scale AI, predictive analytics, and IoT applications for any enterprise value chain in any industry.

Covariant makes AI software that helps warehouse robots pick objects at a faster rate than human workers, with a roughly 95% accuracy rate. As the co-founder, Peter Chen, said in a recent interview: "What we've built is a universal brain for robotic manipulation tasks, we provide the software, they provide the rest of the systems." The company recently closed a $40MM Series B funding round.

Fetch Robotics offers a suite of AMR, a solution that they describe as on-demand automation given their ability to quickly deploy their products. Their robots can both transport and pick goods using attached arms, as well as scan inventory. The robot is built as a platform, so it is flexible enough to have different models built on top of it. The robots can be configured to work with WMS such as SAP's Extended Warehouse Management, and use the data gathered by the software to configure and optimize the robots.

FogHorn provides a software platform for real-time edge intelligence in Industrial IoT environments using machine learning algorithms and Complex Event Processing (CEP) by feeding it data generated from devices such as PLCs, sensors and cameras. The company is device and OS agnostic, providing it flexibility when offering solutions to clients and can work with as little as one device in a plant or an entire plant connecting all the devices through a gateway. FogHorn's main use cases are condition monitoring, predictive maintenance, asset performance management, and process optimization.

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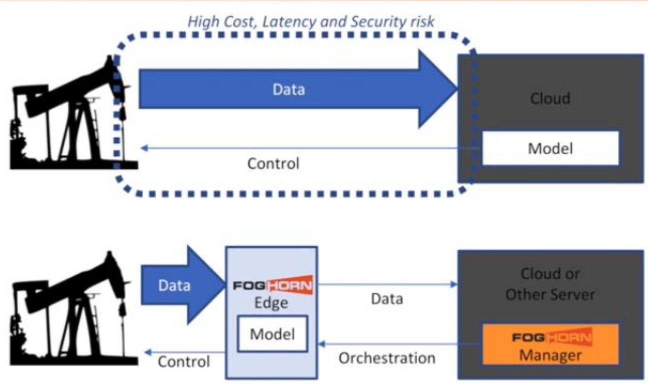
Figure 26 – **FogHorn's Edge Platform**



Source: FogHorn

Humatics is a micro-location platform that uses a combination of proprietary software, proprietary hardware, on-board sensors, and complex algorithms to provide real-time positioning of everything that moves including people, robots, autonomous vehicles, heavy equipment, etc.

Locus Robotics offers a multi-bot pick system called LocusEmpower enabling higher pick rates with less labor. The robot uses a goods-to-person system where warehouse workers can place products on the robot's cart and the robot navigates to the next location. It offers their robots for an upfront fee and an ongoing subscription basis. It integrates with Warehouse Management System (WMS) software.

Opto22 makes I/O, solid state relays, software for remote monitoring and edge programmable industrial controllers that are designed to run on non-proprietary communication standards like Ethernet and Internet Protocol (IP), making communication between other devices simpler.

Realtime Robotics develops a simple, extensible platform for automation. Their autonomous technology is a combination of proprietary software and hardware that enables real-time motion planning. The core collision-free motion planning platform is versatile and continuously accommodates changes occurring in a work cell. This allows users to operate single or multiple robots safely at full speed in unstructured and uncaged environments. The technology works seamlessly with robots, PLCs, end-of-arm tools, and CAD models.

Sensia is the product of a partnership (JV) between Rockwell and Schlumberger. As the first fully integrated oilfield automation provider, it combines the unification of sensing, intelligence and action to bring automation solutions to the oil & gas production, transportation and processing markets.

Soft Robotics offers robot-picking and gripping technology, with a patented gripper inspired by the arms of an octopus, which are deployed in manufacturing facilities around the world and used in industries such as packaging, supply chain, industrial and collaborative.

Vecna develops a set of autonomous mobile solutions that include automated material handling robots (with three types of robots), hybrid fulfillment, and workflow

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optimization. The company also offers Pivotal, a multi-agent AI-based orchestration engine that analyzes current state of operation and adjusts operational processes accordingly.

Veo Robotics uses advanced computer vision and 3D sensing to make standard industrial robots responsive to humans so they can work safely side-by-side. With its control system *FreeMove* manufacturers can combine the speed and precision of industrial robots with the judgement and dexterity of humans to build more efficient production lines.

The list is focused on industrial and warehouse mobile robots and excludes other robots such as retail-focused for the purposes of this report. For additional detail, please refer to our 2019 and 2018 Robotics AoTC series HERE and HERE.

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Autonomous and Connected Vehicles

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We see connected vehicles and Autonomous driving applications as prime examples where edge computing is already playing a critical role, and that presents a large growth opportunity for edge processing as adoption scales.

Cars today are becoming essentially computers on wheels, and as functionality increases, so does the vast amount of data that needs to be processed and analyzed both on and off the vehicle. Recently, the number of sensors and ECUs in a typical luxury vehicle grew to more than a hundred decentralized and disconnected devices as content has been added, but the efficiency of this approach has limited functionality due to weight and size of the packaging as well as limited integration these systems. To solve these problems, we have begun to see these features centralized into domain and zone controllers that utilize edge computing to optimize for advanced features via sensor fusion. We see this domain centralization moving toward a server approach within the vehicle over the next 5-7 years. Managing the abstraction of software from hardware as separation of I/O from compute as two important changes that must occur to support the vehicle of the future. Edge computing provides the benefits of processing speed, security, and reliability for key features such as predictive maintenance, traffic management, fleet management that utilizes over the air (OTA) updates to make cars more connected.

What Is the Technology Needed to Make Autonomous Driving a Reality?

Autonomous driving largely consists of three key tasks – Sense, Compute and Act. Technologies in hardware, software, semiconductors, and AI used to "sense" and "compute" is still being formulated for Level 4 and 5 systems; however, Levels 2 and 3 have largely been defined at this point and are beginning to move from higher end vehicles to the mass market. As costs come down and NCAP standards require the inclusion of advanced safety features for 4- and 5-star testing outcomes, we see more widespread adoption of ADAS hardware.

Figure 27 – Key Component Providers in the Sense and Compute Functions of AVs

Sense

Vision Software Providers	
Bosch	Mobileye
Continental	Veoneer

Lidar Providers	
Innoviz	LeddarTech
Quanergy	Velodyne
Luminar Technologies	Oryx Vision

Radar Providers	
Aptiv	Magna
Bosch	NXP
Denso	Valeo
Halla	Veoneer
Infineon	ZF TRW

Compute

Vision Processing Chip Providers	
NVIDIA	Mobileye
Texas Instruments	Toshiba

Sensor Fusion Software Providers	
Aptiv	Denso
Aurora	Google
Bosch	Zenuity
Continental	

Sensor Fusion Chip Providers	
Infineon	Toshiba
Intel	Xilinx
NVIDIA	
NXP	

Mapping Providers	
Baidu	Navinfo
Google	TomTom
HERE	Zenrin

Source: Cowen and Company

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The "sense" task is made up of multiple inputs to the "compute" system. Cameras, radar, and lidar sensors provide inputs to a computer similar to the manner in which human eyes would to the brain. Ultrasonic sensors and V2X inputs provide data the way ears would feed information to the brain. GPS and mapping also provide additional data to the car's computer so that the system can understand the precise location of the car in the context of "feeling" nearby surroundings and physical conditions.

Figure 28 – Shifts in Tasks When Humans Are Removed from the Driver's Seat

Removing the Human from the Driver's Seat	
Manual Driving	**Autonomous Driving**
Decision Making Capabilities	Machine Learning Algorithms
Memory	Maps and Environmental Models
Eyes	Sensors
Ears	Vehicle to X Communication
Reflexes/Coordination of Movement	Actuator Control

Source: Cowen and Company

The "compute" task can be thought of processing information, largely at the edge (in the vehicle) but also more centrally in the cloud. Edge processors pre-process raw data (such as image pixels and radar signals) from sensors and supply pertinent information (such as object type, location and distance) to the central computer for decision making. Edge processors are typically located close to the sensors to minimize the amount of data being transmitted to the central computer to avoid latency issues and increase safety. A central computer is also needed to take all pre-processed data from a series of sensors and the system decides on the response to the current driving condition based on real time data and software algorithms.

In the final Act state, the autonomous driving system replaces tasks that were previously human controlled inputs such as steering, acceleration, and braking. Additionally, the Act state leverages communications to broadcast its location, trajectory and expected future behavior to other vehicles, pedestrians and the infrastructure via V2X protocols and 5G to increase safety.

What Data Services Coming Will Connected Cars Enable?

We see the car being the third wave of connected devices, following computers and phones. The market is still very early, but data and AI along with mega-trends of ride sharing and electrification will shape which user experiences are offered by connected car data in the future. In comparing the connected car to phones, we see some commonality but also major differences. Compared to phones, connected cars have larger screens, more power, places to mount cameras and telematics data. Data that can initially be useful includes current location, destination, estimate time of arrival and real time traffic for example. Note your car is putting off all kinds of telematics data that normally we don't care about, but if packaged and presented correctly, as Aptiv is trying to do through Control-Tec, can offer a richer user experience.

Data points such as GPS location, fuel level, bearing, seat belt clicks, speed, wheel slip, internal/external temperature, gear shift state, infotainment state, NAV destination and time spent driving aren't discretely that important, but in our exploration of use cases with Otonomo and Xevo below, we highlight a few use cases where they can be synthesized together to offer a richer experience to the consumer.

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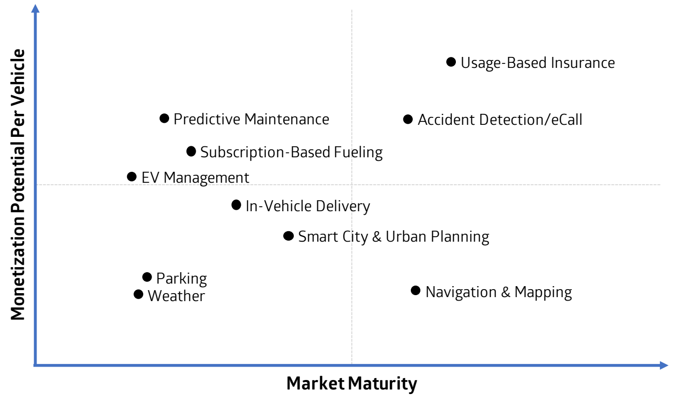
Aptiv's Otonomo Investment Provides Connected Car Platform

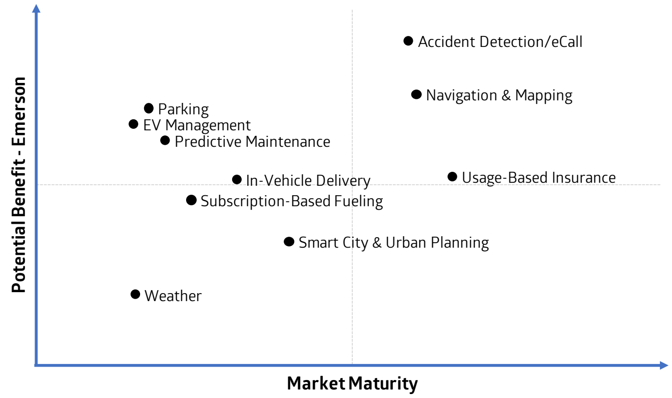
Otonomo, a cloud-based automotive data services platform for connected cars that Aptiv has invested in, has a well-publicized contract with Daimler and the aim is to leverage neutral servers that protect customer privacy, while providing simple and secure data access that transforms vast streams of data coming from the vehicle into actionable insights for services for the OEM and a tailored experience for the driver. The graphics below show a matrix of benefit to the vehicle OEM and a fictitious driver named Emerson based on data services that provide benefit to the related party compared to market maturity. Otonomo has noted 4 data services appear to have a benefit for both parties immediately, ranging from EV management, parking, accident detection/emergency calling and navigation and mapping. Daimler rolled out the service in mid-December 2018 and now is leveraging data such as fuel status, electric vehicle battery levels/ranges, odometer reading and status of vehicle features such as windows, interior lights and door and trunk lock status. The company hopes that app developers will develop services for Mercedes-Benz customers. Note Daimler is one of otonomo's 75+ partners. Lear has taken a different approach with the Xevo acquisition, which is more aligned with partnering with merchants initially to provide benefits to drivers.

Figure 29 – Monetization Potential Per Vehicle



Source: Cowen and Company, Otonomo

Figure 30 – Potential Benefits – (Emerson)



Source: Cowen and Company, Otonomo

Lear's Acquisition of Xevo - Leveraging Connected Cars

Lear acquired Xevo to broaden its scope in E-Systems beyond connectivity hardware, gateway modules and security software toward a connected car marketplace. Prior acquisitions of Arada, EXO Technologies, and Autonet Mobile, broadened Lear's E-Systems segment from a hardware only solution toward software capabilities. Xevo now has a SaaS based revenue stream to the story. Lear should also accelerate Xevo's entrance into Europe and China, with China likely being the biggest potential opportunity. From a competitive environment, internal OEM developments and on-phone platforms are the primary competitors.

The traditional driver spends 300 hours a year in a car. Xevo is a platform that leverages a broader connected car platform that aims to make the ride more enjoyable through commerce. The car journey can be improved over time through multiple vectors.

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- Be personalized – deduce where you are going and what you would like
- Improve safety – warn you of upcoming problems
- Maximize driver enjoyment through greater interfaces without being distracted through phone use

Xevo has a long history in connected car software dating back to 2011, when the company was designed into Toyota's Entune 11CY platform. Xevo started with fairly basic applications such as checking fuel and battery levels, unlocking and starting a car, getting notified of critical problems and calling emergency services after a collision. While the company was largely exposed to Asian OEMs prior to 2016, 2017 saw a transformation at new platforms with the GM Marketplace launched and last year the FCA market was launched. The Xevo platform integrates voice, contextual recommendations, Apps, Commerce, Identity and OTA Updates. The Xevo product consists of two primary applications – Journeyware and Xevo Market.

Journeyware is a client application with cloud features that enables consumer commerce, multimedia applications and enterprise services. This revenue stream is a license revenue stream tied to vehicle sales, mostly with Toyota, Lexus, Honda and Subaru to our understanding. The system today uses information from GPS that is reasonably accurate. The platform allows vehicle data collection, analytics and monetization along with customized OEM experiences that leverage personalization and AI based recommendations. The system over time will learn the driver's schedules and preferences (calendar, social circles, and media choices) and infer destinations and stops as well as be able to migrate profiles of drivers automatically (seat positioning, in-cabin temperature, pre-stored music channels).

The Xevo Market has launched on Cadillac, Chevrolet, Buick and GMC vehicles. Xevo's "moat" on the Market segment is signing up merchants, since merchants don't want to deal with all of the OEMs separately. Xevo will write the software code for a specific app for the merchant that is platform agnostic (working on Apple, Google, QNX, Linux, etc.). Driving consumer usage is also key to Lear being paid. Lear's global platform should better position Xevo in getting placement in more OEMs as well as bolstering the offering of a turnkey connected gateway module. We believe Xevo generates revenue per transaction as well as receives bounties for getting people to use an application within the car.

The platform enables commerce within vehicle apps and is a recurring transaction-based business model. Essentially the revenue model is driven by vehicles that are connected to the Xevo market platform (total eligible vehicles) and what the active engagement rate of those drivers is with the platform. Brands like gas stations and coffee shops that have phone-based apps (that you aren't supposed to be using while driving) can be brought into the vehicle. The platform acts as a connected car agency for merchants – think the Starbucks app integrated into the vehicle mapping and having your voice order a triple grande skim latte while on the go. The platform generates revenue for Lear from commerce, advertising and data monetization. We believe Xevo is likely to receive a bounty for signing up a user with a merchant (we assume ~$3-10) as well as paid per transaction (we assume ~$0.50). This Market platform will disintermediate Lear from a revenue stream driven by global light duty vehicle production over time, but driving merchant growth and usage by consumers will be key to the story. We see the most likely early merchant markets of success being gas stations, restaurants reservations and fast food. Management noted that gas station capability was being rolled out currently in which the system will know you are low on gas, will recommend a gas station where to go, and your account profile will have your

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Shell/Exxon/etc. profile loaded so points and savings can be achieved with one click of the screen, and location awareness will know exactly what pump the driver is at. Longer term, we see revenue growth opportunities for insurance, parking, and tolls to be integrated into the platform.

A scenario of low fuel was presented by Xevo management at the TU Automotive conference in 2019 that we found fascinating. With a traditional car, when the vehicle has less than two gallons, a warning light on the dash lights up. On the Xevo enabled marketplace platform, which works on any cockpit from the likes of Visteon, Harman or Aptiv, among many more, a richer experience can be offered. Notifications can be adapted to when the user typically refuels (perhaps on the way to work). Use factors such as price, what side of the road the station is on, how out of the way is the station, do I have time before my meeting or can I wait until after my next stop, all can factor in to where the navigation system will tell the driver to stop. In addition, merchants such as Shell for example can have their own app, which Xevo develops, on the screen and the Shell Rewards program along with stored payment will be in the dash making the refueling experience different. The EXO acquisition will know precisely where the vehicle is when entering the station (let's say Pump 5) and the driver can press Shell on the home screen once the vehicle is noted to be in the park state and the car will "talk" to Shell directly and payment can be accomplished directly to the pump.

The second scenario that Xevo discussed at that conference consisted of a very hungry family of 4 on a long road trip passing a billboard for a restaurant that appealed to them. The scenario consisted of a very hungry family of 4 on a long road trip passing a billboard for a restaurant that appealed to them. In a non-connected car environment, the driver would have to do the mental math on whether the restaurant was close enough to wait to eat there or should the family stop closer. In the Xevo Marketplace system, the billboard can appear on the head unit display within the vehicle, sharing information about which side of the road it is on, how far away and offer one click to navigate to the restaurant. The restaurant would also receive information about the state of the vehicle such as the fact that a car is headed in their direction and it is five miles away, it has been driving continuously for 4 hours, there are 4 seat belts clicked and fuel is below or above when it is normally filled (i.e. the driver may or may not have a reason to get off the Interstate at your exit). The restaurant then, depending on conditions such as volume of people eating, can decide if they want to push an advertisement or promotion to the car to entice the driver to stop. Lear and the OEM would take a cut on this advertising revenue. The restaurant can decide to make an offer just for this car, but not every car passing by based on predetermined parameters. Perhaps the driver does not want to stop but wants to pick up food at the restaurant. GPS location from the EXO acquisition could tell the restaurant the car for pickup is 10 minutes away and once it arrives at the restaurant it will tell the restaurant exactly where it is parked for curbside delivery. Note this exact geo-location feature could also be used for big box retailers looking to leverage car data for curbside delivery or vendors using the vehicle for remote deliveries, which is something Otonomo's presentation discussed.

Tesla Is a Pioneer in Connected Car, Using Neural Network to Build Autonomous

Tesla has been a pioneer in building connected cars that are capable of software updates through over the air (OTA) updates. The company regularly adds new features to its existing car fleet, ranging from critical functions such as improving breaking time and remote service, more frivolous functions such as adding games, and most notably improving the vehicle's driver assistance functionalities and promising a self-driving future. We like the company's ability to process data on the vehicle, and improve through software updates, and are seeing many of the large traditional OEMs begin to

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copy some of the same functionality for remote diagnostics and other critical features. Tesla's plan is to utilize its existing vehicle fleet to improve its self-driving software through a neural network that will "learn" cars already on the road and improve the edge cases that are needed in order to enable higher levels of autonomous driving. CEO Elon Musk has indicated that the iterative process of improvements via the neural network will eventually enable the fleet to run a network of robotaxis using the current hardware.

At its autonomous driving investor day (HERE), Tesla unveiled some of the specs on its 3.0 hardware full-self driving chipset, which was designed in-house. Samsung is supplying the special-purpose chip out of its fab in Texas. This new system, designed by Pete Bannon, is purpose built to leverage Tesla's neural network-based computing software. This new system boasts a considerable level of redundancy as well as on-board security features. The FSD board houses two separate, but identical systems, each with its power, communication (I/O), memory, and 14nm chipset. These systems share sensor information and other input data to make decisions based upon the company's neural network software. The decisions are cross referenced between the new systems, which helps to reduce errors.

Where we see potential challenges for the company in this strategy, which we see as fully baked into the valuation despite significant execution risk, is whether the hardware sensor suite will be capable enough without lidar, and also the timeline that the company has set, which seems unrealistic in our view.

Elon Musk, when probed about absence of Lidar in Tesla's autonomous strategy, has noted that "Lidar is lame" and predicted that his competitors would eventually abandon the technology. Mr. Musk drew comparisons between the stereoscopic vision of humans and Tesla's own camera-based vision strategy. However, in a system designed to ultimately be safer than human operators, we are perplexed at Tesla's continued resistance to Lidar technology. This issue is particularly acute given the company's focus on the "long tail" edge cases, where we believe the addition of Lidar could be most useful given its ability for higher resolution sensing. This could be a risk for the company longer term if well capitalized companies like Waymo and Cruise Automation as well as start-ups like Zoox are able to make a compelling case to regulators on enhanced safety profile of autonomous systems that include Lidar technology.

Given the early stages the self-driving software appeared to be capable of at our test drive at that event last year, we are very skeptical that the company will be able to solve Level 5 autonomous this year as promised, or even if the company will be able to solve it in the next 3 years when the first Model 3 leases come off to enter the Tesla Network. The software was at that time capable of Level 2+ driving only on highways, and engineers we spoke with indicated that it was not yet able to recognize many of the basic needs one would have on suburban or urban roads, such as turning right at red lights (while watching for crosswalk human traffic) or recognizing hand gestures from a police or construction worker. We note that stopping at stop signs and recognizing red lights have recently been pushed for beta tests on customer's vehicles, but literature from the company and reviews online suggest that the features continue to be fairly experimental whereas many competitors have spent years perfecting these features already.

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Evolution of the Cockpit, Connected Cars Poised to Leverage the Data

Foundationally, telematics is the starting point for the majority of connected vehicle functionality. IHS estimates that about ~24mn telematic control units (TCUs) with 4G functionality were sold in 2019; that number is forecasted to jump to ~30mn by 2024. The automotive industry is already contemplating the impending 5G deployments, with two OEMs already supporting the technology in the 2020/2021 timeframe. Longer term (2025+) 5G will help to enable more advanced autonomy driving functionality, including remote driving, highway platooning, see-through/sensor-sharing, and real time local updates. In the meantime, a 5G network will be capable of supplying vehicles with real time traffic information, highspeed internet access with real-time video steaming, as well as cloud-based graphics processing for video game streaming.

Domain controller momentum should continue to pick up speed as the number of electronic controls units (ECUs) in vehicles shows no sign of slowing. Some luxury vehicles can now have anywhere from 150 to 200 ECUs, which not only increases costs due to increased engineering and assembly complexity, but leads to higher power consumption, increased weight, and delayed software updates. These higher power consumption needs are a key reason we see Aptiv's Smart Vehicle Architecture (SVA) as a game changer for next gen vehicles in 2023 and beyond. As with the digitization trend, Cockpit domain controllers (CDCs) are not limited to premium vehicles. Economy CDCS are quickly gaining relevance with more than 1/3 of the total global automotive market expected to adopt the technology by 2026, according to IHS. This shift will be important to first movers in the space like Aptiv and Visteon, as the challenge of obtaining design wins will likely create deeper and longer-term supply relationship with OEMs. The value in the cockpit is slowly shifting away from periphery components and toward centralized hardware and software development.

Smart Vehicle Architecture Brings Server Model with Edge Computing to the Car

One of Aptiv's main area of focus is on next generations "smart vehicle architecture". The internal dynamics of the modern automobile are changing rapidly, especially in light of the increase focus on vehicle connectivity, safety, autonomy, and electrification. The traditional architecture is ill suited to handle the vehicle's transition from standalone device to a consumer product operating as part of an IoT ecosystem. Aptiv sees vehicle architecture evolving over the next 5 to 7 years as auto OEMs move from a distributed system to centralized computer platform before finally transitioning into a server-based compute system. The abstraction of software from hardware and the separation of I/O from compute are two important changes that must occur to support the vehicle of the future. Aptiv's position as both the brain and nervous system of the vehicle enables it to leverage the foundational elements of a vehicle like power, data, compute, and software to provide high value solutions to OEMs' greatest challenges like active safety, electrification, and infotainment/connectivity. The company highlighted 10 programs for its central compute platform, which we expect to grow as the company begins deploying zone control in 2022 to address I/O and networking, and see full SVA with a unified power and data backbone in 2025 as a competitive advantage that we have not yet seen from other players in the industry.

Smart Cities

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The smart city, and by extension the smart grid, has increasingly grown in importance as governments, utilities, and municipalities seek to address the challenges of rising pollution, overcrowding, and dwindling resources. The migration from rural areas to the city has continued to gain steady momentum. By 2050, 66% of the world's population is forecast to live in urban centers, up from just over half today. Despite occupying just 3% of total land surface, cities currently consume 76% of all energy generated and produce around three-quarters of all carbon dioxide emissions, according to a report by the Intergovernmental Panel on Climate Change. Smart grid and smart city infrastructure deployments can help to better utilize existing assets, improve energy efficiency, decrease emissions, reduce unplanned maintenance costs, strengthening grid resiliency, and provide new insights into city planning. Smart city providers and their customers are beginning to leverage higher degrees of edge computing in order to better digest and analyze the massive influx of data generated by these smart IoT installations. This should help to create more robust full featured solutions at the cost of low bandwidth and ultimately provide new economic use cases to improve the value of smart city deployments to governments, utilities, and municipalities.

Before diving into edge computing in a smart city, let's define what a smart city is; *a smart city is an urban development initiative to integrate information and communication technologies with a city's assets over a protected and secure connection.*

We commonly use the term "smart" for any object that is connected to a network. Cities can gather data through a variety of different sensors that are already in place, including meters to measure utilization of water, gas, and electricity; cameras to monitor traffic, congestion, and parking spaces; and weather sensors to monitor climate conditions such as heat waves, humidity, and air quality. A set of new sensors can be added to capture a lot of incremental data on lighting, road condition, waste management, and noise levels among others.

The majority of data that is collected today needs to be sent to a central location for analysis. A data scientist, city planner, or utility could then leverage the data to find patterns, make predications, and solve unique challenges. Importantly, this data needs to be interoperable and scalable in order to maximize the value of the system. The transmission of the data can be accomplished through a wired connection using fiber-optics or wireless through a cellular network or via a private RF mesh network.

As smart grid AMI deployments continue to gain acceptance by regulators and utilities, coupled with the growing use of smart infrastructure by cities and municipalities, we have started to see an increased focus on edge computing. Often times depending on communication technology choices, there are physical limits on the bandwidth or throughput of a data transmission. This will lead to the difficult choice about what data is collected or how often it is transmitted. By leveraging edge computing, these smart grid/city deployments are able to push more intelligence through the grid and limit the need to centralize all of the data collected. This also improves the versatility of these deployments, enabling a degree of future-proofing as nodes are capable of receiving not just firmware updates, but new software. This new functionality could unlock additional use cases and further improve the value of these deployments for key stakeholders.

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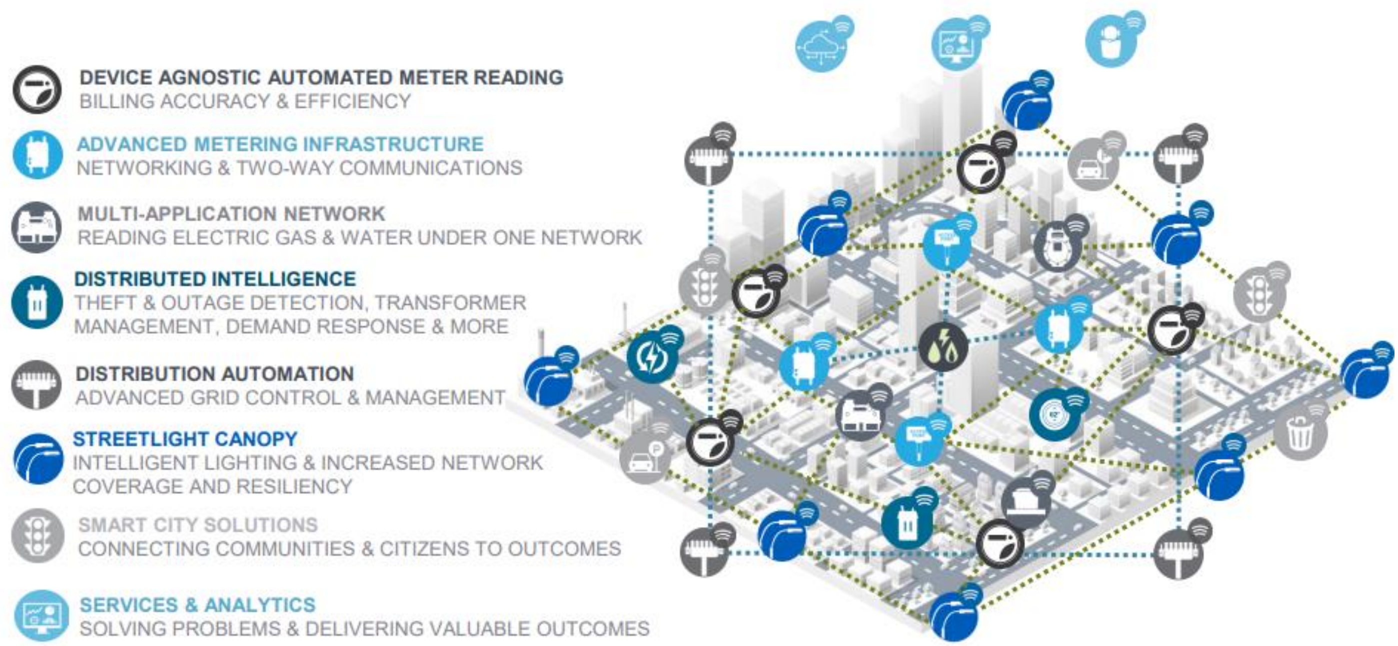
What Can A Smart City Do?

Sensors Are Becoming Ubiquitous And Allow For a Multitude of Applications

Similar to how consumers are adding sensors to their own lifestyle choices, such as Fitbits to monitor health, cities are also adding sensors across their footprint to monitor their vital signs. When rolling out new applications, cities often want to leverage a network that allows sensors to “talk” to each other and back to the cloud via a network that is on city-owned property. Given that many of the applications that a smart city deploys are outdoor in nature, we have found street lights a natural place to initially add intelligence since they can provide adequate coverage across the city boundaries.

Outside of city-owned sensors, a smart city can also leverage the citizens as sensors. Using the public as a data collector isn’t a new idea as it is essentially the goal of 911 and 311 phone systems in place for decades. However, smart phone apps allow the power to be put in the hands of citizens, even via third party applications like Google’s mapping application Waze. For example, the city-run Boston traffic management center uses Waze data to supplement live feeds from its network of traffic cameras and sensors, getting a more detailed picture of what’s happening on city streets. Messages from Waze users can alert the center to traffic problems as soon as they develop, allowing officials to respond more quickly.

Figure 31 – Example of Smart City Infrastructure Leveraging Smart Gird Base



Source: Itron 2019 Analyst Day

Smart street lights are perhaps the poster child for smart city applications as their benefits not only include energy reduction, but also can improve road safety. These installations can be further enhanced by the addition of cameras to provide traffic updates, air quality sensors to help city planners, or acoustic sensors for gunshot detection. Acoustic sensors can also be used to detect ambulance sirens and alter traffic patterns and lights to improve travel time back to a hospital. Cities can also employ structural health monitoring (SHM), which uses sensors (crack detection, crack

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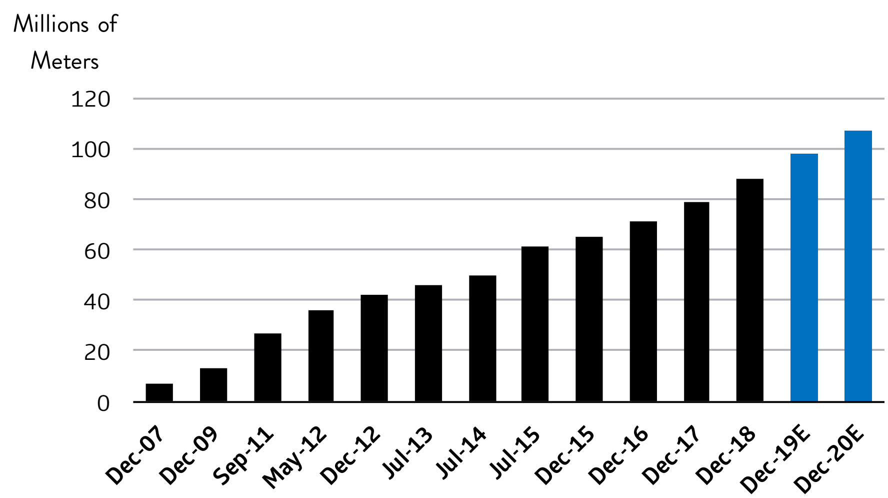
propagation, accelerometer, linear displacement, inclinometers, wind pressure, etc.) to evaluate construction projects or monitor existing assets like buildings, bridges, or dams. Smart cities can also leverage smart deployments to reduce emission by better guiding citizen to available parking. The US Department of Transportation estimates that 30% of urban traffic congestion is parking related. This also has the added benefit of allowing more time for commerce, improving social benefits to both consumers and businesses. Sensors can even be utilized for more efficient waste collection as traditional systems specify collection based on a fixed route and schedule. IoT solutions can optimize routes based on need.

Figure 32 – U.S. Smart Meter Installations (2011 – 2018 & 2019E/2020E)



Source: Edison Foundation, Cowen and Company

Smart metering remains the most prominent and widely used applications for smart infrastructure. Originally undertaken to enable automated meter reading in the early 1980s, it has expanded from electricity to gas and water meters. Advanced metering infrastructure (AMI) can now allow 2-way communication between devices on the network, enabling the ability for voltage management, grid stabilization, loss or leak detection, preemptive maintenance, demand response, and distributed automation.

The Smart City Barriers and Our Proposed Solutions

While we see an intersection of the smart grids, smart cities, and smart buildings (either commercial or residential) playing out over time, we note the industry does face challenges due to the conflicting needs of the utilities, cities and buildings. Initial smart cities rolling out are typically executed in conjunction with utility smart gird deployments, which enables both entities to use the same network. We expect the integration into buildings to take some more time but see initial applications such as demand response as a use case. Smart grid infrastructure can integrate within an energy efficiency program at a building and, in some cases, the monetization of reduced electricity load can help fund an efficiency retrofit. No one has rolled out a true smart city yet. Rather, cities are starting with bold long-term visions and beginning with one or two applications initially. Other problems are agency problems. For example, when equipment vendors try to make buildings more efficient, they often discover that the

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interests of tenants and landlords are not aligned; however, this is slowly changing given the vast preponderance of corporations that have announced sustainability initiatives in recent years. We discuss some barriers to smart cities below and some potential solutions.

1. Just as it is the case for humans, cities are experiencing an increasing wealth gap. A lack of investment and funding in new technologies from poorer cities would only widen the current gap going forward as efficiency and savings measures are not put in place. Potential solution: We see public-private partnerships as a possible solution.

2. The current applications used in smart cities are commonly siloed and not prone to scalability, which creates very expensive sets of redundant processes. At this time, municipalities have not thought about ways to leverage existing systems to accommodate new technologies and thus smart application installation costs have risen. Potential solution: Companies providing systems that can accommodate several applications should be preferred.

3. Collaboration and communication between departments should be greatly improved to effectively take advantage and implement existing technology. The root of the problem lies in the fact that municipalities have been divided into departments for at least the last 100 years. Potential solution: Municipalities could elect a city planner to oversee the installation of a set of new smart applications, starting with one and layering new tech using the network already in place. Having a “smart city CEO” would help focusing on one app at a time while keeping in mind the potential entire smart structure.

What Technology Is Needed & How Does It Communicate?

Cities, boroughs, and townships are increasingly relying on data and automation in order to improve the daily lives of its citizens. While smart grids were initially pioneered by utilities through various advanced metering infrastructure (AMI) initiatives, municipalities are quickly moving to implement their own systems. Smart cities seek to incorporate IoT technologies in order to more efficiently manage municipal assets by lowering costs and improving consumption.

Municipalities have a tendency to own their smart city networks, funded outright through debt offerings. This is dissimilar to utilities, which will typically rate base their capital improvements. Savvy city planners often will look at smart systems holistically, calculating not just the payback period on the initial system but on the potential for additional functionality to be added over time. IoT companies have sought to address cities’ needs using several different communication technologies overlaid with either open standards based or proprietary protocols. While communications technologies selections can vary based on application and topology, there has been a strong migration by municipalities toward open standards-based systems. This not only improves security but also allows for interoperability between systems. In the past, non-interoperability has been a pain point for customers as they are locked into one specific system solution, unable to adapt to the rapidly changing smart city landscape. RF Mesh has gained the most steam with success by Itron and Landis+Gyr. Cellular is rarely used domestically, but may change as the communication network migrates from 4G to 5G. Hybrid systems have been developed but companies still do not have integrated circuits. This makes these hybrid solutions more expensive and more difficult to justify economically.

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While Utilities have been using edge computing functions for years, the introduction of true IoT solutions opens up a host of new functionalities. Landis+Gyr introduced its Revelo smart meter in January 2020 which leverages its Gridstream Connect platform to enable edge computing functions and multilayered communications. Landis+Gyr's Gridstream Connect ecosystem has apps directed at both grid operators and consumers to offer solutions that address not just the residential market, but for commercial and industrial applications as well. Grid Apps can extract and process the raw data to provide actionable analytics that will allow utilities to better identify problems on the grid and potentially leverage preventative maintenance to avoid larger problems. Consumer Apps will also be able to generate data that can provide valuable analytics about usage to help individuals and families save money and make better decisions. The smart city becomes smarter the more devices that are added to the network. Companies like Itron and Landis+Gyr are not just focusing on meters, but leveraging streetlights and other distributed sensors, which have the ability to run software applications locally connecting not only with the network, but peer-to-peer. Utilities and municipalities are then able to leverage a suite of apps made available by the network provider or create proprietary ones using a SDK.

Figure 33 – Landis+Gyr's Revelo Electric Meter With Gridstream Connect Functionality

Source: Company Reports

Communication Technologies That Can Be Used in a Smart City

Fixed RF systems (Wi-SUN, Zigbee, Wireless HART): In basic fixed radio frequency (RF) systems, meters communicate over a private network using RF signals. Each node communicates via the network directly to a data collector or repeater. In addition, a mesh network can be set up to allow nodes to talk to each other before reaching an access point or repeater. Repeaters may forward information from numerous nodes to more sophisticated data collectors, which often store the data from other nodes within range. The data collectors then upload the data to the host system at preset times using the best communication method available, ranging from public networks to microwave to Ethernet connections. The communications between the data collector and the network controller are usually two-way, and allow the network controller to query for a recent data updates and the status of one or a group of nodes. One of the key features of the more advanced RF networks that appeal to customers is the ability of the network to "self-heal"—i.e., if the nodes have more than one communication path to the main hub of the system, and the best path is no longer available, nodes can change their communication path.

Systems utilizing public networks (5G / 4G LTE / 3G / 2G, Wi-Fi): These systems utilize existing public networks such as paging, satellite, internet and/or telephone (cellular or landline) networks to provide for communication between nodes and hubs. One major advantage of these systems is the ability to deploy across a wide area with low densities, and the possible lower up-front cost of deployment because a customer does not need to build private infrastructure. The most common public network used for a smart city deployment is cellular, but the market share of this technology is estimated to be less than 5% globally. The downfall is that cellular technology changes fairly regularly, faster than the expected life of the node. The other gating factor is that often times customers want to directly own the network versus rely on a third party.

Power line communications (PLC): PLC systems send data through power lines by injecting information into either the current, voltage or a new signal. This can be accomplished by slightly modulating the voltage or current signal as it crosses the zero point or adding a new signal onto the power line. The system is more commonly used by utilities, which have equipment installed in substations to collect the meter readings provided by the endpoint, and then the information is transmitted using utility communications or public networks to the utility host center for the PLC system. PLC systems are well suited to rural environments, but have also been successfully used in urban environments.

LPWA (LoRA, Ingenu, Sigfox, etc.) or Low-Power Wide-Area Networks are a long range, low power, slow transfer rate wireless communications technology, which is typically paired with battery powered sensor technology. These battery powered sensors can in some instances operate for up to 10 years making them ideal for deployments that are unable to rely on existing infrastructure like streetlights.

Other Emerging Technologies to Monitor

- ***NB-IoT or NarrowBand Iot***
- ***EC-GSM***
- *Weightless &* Weightless-N*
- *Telensa*
- *Haystack*
- *MySensors*
- *Symphony Link*

Networking Protocols - IPv6 Driving Broader Adoption

The Open System Interconnection Model (OSI) is a model designed to standardize communications and improve the interoperability of disparate systems. In a smart city network, the focus is on the network pathing, which is where the structuring and managing of a multi-node network takes place. This includes the addressing, routing, and traffic control of data packs as they move from the physical side of the system up through the stack to the application layer. In general, hardware companies are focused on the physical layer and few have a vision of moving up the OSI stack, similar to what successful networking companies accomplished over time in the telecom equipment market. Longer term, the standardization of the chipset-based solutions coupled with the lack of a vision at the application layer may be the biggest fundamental weakness of

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metering centric companies; hence, we see both Itron and Landis+Gyr making a shift towards "Big Data" oriented initiatives. In order for metering companies to expand gross margins over time, we see it as imperative that they exhibit success in these new areas of growth.

IoT companies have begun to focus on IPv6 over other protocols as it allows for an open standards-based system. This allows for interoperability between system and networks, which is more difficult in proprietary internet protocols. This move by developers has helped to increase demand for smart city deployments as many municipalities feared being locked into one vendor after making a large capital outlay. Having the ability to switch vendors easily or deploy internally developed applications on a customer's own network have become key selling points. This standardizing around one internet protocol also helps to improve the security of the overall system as exploits are more readily identified by developers and patched. This is important as security continues to be top of mind for smart city developers when moving forward with a network deployment.

Top Ideas Poised to Benefit from the Smart City Wave:

- **Itron (ITRI)** – Itron has made substantial progress with its smart city efforts, following the acquisition of Silver Spring Networks. This is in addition to acquisitions like Comverge, which increased the company's big data capabilities. The company has leveraged its smart grid business to provide distribution automation features and the streetlight business from Silver Spring puts them in a good position to drive more distributed intelligence through its smart infrastructure installations. Over the longer term we expect a greater portion of the company's profitability will be derived from its Outcomes business with focuses on grid edge analytics and solutions.
- **Landis+Gyr (LAND.SW) –** Landis+Gyr is focused on expanding its partnership ecosystem that leverages grid edge intelligence as highlighted by its Revelo meter and Gridstream Connect App ecosystem. Additionally, we remain constructive on the company's partnership with Sense and its agreement with Utilidata in August 2019. Landis+Gyr partnered with Utilidata, an industry leader in energy optimization software, to deploy Utilidata's edge applications on Landis+Gyr's smart meters. Leveraging real-time data and machine learning, Utilidata's applications strengthen Landis+Gyr's platform by adding grid visualization, dynamic monitoring of distribution circuits, and real-time fault detection capabilities to enable utilities to collect and synthesize data from an array of grid endpoints. The rollout of Landis+Gyr's smart meters embedded with Utilidata's software is initially planned for the North American market.
- **Xylem (XYL)** – In 2017, through its $1.7B acquisition of Sensus – a leader in smart metering – Xylem entered the smart city space. XYL brings a uniquely broad portfolio of clean water and wastewater infrastructure to municipal customers, which now makes up ~50% of total revenue. Sensus is one of the leaders in advanced metering infrastructure (AMI) and can leverage its communication network to integrate a wide range of products. Long term, we believe that we are still in the early innings of the full value proposition that XYL can provide to its customers. The company's products and services are exposed to powerful thematic trends such as water conservation and measurement, IIoT, and the growth in smart cities. Despite long-term global structural tailwinds, the outlook for the water sector right now is more challenged than it has been in the past several years. Break and fix activity will continue, but forward-looking projects are likely near-term challenged (and many municipalities are just exiting a strong capex period). Muni budgets

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generally lag the broader economy, and rising unemployment and lower tax revenue will likely have lingering (and potentially multiyear) impacts before we see a meaningful recovery.

- **Roper (ROP) –** Roper's Neptune business sits under the Measurement & Analytical Solutions segment and provides smart metering services enabling water utilities to remotely monitor their customers, utilizing Automatic Meter Reading (AMR) and Advanced Metering Infrastructure (AMI) technologies. Although Neptune has experienced solid growth recently and the long-term outlook is positive, near-term uncertainty is more elevated and municipal budgets are likely to soften. ROP also owns TransCore under the Network Software & Systems segment, which provides toll systems and toll products, transaction and violation processing services, and intelligent traffic systems to governmental and private sector entities. TransCore has benefited recently from large projects as cities transition to more intelligent traffic systems, which generate more revenue and optimize city traffic, such as the ongoing NYC congestion pricing project. Longer term TransCore has long runway growth and the current COVID-19 crisis is expected to provide a near-term benefit as human-to-human toll contact is reduced and more cities adopt a contactless tolling system.

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Consumer Edge Devices

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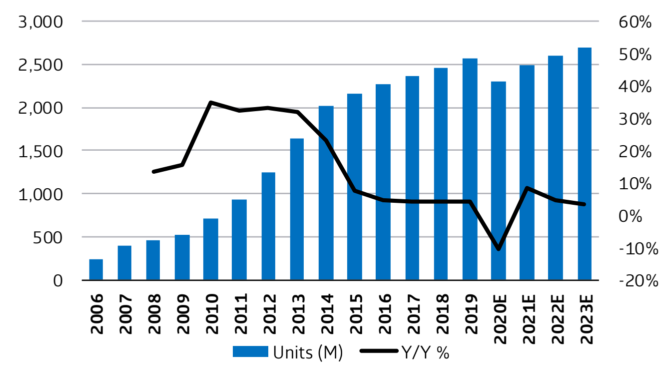
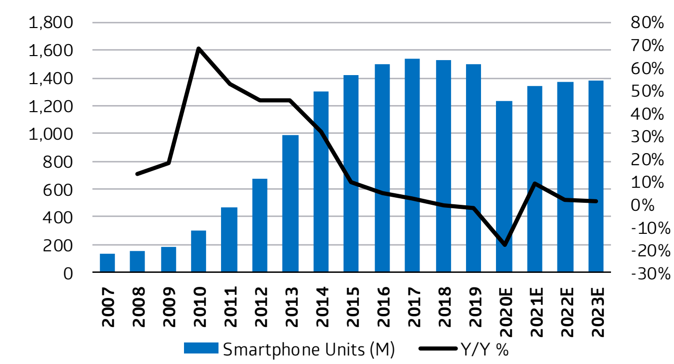
We anticipate the growth in edge computing resources will not only support ongoing growth and utilization of existing consumer edge or client end devices but also foster the growth of smart devices that are often associated with the consumer Internet of Things (IoT). Be it content consumption, content creation, or enabling near-real time connected services, we view the movement of data center computing resources closer to the network edge where consumer end devices are often connected wirelessly via 4G/5G cellular or WiFi LAN networks will be crucial to future market expansion.

Figure 34 Consumer Edge – Unit Forecasts



Source: Cowen and Company estimates

Figure 35 Consumer Edge – Smartphone Unit Forecasts



Source: Cowen and Company estimates

Within the context of this report, our analysis is focused on five broad consumer device segments that are expected to benefit from future growth in edge computing infrastructure. In aggregate, these devices represent an estimated 2.6B in unit shipments in 2019 and are expected to grow slightly to 2.7B in annual shipments by 2023. While this growth forecast assumes a material impact from a macro downturn in 2020 that leads to double digit % Y/Y declines in smartphone and PC units, we expect the smart devices category to see a strong 13% CAGR through 2023 as innovation drives increasing product utility and market penetration rates.

What Is a Consumer Edge Device?

While there is no standard definition for a consumer edge device, we include the two broad categories for the purpose of this report. The first category is comprised of traditional computing connected devices such as smartphones and PCs, which were traditionally used for voice communications, Internet access, and social media, but are evolving to support enhanced user services and experiences underpinned by artificial intelligence (AI) and/or machine learning (ML) algorithms. The increased performance or device complexity (e.g. sensors) needed to support these services are either driving greater resources locally within the consumer edge device or higher dependency on cloud compute resources located nearby at the edge of the cloud. The second category are smart devices but traditionally have been referred to as Internet of Things (IoT) devices. Historically, these smart devices were products that did not have Internet connectivity and offered basic control of different systems in the home but have been redesigned to be cloud connected with mobile app access by users from anywhere in the world plus the addition of AI/ML software techniques that allow them to be "smart" by learning user preferences or run based on defined operating rules, e.g. IFTTT protocols.

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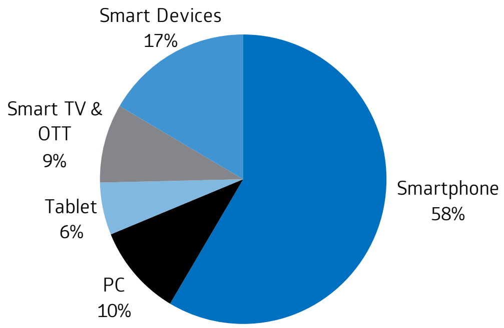
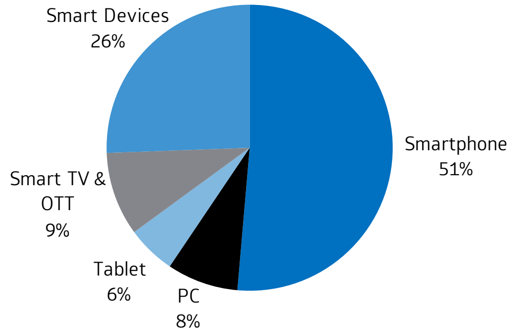
Examples of smart devices today include speakers, thermostats, security cameras, doorbells, etc.

Figure 36 Consumer Edge Devices – 2019 Mix



Source: Cowen and Company estimates

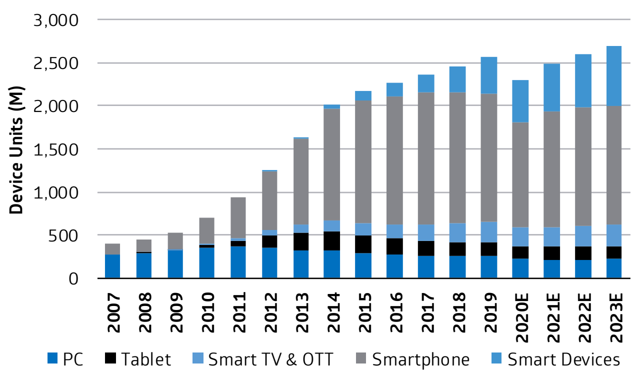
Figure 37 Consumer Edge Devices – 2023E Mix



Source: Cowen and Company estimates

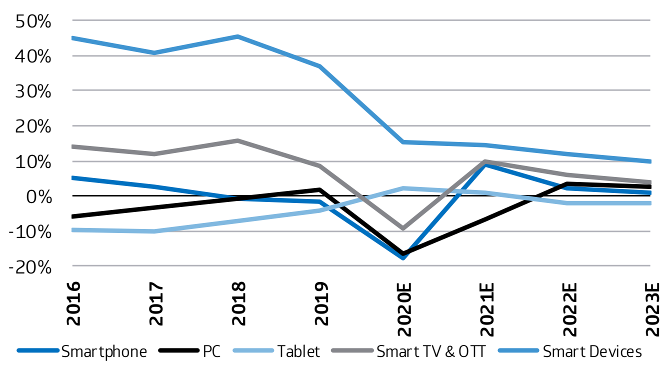
When examining the growth prospects of consumer edge devices, we believe it is instructive to examine how the consumer electronics unit total addressable market (TAM) has evolved historically in order to better understand the market trends currently at play. In terms of markets or devices that are relevant to edge computing growth, the PC market has been a mainstay of the market for the last few decades. Even during the Great Recession of 2008-2009 PC units continued to grow before reaching a peak in 2011 as smartphones, which at the time was the evolution of voice-focused handsets combined with elements of a portable media player and handheld computer, reached a demand inflection point. Along the way, further innovation in form factors led to the creation of the tablet category. While the tablet market saw units peak in 2014, it continues to see new applications in the education market as well as new use cases in commercial and enterprise markets as an extension of the mobile computing product segment. From a video content consumption perspective, the rising popularity of video streaming services has turned nearly every large screen TV display to be a connected display while over-the-top (OTT) streaming boxes further enhance the end user experience.

Figure 38 Consumer Edge Devices – Unit Trends by Type



Source: Cowen and Company estimates

Figure 39 Consumer Edge Devices – Unit Y/Y % Trends by Type



Source: Cowen and Company estimates

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With the growth of hyperscale data centers, cloud computing networks from the likes of AWS, Azure, Google Cloud, etc. have made access to virtually unlimited pools of compute resources a reality for much of the past decade. Consumer edge device companies depend on it for essential infrastructure to support AI/ML infused features and services especially for smart devices. We also view cloud computing resources as essential to enabling AI assistants such as Amazon's Alexa, Apple's Siri, Google's Assistant, and Microsoft's Cortana. This is important as AI assistants are an important element that complements user access and control of smart devices. Today "smart devices" is a broad catchall term within the consumer market that typically includes wearables and is increasingly associated with smart home control devices that bring a level of AI or automation to everyday life. We note that from a hardware feature standpoint, the integration of (sophisticated) sensors is arguably the most crucial element in helping to shape the smart device landscape as awareness of user, environmental, and temporal conditions help to generate the data that fuels AI/ML algorithms. In terms of semiconductor devices that are necessary to run these AI assistants, typically ARM-based mobile smartphone chipsets are suitable for supporting voice recognition features and basic levels of inference. In low-cost smart device applications, we estimate that even 32-bit microcontrollers (MCU) have enough performance to support AI assistant functions. Consumer edge device segments covered in this report and an overview of the state of the market with respect to edge computing include:

1) **Smartphones** – With approx. 1.5B units sold in 2019, smartphones are the largest device segment that we consider to be a consumer edge device given the rising network demands caused by user content consumption and data generation. We expect the upcoming 5G cellular standard transition to be a positive catalyst for driving replacement demand over the coming years. The improvements in network performance enabled by 5G are expected to support new services and capabilities for smartphones. We believe increasing artificial intelligence (AI) and machine learning (ML) oriented apps will drive greater demand on edge infrastructure to support these new functions even as smartphone processors see more integration of dedicated AI/ML processing cores to help accelerate performance. We expect Siri and the Google Assistant to remain the dominant AI assistants within the iOS and Android OS environments, respectively. Key companies in the smartphone segment include Apple, Samsung, Huawei, Xiaomi, Oppo, and Vivo.

Figure 40 Smartphone Market Unit Forecast

	2015A	2016A	2017A	2018A	1Q19	2Q19	3Q19	4Q19	2019A	1Q20E	2Q20E	3Q20E	4Q20E	2020E	1Q21E	2Q21E	3Q21E	4Q21E	2021E
Smartphone Shipments (M)																			
Apple	231.6	215.4	215.8	205.4	41.0	37.5	44.5	72.0	195.0	38.1	30.0	40.0	60.0	168.1	44.0	40.0	48.0	72.0	204.0
Samsung	320.2	306.4	314.8	288.1	69.5	72.0	77.0	69.0	287.5	63.0	60.0	70.8	65.6	259.4	65.5	62.4	73.7	68.2	269.8
Huawei	105.3	133.4	145.9	192.5	59.0	59.0	67.0	55.0	240.0	42.0	47.0	72.4	60.5	221.9	44.1	49.4	76.0	63.5	233.0
Xiaomi	71.0	52.4	91.4	118.7	27.9	32.1	32.1	32.9	125.0	24.0	26.5	30.5	32.2	113.2	24.7	27.3	31.4	33.2	116.6
Oppo	--	--	--	118.0	24.0	28.0	31.0	28.0	111.0	19.0	22.0	29.5	27.4	97.9	19.6	22.7	30.3	28.3	100.8
Vivo	--	--	--	103.0	21.0	24.0	27.0	26.0	98.0	18.0	21.0	25.9	25.5	90.4	18.5	21.6	26.7	26.2	93.1
Total	**1,423.9**	**1,496.0**	**1,536.5**	**1,525.0**	**372.0**	**368.7**	**372.2**	**389.4**	**1,502.3**	**312.5**	**258.1**	**297.7**	**364.1**	**1,232.4**	**337.5**	**325.2**	**327.5**	**353.2**	**1,343.3**
Growth Trend																			
Q/Q %					-4.0%	-0.9%	0.9%	4.6%		-19.8%	-17.4%	15.4%	22.3%		-7.3%	-3.6%	0.7%	7.8%	
Y/Y %	**9.4%**	**5.1%**	**2.7%**	**-0.7%**	-3.0%	-1.5%	-2.0%	0.5%	**-1.5%**	-16.0%	-30.0%	-20.0%	-6.5%	**-18.0%**	8.0%	26.0%	10.0%	-3.0%	**9.0%**
Tech Standard (M)																			
2G / 3G					15	13	11	12	51	10	10	10	10	40	10	10	10	10	40
4G					357	356	360	361	1,434	277	213	228	274	992	247	230	238	258	973
5G							1	16	17	25	35	60	80	200	80	85	80	85	330

Source: Cowen and Company estimates

2) **PCs** – The mature client PC market continues to evolve as new form factors, increasing popularity of gaming, and a positive shift in consumer sentiment by the

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Gen Z age cohort toward PCs has largely helped to slow the decline in unit demand in recent years. According to Gartner forecasts, the PC market saw shipments of 263M in 2019. While we believe most consumer-oriented PCs are used primarily for content consumption, PCs have also seen rising popularity for content creation and social networking within the Gen Z age group. Low-cost consumer devices such as Chromebooks also tend to depend more on cloud-based software resources and services given the cost-sensitive price points and deployments in the education sector. Key companies participating in this segment include Acer, Apple, Asus, Dell, HP, and Lenovo among others.

3) **Tablets** – The tablet market is often considered a part of the mobile PC market given the prevalence of convertible form factors and the popularity of Microsoft's Surface products that are tablets at their core. Since the market peaked at 230M units in 2014, the broader low and mid-range price tiers have seen a marked decline, while premium products such as the iPad, Surface, and Samsung's Galaxy Tab have seen their mix of the overall market stabilize / increase. We expect consumer-oriented tablets to remain primarily content consumption devices though the addition of more enterprise features could place them closer to an extension of the convertible notebook market or as a new device to be integrated into commercial work settings such as medical offices, industrial control interface, and deployment in the transportation sector (e.g. airline cockpits, shared ride service fleets). Key companies participating in this segment include Apple, Google, Lenovo, Microsoft, and Samsung.

4) **Smart TV & OTT Streaming Devices** – Consumers have never had more choice in the video streaming market as the start of 2020 also marked the beginning of the streaming wars in our view. More than just a display for watching content, connected / smart TVs and related over-the-top (OTT) boxes (i.e. video streaming boxes) have become more sophisticated in recent years integrating AI assistants from Amazon, Apple, and Google while also offering ML enhancements in terms of content suggestions and even advertising. As the popularity of streaming rises at the expense of traditional media providers and movie theater experiences, we expect more video data traffic will need to be supported from network infrastructure located closer to end users. While content distribution networks (CDN) are not new, we believe further buildouts in network edge infrastructure will also be added to support video streaming, video conferencing (especially in a post-COVID-19 world), and enablement of more services that adapt to user preferences as the smart TV evolves into a more interactive hub in the home. Key companies participating in this segment include TV makers such as Samsung, LG, Sony, Vizio, TCL, Hisense, and Xiaomi. OTT TV / video streaming box suppliers include Amazon, Apple, Google, nVIDIA, Roku, and Xiaomi.

5) **Smart Devices** – We believe the smart devices category is also in its early days of growth as the number of market offerings continue to proliferate with a range of price points available to the consumer.

- **Wearables – Watches**: Smart watches continue to evolve as more advanced mobile computing cores and increased battery life is supporting the integration of more sensors and prevalence of 4G wireless cellular connectivity. We would expect higher penetration of 4G/5G cellular modems to allow smart watches to directly connect to the network and cloud as a key trend that will continue to grow the category. Key companies participating in this segment include Apple, Fitbit, Garmin, Motorola, Samsung, and Xiaomi.

- **Wearables – AR/VR Head Mounted Displays (HMD)**: The launch of the Oculus Rift and HTC Vive in 2016 marked the start of the latest generation of virtual reality (VR) HMDs in the marketplace. While technical specifications continue to evolve, we believe the processing power and in some cases video streaming required to feed the high-resolution displays within an HMD make them high data bandwidth consumers. While annual units shipments remain modest at 6-7M annually, future augmented reality (AR) HMDs could drive the next way of adoption especially given commercial / industrial use cases. Key companies participating in this segment include VR HMD vendors such as HTC, Oculus, Samsung, Sony, and Valve. AR HMD/glasses vendors include Epson, Google, Magic Leap, Microsoft, Snap, and Vuzix.
- **Speakers**: Low-cost price points and the integration of AI assistants, voice recognition, and natural language processing capabilities have made smart connected speakers one of the fastest growing consume device categories in recent years. This device category reached an estimated 147M units in 2019 and was a device segment that barely existed just 5 years prior. While data bandwidth requirements are generally modest save for music streaming, we believe low-latency is a critical element for the end user experience and can be supported by the growth in edge computing resources and potentially 5G connectivity as smart speakers may potentially evolve to become a smart home sensor hub. Key companies participating in this segment include Alibaba, Amazon, Apple, Baidu, Bose, Google, Harmon Kardon, JBL, and Xiaomi.
- **Security Cameras & Doorbells** (including locks): The addition of WiFi / Bluetooth connectivity, smartphone app integration, and cloud connected controls have also made security cameras and doorbells a fast-growing device category within the consumer market. Support for remote viewing and the peace of mind from connected security services is a big step forward from traditional wired home security camera kits that only record to a local hard drive and require labor-intensive laying of wiring through a home. Given the popularity of cloud storage and prevalence of AI/ML algorithms for video analysis, we believe it will be a matter of time before smart camera/doorbell companies were to offer enhanced (premium) features or services that could detect and alert users of certain events such as recognition of a package being delivered, unusual activity during certain period of the day, etc. Product offerings in the market come from a wide range of companies including traditional home security and HVAC device providers, start-up companies, and Internet cloud companies. We estimate this device category reached 147M units in 2019, making it the largest portion of the smart device category at just over a third. We forecast smart cameras and doorbells to grow at a 17% CAGR through 2023. Key companies participating in this segment include Amazon (including Blink, Ring), Arlo, D-Link, Google (including Nest), Logitech, Wyze, Xiaomi, August, Schlage, and Yale.
- **Display & Signage**: As an extension or hybrid of the smart speaker concept and video conferencing on a PC, the smart display category is still a nascent market that has seen an increased number of offerings in the past year. While the performance and capability demands of smart speakers apply, we expect displays to further increase the network bandwidth and silicon processing requirements depending on level of sophistication of cameras and other sensors. Key companies participating in this segment include Amazon, Baidu, Facebook, Google, and Lenovo.
- **Thermostats**: Similar to smart security cameras and doorbells, the smart thermostat has become a very popular device as smartphone app access and

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cloud connectivity offer end users the convenience of remote control. Given that bandwidth requirements are low, we believe it possible that next generation smart thermostats could offer dual WiFi as well as 5G connectivity integration. Key companies participating in this segment include Ecobee, Google (including Nest), and Honeywell.

- **Plugs & Power Switches**: The addition of WiFi connectivity and app access have also helped to elevate the lowly electrical socket into a cloud connected and remote accessible device within the home. Relatively inexpensive but impactful in terms of convenience, we estimate the smart plug and power switch device market reached ~80M units in 2019. Key companies participating in this segment include Amazon, Belkin (Wemo), iHome, Lutron, Samsung, and TP-Link.

Where Are Consumer Edge Devices Headed?

Looking further out on the horizon, two market forces that we expect to have a material symbiotic influence on the consumer edge device market are 5G wireless and (increasing) autonomous capabilities in smart devices. In the case of 5G, the lower latency allowed along with higher density of cellular basestations especially in urban environments via small cells is expected to not only bring new levels of service capability for existing smartphone and mobile device segments but also introduce more devices and usage models into the network. Be it industrial / commercial IoT devices that are part of the public infrastructure or connected vehicles that can communicate with sensors or vehicles in the surrounding environment for additional context or safety reasons, we expect the inclusion of new devices to the wireless network to serve to enhance the overall user experience and utility of the network itself.

In the following chart of consumer edge device requirements, we believe device segments with medium to high requirements for low latency, bandwidth and compute power could materially benefit from 5G wireless connectivity. This is especially true for smart devices that today are primarily connected via WiFi. From a compute power perspective, we believe PCs and AR/VR HMDs could be the most demanding in terms of cloud computing resource intensiveness due to ML workloads or video processing and rendering.

Figure 41 – Consumer Edge Device Requirements by Segment

Edge Client Device Category	Low Latency	Bandwidth	Compute Power	Storage	Cybersecurity	AI / ML
Smartphone	High	High	Medium	Medium	High	High
PC	Medium	High	High	High	High	Medium
Tablet	Medium	High	Medium	Medium	Medium	Medium
Smart TV & OTT	High	High	Medium	Low	Medium	Medium
Smart Devices						
Wearables - Watches	Medium	Medium	Low	Low	High	High
Wearables - AR/VR HMD	High	High	High	Medium	Medium	Medium
Speakers	High	Medium	Medium	Low	High	High
Security Camera, Doorbell	Medium	Medium	Medium	High	High	High
Display, Signage	Medium	Medium	Medium	Low	High	High
Thermostat	Medium	Low	Low	Low	Medium	High
Plug / Socket	Medium	Low	Low	Low	Medium	Medium

Source: Cowen and Company

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Finally, from an AI/ML connected services perspective, we classify workloads associated with AI assistants as a high requirement in smartphones and a number of smart device segments as we believe the often voice driven interactions with AI assistants demand a level of accuracy, intuitiveness, and comprehensiveness to achieve high levels of user satisfaction. In the case of security video stream captures and smart displays, we anticipate future ML algorithms that can accurately identify threats and take appropriate actions while protecting user privacy as key features that will be enabled by further sensor integration, higher performance semiconductor chips, and evolution of software algorithms. Even as more edge devices utilize mobile ARM processor with integrate neural network engines for accelerating inference workload performance locally, we still expect a significant amount of the processing to still be handled within a data center. We estimate only 20-30% of intra-data center IP traffic actually makes it beyond the physical boundaries of the data center to reach end users.

Company Implications

Apple (AAPL) – Our Outperform rating on Apple continues to be predicated on the Services business as a long-term growth driver for new recurring revenue streams that should drive the valuation multiple higher while the iPhone and other hardware businesses remains a steady cash flow generating annuity for the company. In the current COVID-19 affected demand environment, we view the stock as a defensive name given that the Services segment that continues to benefit from the 'work from home' environment, and a cash flow generating iPhone demand trajectory that should improve once we 'get out of home.' Looking into CY21, a 5G iPhone cycle coupled with further growth in Services is expected to drive a reacceleration in revenue and earnings. Reiterate Outperform and $335 price target.

Universal Display (OLED) – Universal Display (UDC) is the leading supplier of emitter materials for organic light emitting device (OLED) based display panel technology. We continue to view UDC's long-term growth prospects positively given secular growth in OLED display technologies, limited competition, and a strong balance sheet with net cash of $640M (~$14 / share). We expect smartphone demand and sector sentiment to improve into 2H20 and an expanding customer base for OLED TVs and industry production capacity are positives for driving the next phase of long-term revenue growth. Our Outperform rating is based on a price target of $200.

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IT Services

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Akin to the explosion of mobile application development in the consumer world, we anticipate similar, if not broader, activity to unfold in the enterprise IT landscape on an ever-expanding universe of connected systems and devices (IoT) comprising Industry 4.0. The confluence of traditional operational technology and mechanical engineering across sectors with cloud and intelligent automation technology effectively connects enterprise physical assets to digital networks. This supports cost and operating efficiencies and offers new revenue opportunities derived from data not previously accessible and at real-time. Edge Computing is an enabler of this technological sea change. As an extension of core cloud computing, decentralized processing of data serves as a critical conduit for successful scale and efficiency to mitigate latency and bandwidth concerns that are arising with material increased data flows.

Consultancies & IT Services companies stand to gain in serving enterprise clients' edge computing and IoT/Industry 4.0 lifecycles. Activities come in the form of upfront business & strategy ideation, including application and infrastructure architecture consulting, downstream systems integration and application development, and platform managed services activities. With growing data processing activities, data orchestration services are critical and there are also natural extensions to edge analytic applications, and significant requirements in cybersecurity services with the expansion of vulnerable endpoints and layers (individual device, infrastructure connectivity, and application). Marriage of these capabilities, with industry domain knowledge depth is critical to ensure optimal application of the tech to business, considering applicable regulations.

Edge computing unlocks greater potential for Industry 4.0, which in turn presents massive Services opportunity through the horizontal integration of operational technology and information technology, and the development and support of clients' new products, business models and services. The pace of projected expansion is attractive as Gartner currently sees only ~10% of enterprise-generated data created and processed outside a traditional centralized data center or cloud, but ~75% by 2025. Increased data processing capability supports an IoT market that is expected to grow to 75.4 billion connected devices by 2025 (+145% from 2020). To get there, combined corporate spend across the global ER&D and digital product engineering is projected to nearly double by 2025 to over $2 trillion; we see the outsourced component rising to 50% over this period to $1+ trillion yielding an attractive ~20% CAGR.

With no clear industry standards yet defined, and a reported 600+ separate IoT platforms in the market, the customization requirements of edge computing and Industry 4.0 initiatives across global enterprises yield the notable Services potential. We see enterprises pursuing a combination of internal resources and external consultants/outsourced services providers. Still, the nascence of this market yields a landscape with only few definitive market leaders. ACN has been most visible in its investment efforts, developing the largest IoT franchise in Industry X.O. Scale and services/server product mix is a benefit for players such as IBM, ATOS.FR and NTT Data to address enterprise edge needs, while the cloud services and systems integration breadth of traditional offshore players like TCS.IN and HCL.IN place them among the top in satisfying edge and connected product engagements. Notable consolidation of ER&D firm Altran by Capgemini was a key accelerant in its Industry 4.0 offering. Among digital product engineering providers, EPAM has the right mix of software engineering depth with a building business in physical product design/consultancy. We see a natural convergence of the digital product engineering and ER&D markets and anticipate M&A activity to bring new leaders to this mix.

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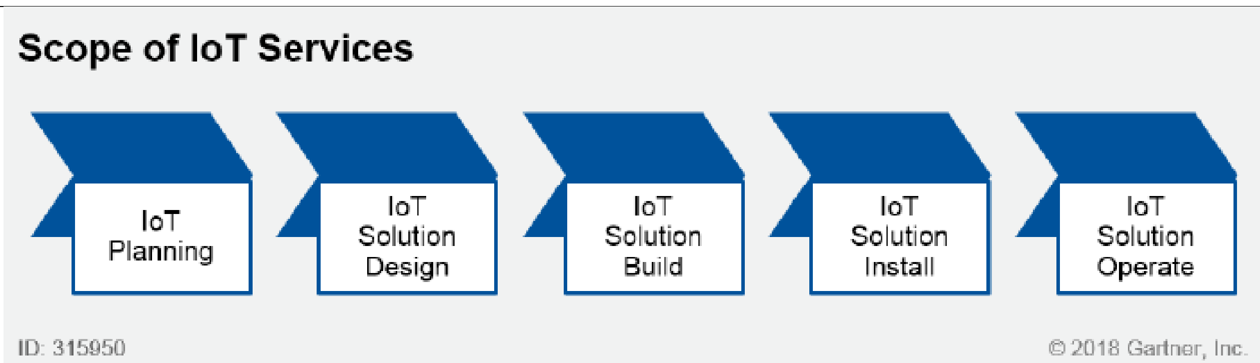
Edge & IoT Lifecycle Services Offerings

Edge Services opportunities span the lifecycle of an enterprise cloud strategy. Apart from added effort in hardware and infrastructure selection, such Services activities largely mirror those of IoT and Industry 4.0. This includes the consulting and planning of technology stack deployment to the integration and implementation of solutions and subsequent managed services. IoT service providers can solely focus on one distinct phase in the IoT deployment cycle or provide end-to-end service offerings. Planning work consists of advising clients on the benefits of edge and IoT and use cases for deployment.

Design work consists of design thinking and the development of physical and digital schemes of IoT solutions for deployment. This naturally leads to build activity, comprising the digital product engineering and application coding of an IoT solution that will be deployed. Following QA testing of the product, a service provider will deploy the IoT solution for the client. Ongoing activities beyond implementation present an annuity revenue stream via outsourced operations surrounding the edge computing and IoT solutions. Outsourcing arrangements no different from traditional IT management come in the form of a managed services agreements.

Figure 42 The Scope of Edge Services Opportunity Is Broadly Similar to That of IoT Services



Source: Gartner "Market Guide for IoT Service Providers" 3 January 2018

Currently, the bulk of Services activity involves edge and IoT is front-end consulting, including ideation, proof of concepts (PoC), and some reactive engagements that are addressing first movers that had challenges (not getting the return or experience we expected) and require reorganization of the target model. Consulting services are serving two primary channels, including:

- **Technology-associated:** including selection across sensors, applications, networks & infrastructure; and
- **Organizational / operating model:** how an enterprise aligns itself and forms the product-oriented teams and organizes/collaborates (plan, build, run). Also, support with breaking down silos between functions and determining a common language.

As more defined outcomes materialize, there will be an boon to Digital engineering and DevOps services that include software product development (agnostic to hardware) as well as applications that support IoT software applications that include connectivity,

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mobility, predictive maintenance and real-time supply chain; this incorporates operational technology data analysis and management, PLM and MES applications.

Figure 43 A More Granular Look at the Services Value Chain: IoT

Internet of things (IoT) value chain			
Strategic consulting	**Productization**	**Deployment**	**Operations**
• Governance, security, data protection strategies • IoT technology roadmap • Planning, prioritization, and business case development	• PLM version control, change management, network protocol, 5G, new data format, new regulatory requirements • Product engineering, software engineering, embedded technology, device security, custom app development, prototyping, and network engineering	• Data network and system integration, end-to-end process integration • Run-time and backend infrastructure, security, cloud hosting, and network management	• IoT platform and application support, product tech support, device management, and sensor management • Data and analytics services including business analytics, operation analytics • GRC (governance, risk, and compliance) services; real-time monitoring and reporting services, compliance audit-system, information, process, security—data, device, system, network, and control

Source: HfS Research; Ernst & Young

Figure 44 A More Granular Look at the Services Value Chain: Industry 4.0

Industry 4.0 Value Chain						
	R&D	**Design**	**Operations**			**Support services**
			Inbound	**Production**	**Outbound**	
Activities value chain	• Market research • Basic research • Technical feasibility • Applied research	• Feasibility study (cost, quality) • Prototyping • Testing • Regulatory compliance	• Demand planning • Inventory management • Procurement • Transportation and logistics	• Production planning and scheduling • MRP I and II • Manufacturing and IT support • Quality control and waste management	• Order processing and fulfilment • Transportation and logistics • Aftermarket services • Sales and distribution • Warehouse management	• Finance • Human resource management • Marketing
	Industry 4.0 components			**Generic technology components**		
Technology components value chain (Scope: Enabling technologies for Industry 4.0)	• Robotics • Manufacturing Automation, IT support systems (SCADA, PLC, MES HMI, ERP) • 3D printing • Small batch manufacturing			• Big data • Predictive analytics and AI applications (visual analytics, machine learning, computer vision, etc.) • Internet of things (IoT) • Digital twin or simulation • Microservices, as-a-service model • Cybersecurity • Augmented reality (AR) • Virtual reality (VR) • Blockchain • Drone		
Workforce	Digital-ready workforce to enable and drive new operating models, innovative business models, and applications of new age technologies					

Source: HfS Research; Accenture

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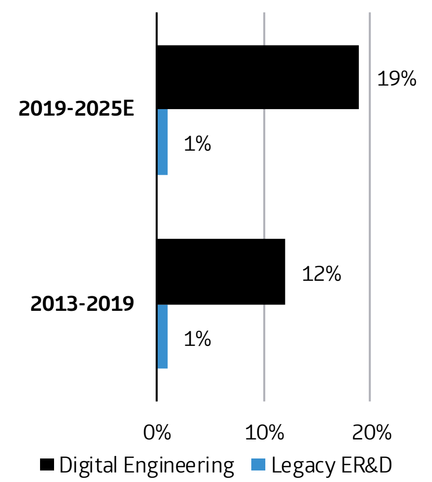
Industry 4.0 Yields Notable Digital Engineering and ER&D Opportunity

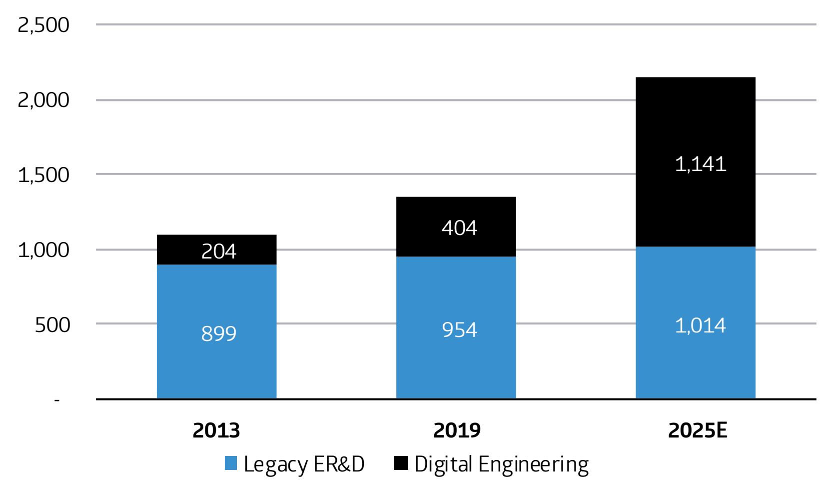
The penetration of connectivity in manufactured devices is deep already. According to Accenture's Technology Vision 2020 survey, 49% of companies cited more than half of their products now have requirements for software updates & support after purchase. This is a large market that is set to get larger. Combined, corporate spend across the global engineering R&D (ER&D) and digital product engineering is projected to nearly double by 2025 to over $2 trillion; we see the outsourced component rising to 50% over this period to $1+ trillion yielding an attractive ~20% CAGR.

Figure 45 Growth Across Subsets; DE Strength



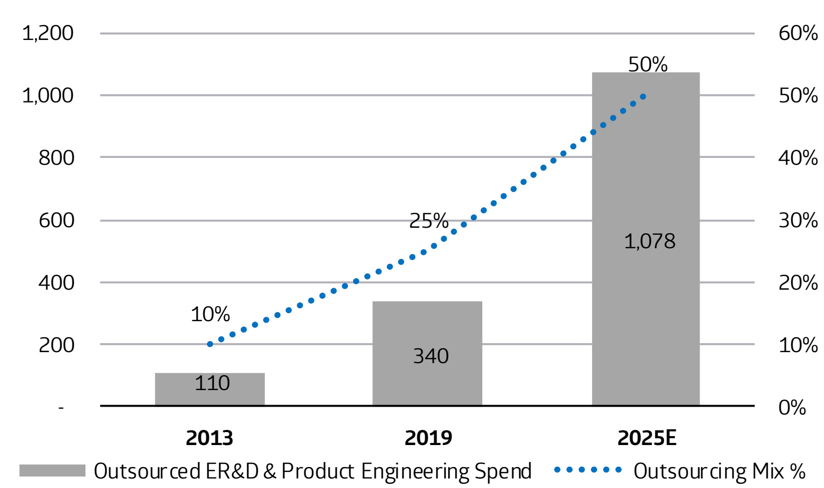
Source: Zinnov; Cowen

Figure 46 Combined Digital Engineering & ER&D Projected to Exceed $2Tn (Internal & Outsourced)



Source: Zinnov; Cowen

Figure 47 Outsourced Market Gains Traction as Capabilities Continue to Evolve



Source: Zinnov; Cowen

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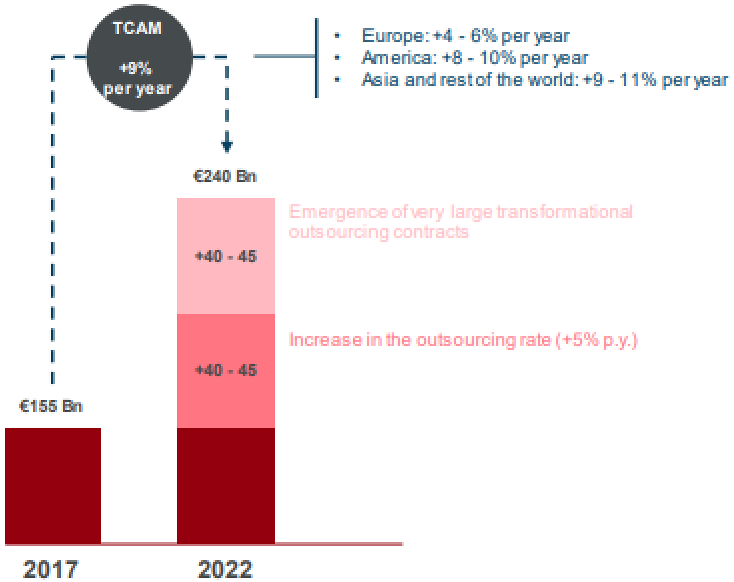
There are various subsets of this addressable market. The ER&D market includes the outsourcing of design, prototyping, mechanical engineering, systems engineering, software engineering, testing, manufacturing, aftersales services and IT activities linked to R&D. The industry is expected to reach €240bn in 2022, reflecting a CAGR of ~9%. European providers dominate the market, but it also includes Multinational, Indian Offshore, and Digital native IT Services competitors, and growing competition is to be expected as ongoing convergence of OT/IT continues.

Separately, the smart factory platform development environment with connectivity across technologies such as MES, ERP, PLM is estimated to be worth approximately $154 billion in 2019, growing at a CAGR of close to 10% through 2024. Adjacent to this, Gartner predicts that spending on IoT-enabled predictive maintenance will increase to $12.9 billion, up from $3.4 billion in 2018.

Figure 48 Core ER&D Market Projected at Attractive +9% CAGR



Source: Altran

The concept of IoT is mature; however, deployment is not, and as enterprises struggle to optimize IoT strategy, the need for external support is clear. According to a December 2018 study by HCL/451 Research, 80%+ of enterprises expect to contract with specialist external support in order to help in the development of IoT strategies, the IoT architecture/integration planning, and the support of IoT operations, or drive the infrastructure management aspects of IoT. Post-development maintenance and support is the least cited area for external support, but still 43% of the survey, showing even the lowest priority area appears to hold ample IT Services opportunity.

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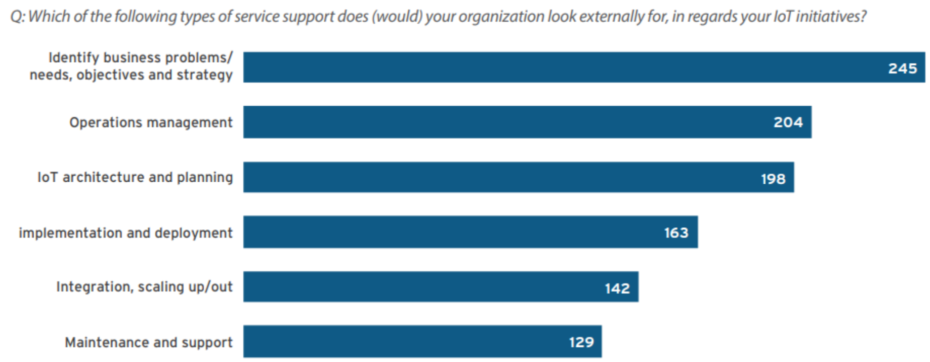
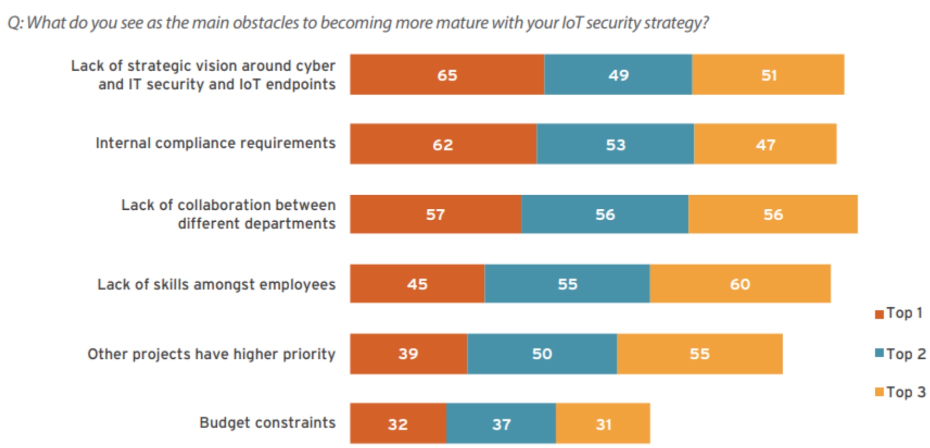
Figure 49 HCL/451 IoT Study: External Support for IoT Initiatives Is Broad Across the IoT Lifecycle



Source: HCL; 451 Research; Dec 2018 n=300

Specific to IoT security, a common hindrance from a more mature strategy shows a lack of internal skills among employees and siloed functions; this leaves opportunity for external specialists. When prompted to identify the top 3 obstacles, 'Lack of collaboration between different departments' was the top cited secondary concern and third most cited primary concern. 'Lack of skills among employees' was the 4th most cited primary concern, second most cited secondary concern, and top cited tertiary concern.

Figure 50 HCL/451 IoT Study: Skills and Collaboration a Common Hindrance to IoT Security Maturity



Source: HCL; 451 Research; Dec 2018 n=300

The relative potential revenue opportunity in an IoT initiative spans the Design, Build and Run Phases. HCL sees this revenue split across a representative sample of its client engagements as ~5-10% Define, ~35-40% Build, and ~45-50% Run. This suggests a potential broader opportunity at the later stages of an IoT initiative versus the integration and implementation phase that most clients see the greatest need for external specialists. When considering budget types across its Fortune 500 base, HCL's experience shows large-scale corporate-wide programs ($500MM average over 3-5 years), disparate business level programs ($50MM average lasting ~3 years), and individual product/function level, stepping down to ~$10MM, but still ~3 year terms.

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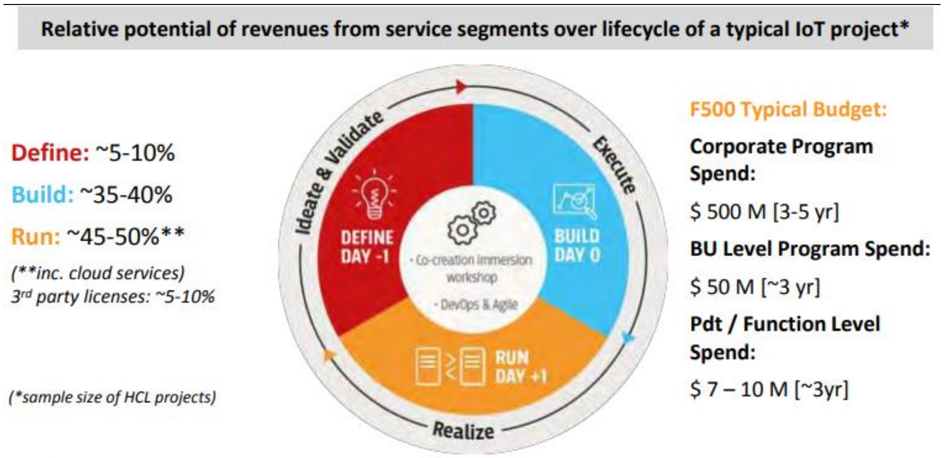
Figure 51 The Services Opportunity in IoT: Revenue Potential Define-Build-Run & By Budget Type



Source: HCL

Who's Early to the Party? Some Usual Suspects, But Still a Nascent Space

The nascence of the edge computing and Industry 4.0 market yields few definitive market leaders. ACN has been most visible in its investment efforts, developing the largest IoT franchise in Industry X.0. Scale and services/server product mix is a benefit for players such as IBM, ATOS.FR and NTT Data to address enterprise edge needs, while the cloud services and systems integration breadth of traditional offshore players like TCS.IN & HCL.IN place them among the top in satisfying edge and connected product engagements. Notable consolidation of ER&D firm Altran by Capgemini was a key accelerant in its Industry 4.0 offering. Among digital product engineering providers EPAM has the right mix of software engineering depth with a building business in physical product design/consultancy. Large cloud systems integrators have proficiencies catering to edge computing; however, the traditional separation of operational technology from information technology in enterprises – which made sense due to varying DNA of respective areas – needs to come together and this likely spurs growing M&A between the IT Services and Engineering R&D outsourcing sectors.

Aside from the largescale management consultancies, there are three broad types of Services firms that address edge & Industry 4.0 from varying angles. These include:

- **Digital product engineering companies** (such as EPAM, GLOB, Luxoft-DXC, DAVA, GlobalLogic, etc.)
- **Large-scale & traditional IT Services/offshore system integrators** (such as ACN, ATOS.FR, IBM, CAP.FR, TCS.IN, INFY, CTSH, HCL.IN, DXC, etc.); and
- **Engineering R&D/OT firms** (such as Altran-CAP.FR), Alten, etc.).

The most successful partners to address Industry 4.0 challenges are those that combined the skillsets that each of these classes of service providers are known for.

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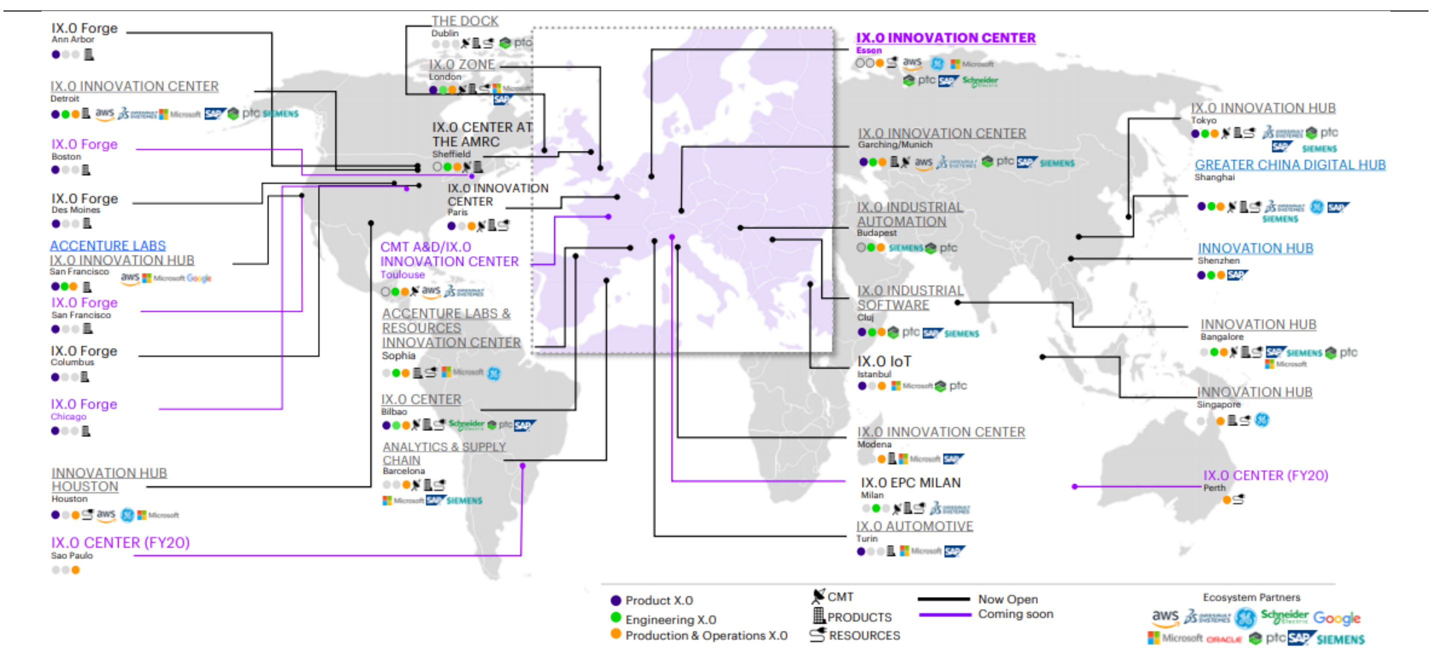
That is, strength in coding aptitude with a creative sense to spark new designs and product development – creativity and custom engineering depth characterize the Digital product engineering Services companies above – to the enterprise-scale cloud modernization strength of the Sis, to the physical engineering aptitude that ER&D and OT firms above offer.

We highlight Accenture, Capgemini, EPAM and HCL Tech with notable offerings and focus in this nascent market.

- **Accenture:** ACN has been most visible in its investment across its IoT/smart connected products and services franchise, dubbed Industry X.0, spanning intelligent devices (consumer & industry), industrial facilities, vehicles and homes that are interconnected via IoT. Accenture employs three core techniques via industrial design thinking, physical technology demonstrators through its innovation centers (rapid prototyping of solutions) using sensors, using analytics, and industrial IoT platforms.

  The company clearly benefits from its overall scale across the consulting through SI and managed services value chain; however, it has also been most visible in forward-looking investments that incorporate creative product design and deep engineering capabilities, and a broader proposition that considers operations management and supply chain. It has executed on high-value tuck-in M&A deals, developed internal IP and patent filings across IoT/robotics/and industrial applications (600+), and boasts over 10,000 Industry X.0 professionals. It has the most expansive network of physical facilities to co-innovate with its clients and work with broad technology partners, across 20+ strategically located sites in its global Industry X.0 Innovation network.

Figure 52 Accenture Industry X.0 Innovation Network: 20+ Integrated Global Facilities



Source: Accenture

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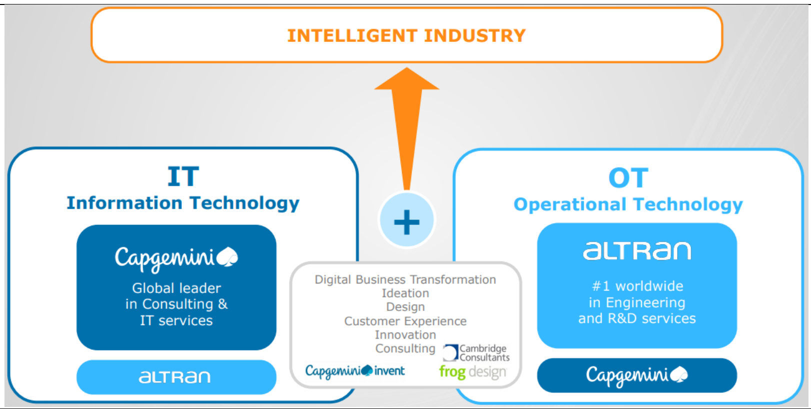
- **Capgemini:** CAP.FR's recent acquisition of Altran for €3.7 billion is the largest bid to date and first major combination of a global IT Services provider and OT/ER&D firm. The combined scope of its Engineering and R&D services represent annual revenues ~€3.4 billion and 54,000 professionals. The combined base of industrial and manufacturing clients with a leading footprint in Europe position it in key areas as Intelligent Industry gains scale. Its offerings span intelligent products, intelligent operations and support and services. It is a top provider to A&D, Telecom, and Semiconductor & Electronics sectors with access to most of the top 20 global R&D spenders across auto (VW, Daimler, Ford, BMW, GM, Toyota), industrial manufacturing/automation (Bosch, Siemens) and life sciences (Roche, JnJ, Pfizer).

Figure 53 Capgemini + Altran Yields an Offering Well Suited to Address Intelligent Industry Needs



Source: Capgemini

- **EPAM**: EPAM's pure-play expertise in both digital platform engineering services and integrated physical and digital design makes it a natural beneficiary of Industry 4.0. Its Made Real Labs via the Continuum acquisition, combined with EPAM Garages, yields a growing physical network for experiential prototyping. Through these and its heritage strength in software engineering for high-tech clients and these physical facilities EPAM boasts an end-to-end offering. Continued front-end investments are expected to broaden its consulting and design breadth.

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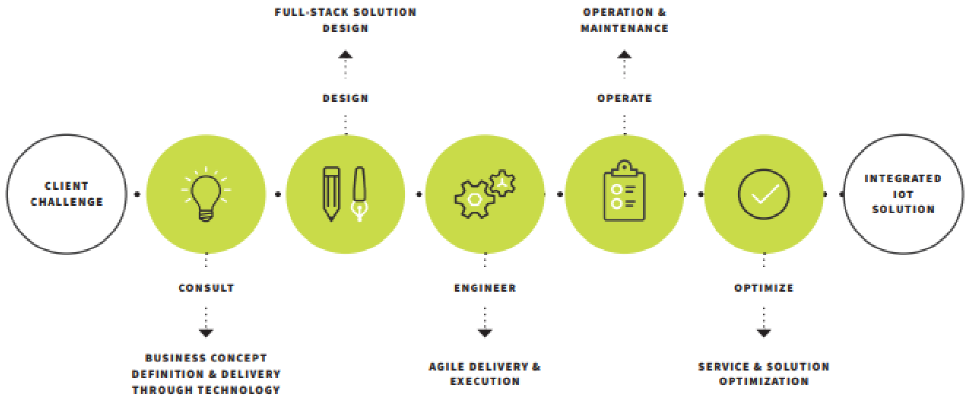
Figure 54 EPAM's IOT Solution End-to-End Delivery Approach



CONSULT	DESIGN	ENGINEER	OPERATE	OPTIMIZE
• IOT STRATEGY ASSESSMENT • BUSINESS PROCESS CHANGE MANAGEMENT • INNOVATION AS A SERVICE • BIG DATA CONSULTING	• SERVICE DESIGN • IOT SERVICE PROTOTYPING & PROOF OF CONCEPT • IOT SOLUTION & NETWORK ARCHITECTURE DESIGN • PRODUCT MANAGEMENT & BUSINESS ANALYSIS	• PRODUCT-FOCUSED IOT APPLICATION DEVELOPMENT • SYSTEMS ENGINEERING & INFRASTRUCTURE • AGILE DELIVERY ORGANIZATION	• IOT ANALYTICS • BIG DATA SERVICES • IOT DATA MANAGEMENT	• IOT SOLUTION TESTING • TRANSFORMATION SERVICES TO IMPROVE OPERATIONAL EFFICIENCY • INTELLIGENT AUTOMATION IMPLEMENTATION

Source: EPAM

- **HCL Technologies:** HCL is a leader among offshore service providers with critical mass in both IoT and ER&D. Within its IT Services offering, it established IoT WoRKS in 2015, a dedicated IoT business unit. It launched multilocation innovation centers in 2018 in the US and India (IoT COLLAB) for co-creation opportunities with clients. It has reached several hundred million in sales and sees the unit growing in excess of 30%+ annually, an engine within the overall company, as it offers full lifecycle services and platforms. An example of developed proprietary IoT offerings is iCE.X, a scalable IoT device management platform for consumer premises equipment (CPE), small cells, gateways, sensors and various IoT devices. Through organic and M&A investments it also built out a notable Engineering and R&D Services unit providing comprehensive engineering services and solutions across software, embedded, mechanical, VLSI and platform engineering that support the end to end lifecycle of products – both hardware and software across industries. This segment rose to $1.7Bn of FY20 revenue, +12% y/y, and comprised ~17% of its overall business.

IT Services Proprietary Offering & M&A Investments

Below are select proprietary platform solutions of IT Services providers that support enterprise clients to develop, deploy and manage IoT applications. The activities span device management, data management, analytics, streaming data processing, asset modelling and edge processing.

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Figure 55 Representative Edge & IoT Proprietary Solutions Across IT Services Providers

Company	Edge / IoT Offering	Description
ACN	Connected Platform-as-a-Service (CPaaS)	open IoT platform
	Accenture Insights Platform (AIP)	cloud-based, end-to-end analytics solution
ATOS.FR	BullSequana Edge	edge computing server supporting Atos Edge Computer Vision, Atos Edge Data Analytics & Atos Edge Data Container (EDC)
	Codex IoT	private IoT platform; managed on-premise solution powered by MindSphere
CAP.FR	Capgemini XIoT Platform	configurable and agnostic solution to securely manage/connect products & assets. Built with Intel, based on the 5A-layer IoT reference architecture and covers layer 1 – the IoT Middleware from Edge to Cloud.
DXC	DXC Industry 4.0 Platform	federated Industry 4.0 platform with use cases, blueprints, integration projects, operational offerings
IBM	IBM Edge Application Manager	operate AI, analytics and IoT workloads; a single administrator can manage up to 10,000 edge nodes at the same time
	Vertical Edge Apps & Services	IBM Visual Insights, IBM Production Optimization, IBM Connected Manufacturing, IBM Asset Optimization, IBM Maximo Worker Insights and IBM Visual Inspector
	Watson IoT	open IoT platform for device management, analytics, data management, software development and security, and robust integration
INFY	Infosys Sense Suite	service delivery platform across the IoT stack for data ingestion, processing and visualization capabilities
TCS.IN	TCS Connected Universe Platform (TCUP)	enterprise grade, multi-tenant, componentized and cloud-agnostic IoT platform
	TCS IP2 Solution	combines IoT with AI and digital twin technologies to support critical assets of utilities, enhance reliability, improve flexibility, cut emissions, and reduce costs

Source: Company reports; Cowen

We see a natural convergence of the digital product engineering and ER&D markets and anticipate M&A activity to bring new leaders to this mix. The targets below reflect skills that advance IoT/Industry 4.0 efforts at major IT Services providers. These include consultancy, engineering and integration across areas such as consumer & industrial user interface and material design; interaction innovation; mechanical and usability engineering; prototyping; design research; and brand strategy.

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Figure 56 Edge / IoT / Industry 4.0 Services M&A

Acquiror	Target	Annc Date	Description	HC
Accenture	Altitude	Jan-17	product design and innovation firm	30
	designaffairs	Jun-18	strategic design consultancy	100
	Pillar Technology	Aug-18	smart embedded software company	320
	Mindtribe	Aug-18	hardware engineering firm	40
	?What If!	Mar-19	product design and innovation firm	150
	ESP	Mar-19	consulting and manufacturing services provider for the life sciences	200
	Zielpuls	Apr-19	product design and technology consultancy focused in automotive	190
	Nytec	Oct-19	product innovation and engineering company	250
	Pragsis Bidoop	Sep-19	big data, AI and advanced analytics firm	200
	Happen	Oct-19	product innovation and analytics firm	50
	Silveo	Nov-19	supply chain consultancy & manufacturing software for SAP and Dassault	50
	VanBerlo	Feb-20	product design and innovation agency	90
	ESR Labs	Mar-20	smart embedded software company focused in automotive	130
	Callisto Integration	May-20	design/implement of manufacturing execution, IIoT & shop-floor control systems	160
	PLM Systems	May-20	digital manufacturing advisory, services and solutions provider	210
Capgemini	Altran	Jun-19	engineering and R&D services (ER&D)	47,000
Altran	Aricent	Nov-17	integrated design and engineering services	10,500
Cognizant	Idea Couture	Jul-16	digital innovation, strategy, design and technology services	170
	Brilliant Service	Mar-17	intelligent products and solutions company	70
	softvision	Oct-18	digital engineering and consulting company	2,850
	Zenith Technologies	Jun-19	life sciences manufacturing technology services company	800
DXC	argodesign	Oct-18	product design consultancy	25
	Luxoft	Jan-19	digital strategy consulting and engineering services	13,000
Luxoft	Radius	Oct-14	next-generation technology solution provider	25
EPAM	Great Fridays	Oct-14	product and service design group	60
	Continuum	Mar-18	innovation design firm	150
GlobalLogic	REC Global	Jan-16	embedded software engineering firm	500
HCL	Geometric	Apr-16	PLM, engineering solutions and services	2,600
	Butler Aerospace	Oct-16	engineering, design services and aftermarket engineering services to A&D	900
	H&D International	Jun-18	IT and engineering service provider	1,400
	Sankalp Semi	Sep-19	technology design services provider	500
IBM	The Weather Co.	Oct-15	product/tech assets: data science experts, precision forecasting & cloud platform	NA
	Oniqua Holdings	Jun-18	maintenance repair & operations, inventory optimization solutions & services	70
Infosys	Brilliant Basics	Aug-17	design and product studio	50
NTT Data	Transatel	Dec-18	IoT cellular connectivity management provider & Mobile Virtual Network Enabler	220
Wipro	ITI	Jun-19	digital engineering and manufacturing solutions company	130

Source: Cowen and Company

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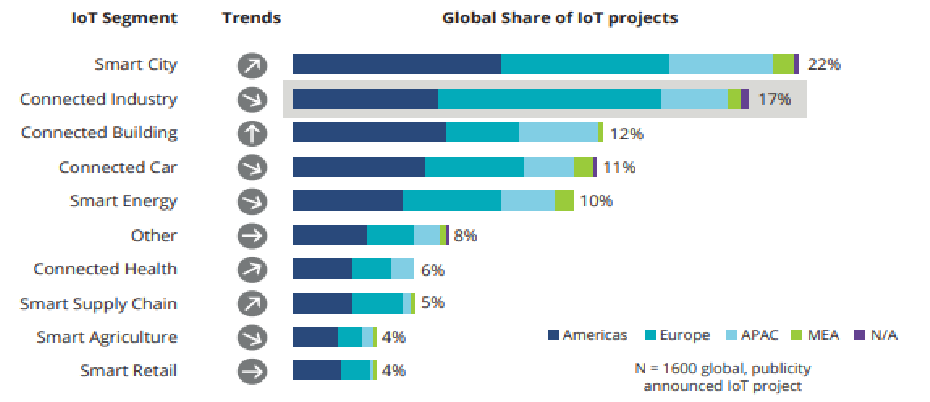
Top Opportunities & Select IT Services Solutions

The largest opportunities for IoT development span Smart Cities, broadly around the world with Americas and Europe of comparable scale. Connected Industry and Connected Building are also a high priority and the interconnection between those likely present interesting collaborative assignments.

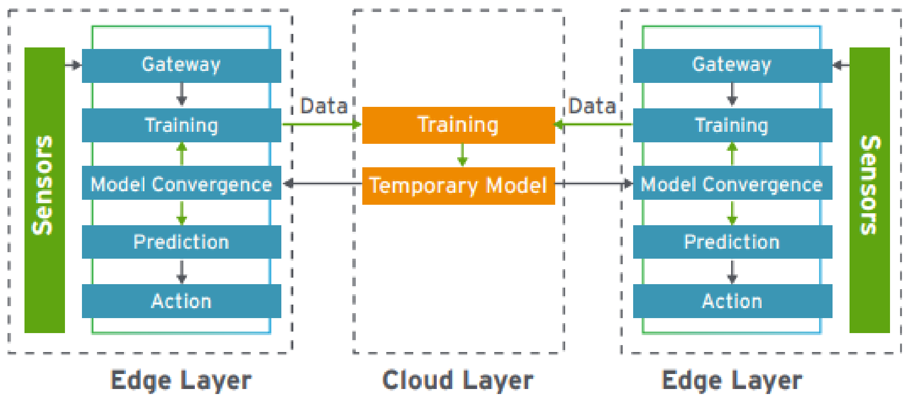
Figure 57 Global Share of Enterprise IoT Projects and Connected Industry IIoT – 2018



Source: ISG; How to Maximize the Value of IIoT and IoT Strategy

Example of a meaningful Services activity includes the design, development and management of in-place analytics tool, with software that analyzes large data sets from devices in their local environment. A further extension of this is geo-distributed machine learning. An excerpt from Cognizant's edge practice below shows the edge enabled GDML technique, whereby each compute node runs a local component of the algorithm on the data available and calculates interim results.

Figure 58 Three-Tier Edge Analytics - Geo-Distributed Machine Learning (GDML) Architecture



Source: Cognizant

Further demonstrations of TCS IoT solutions across industries and a predicative maintenance solution from Capgemini give a sense of Services activity.

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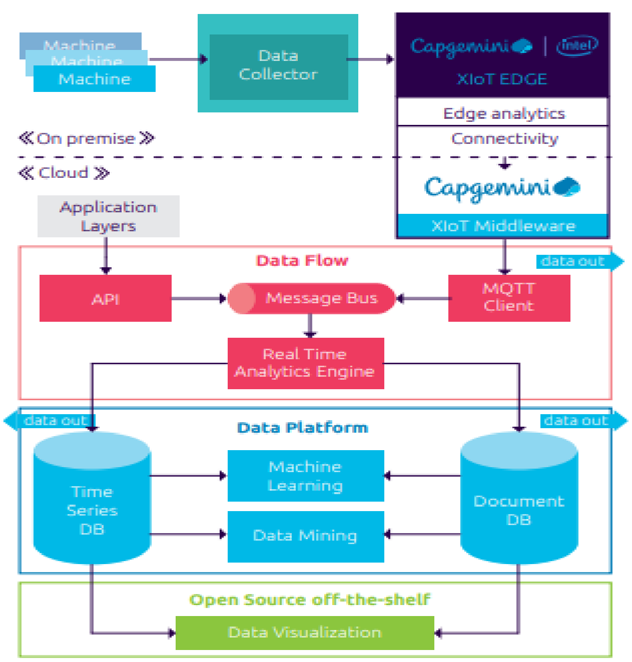
Figure 59 TCS Application of IoT in Different Industries – Representative Solutions

Industry	Solution or Service	Sensors / Devices	Analytics	Interface	Outcome
Utilities (energy, water, gas)	▪ Real-time collection of usage data ▪ Demand-supply prediction ▪ Load balancing ▪ Dynamic tariff generation	▪ Energy, water, or gas meters	▪ Historical usage analysis, usage prediction, demand-supply prediction	▪ Can be accessed on any internet connected device	▪ Consumers connected to these smart networks have seen significant cost and resource savings.[1]
Manufacturing	▪ Remote monitoring and diagnostics ▪ Production line automation ▪ Equipment handling and diagnostics through sensors located on the production floor ▪ Remote expert diagnostics in case of failures	▪ Supervisory control and data acquisition (SCADA) systems / Programmable Logic Controllers (PLCs ▪ Controllers or gateway ▪ Cameras ▪ IoT devices mounted on asset ▪ IoT devices embedded in machines	▪ Anomaly detection in equipment usage and functionin ▪ Predictive maintenance ▪ Automatic quality monitoring in production line	▪ Mainly on central consoles ▪ Can connect to experts on their mobile terminals for remote consultation	▪ Reduced field support costs, lower breakdowns, improved operational efficienc ▪ Optimal scheduling of production lines ▪ Anomaly detection and emission detectio ▪ Improved quality and lower energy costs
Healthcare	▪ Remote expert doctor consultation/ monitoring ▪ Chronic disease management ▪ Elderly care ▪ Wellness and fitness programs	▪ Wearable and personal medical devices ▪ Mobile phones	▪ Anomaly detection in recorded medical data ▪ Historical correlation	▪ Remote tele-consultation on medical super-specialist mobile terminals with the aid of clinical decision support systems	▪ Lower cost of care ▪ Improved patient outcomes ▪ Real-time disease management ▪ Improved quality of life for patients

Source: Tata Consultancy Services

Figure 60 Capgemini Predictive Maintenance Solution



Source: Capgemini

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Video Game Streaming Services

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Cloud gaming has been a fairly big buzzword for the past couple of years, as major industry players have rolled out nascent cloud services, and would-be insurgents have launched new cloud platforms. Both Microsoft (xCloud) and Sony (PlayStation Now) have launched cloud gaming services, while Google has its Stadia virtual gaming platform, and there are several other smaller cloud gaming services. The basic idea of being able to play any game on any screen you own anywhere is a powerful one, as is the idea of being able to take advantage of the latest graphics technology on a dumb terminal with no need for expensive hardware upgrades. Loading times are also greatly reduced when a game is streamed instead of played from a hard drive. The potential for a 'Netflix of gaming' certainly catches one's attention, given that company's runaway success and impressive market cap.

However, cloud gaming has yet to catch fire in a meaningful way. XCloud still lacks support from major third-party publishers, in part because Microsoft appears to be using it as a bit of a loss leader for its overall Xbox platform. PlayStation Now only includes older library titles. Stadia had a bare-bones service offering at launch and lacks any killer first party exclusive games. Cloud gaming as an idea has actually been around for over a decade, with the ill-fated OnLive service announcing itself in 2009, launching in 2011, and then shutting down in 2012.

Not Ready for Primetime Yet, But Edge Computing May Be a Key Step Closer

In our opinion, the real reason that cloud gaming is still a small part of the market is that consumers do not see it as an acceptable alternative, let alone an improvement, to the traditional console/PC ecosystem. While cloud gaming can work well, it is highly dependent on the quality of the internet connection. We have experimented with Stadia in a large variety of settings and the fidelity of the experience varied greatly. The traditional console/PC model delivers a high-quality gaming experience to approximately a six-sigma reliability standard; streamed gaming is not yet anywhere near that. While connection quality is generally not a major concern when streaming videos on Netflix, as people are used to occasional buffering, with video games – particularly multiplayer – any lag or stutter is an absolute showstopper, and cloud gaming does not have consistently good answers for that problem yet.

The issue with cloud gaming is less the raw bandwidth speed and more the consistency of the connection. Experts we have talked to have suggested that cloud gaming won't be a true mass market product, able to deliver an experience that is consistently as good as traditional console/PC, until 5G internet is widely available. Edge computing is a key component of 5G internet and thus will be a key component of any cloud gaming service that intends to be a true replacement for the existing console/PC ecosystem. Until then, we expect cloud gaming to be at most an 'also' service, with hardcore gamers using it to play games when away from their main gaming device, but still relying on the traditional console/PC setup for the majority of their core gaming experiences.

Will Edge-Enabled Game Streaming Make a Big Difference to the Market? Still TBD

Assuming edge computing does enable consistently reliable game streaming, what then? It's important to note that, unlike some other applications of edge, game streaming won't create a new market; it will merely create a new delivery system for a product that already exists. Cloud gaming will likely enable some interesting new options for game development; we are already seeing studios use the cloud to test new builds of games in development while developers are confined to their homes due to

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COVID-19. The cloud could enable games of greater scale to be delivered to consumers. However, we tend to see these changes as evolutionary rather than revolutionary as far as the video game publishers are concerned.

One potentially significant advantage for cloud gaming is that it obviates the need for consumers to buy an expensive piece of hardware in order to use gaming software. In theory this could open up the market beyond the few hundred million or so 'core' gamers in the West that currently exist. However, with consoles listing at $200-$400 (depending on what point of the hardware cycle we are talking about) and lasting 5-8 years, that cost is really pretty small (less than the cost of one game per year). We tend to think that the bigger barrier for attracting new consumers to core 'AAA' games is the 17 buttons on the controller, rather than the $300 cost of the box. Additionally, nearly all potential consumers already have powerful portable gaming devices in the way of smartphones, so we don't really see there being a 'underserved' demographic that cloud gaming will open up.

While we are unconvinced that cloud gaming will play a big role in opening up the gaming TAM, we do think that it will allow core gamers to play their game in more locations than they can currently. This means more time spent gaming, and thus potentially more money spent on gaming, assuming the gaming companies can monetize their live service models effectively as engagement grows. Again, we see this as an evolutionary change rather than a revolutionary change, and would expect the benefits to industry growth to be incremental over a several-year period.

Two other arguments for why cloud gaming could drive significant benefits for video game publishers are (1) it could enable subscription services for video games similar to what Netflix is for TV/film, and (2) it could reduce or remove platform fees, which typically amount to 30% of the retail price of a game. We are skeptical about both of these arguments. Subscription services have been around for a long time in gaming, but have generally failed to find broad acceptance, because video games are fundamentally consumed on a la carte basis over many hours, days, months, or even years of play, unlike television shows. We also expect platform fees to continue regardless of the cloud because cloud gaming doesn't eliminate the need for a gaming platform, it just virtualizes it. We note that as physical retail continues to diminish and likely eventually goes away, the number of retailers the video game publishers will have to sell through is going to diminish, not increase. That tends to argue for reduced bargaining power with the platform companies rather than an increase.

Expect Broad-Based Benefits from Cloud on Software Side; Microsoft Has Pole Position on Platform Side

While we continue to view cloud gaming as most likely being a marginal benefit to the game software side of the industry, whatever benefit does accrue to game engagement and monetization as a result of the cloud should flow fairly evenly to all the major industry players on the console/PC side, including our covered companies **Activision Blizzard, EA, Take-Two,** and **Ubisoft.** We don't think any of those companies has a particular advantage when it comes to exploiting whatever benefits the cloud has to offer to video gaming.

On the platform side, though, we think **Microsoft** potentially stands to gain meaningfully from an expansion of the cloud gaming market. They are relatively uniquely positioned in that they have all of (1) the technological expertise to run a cloud service, (2) a highly developed gaming ecosystem built over two decades of running three (soon to be four) hardware platforms, including being the leader in online services, and (3) some highly

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desirable proprietary IP, including *Halo.* As we indicated above, Google lacks (2) and (3), while Sony lacks (1), although they do have the option with partnering on the technology side (ironically though right now their most likely partner is actually Microsoft based on a memorandum of understanding between the two). If the console/PC ecosystem does fully transition to cloud gaming over the next 5-10 years, Microsoft at the very least should benefit from getting rid of its low/no margin hardware business while retaining all of its high margin gaming software and services (which we not would also reduce current risks related to its retail partners, particularly GameStop). Additionally, depending on how attractive its offering is relative to competitors, Microsoft could gain share at the expense of Sony and Nintendo (which has no cloud initiative at present).

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Defining The Edge (Glossary)

Key Terms – Below we highlight a few key terms that have been defined by LF edge that we use throughout this report that are important when discussing edge computing. We recommend investors visit State of the Edge's Glossary for a more comprehensive list of terms **here.**

- **Access Network Sites (ex: Radio Base Station at a Macro Tower) –** the sub-layer of infrastructure edge closest to the end user or device, zero or one hops from the last mile network. The Access edge layer functions as the front line of the infrastructure edge and may connect to an aggregation edge layer higher in the hierarchy.

- **Backhaul/Fronthaul –** Backhaul is the transmission of network traffic from a remote sight (such as a cell phone tower) to a more centralized/aggregation site (toward the core network). Fronthaul is a commonly used term in C-RAN/wireless networking that describes the transmission of traffic from the baseband unit (BBU, the intelligence at the aggregation hub) out to the remote radio head.

- **Core Network –** The part of the network where service providers are connected to one another.

- **C-RAN/C-RAN Hub –** Cloud-Radio Access Network is the next evolution RAN network. Historically the wireless baseband unit (the intelligence of the cell site) is placed at the physical location of the cell site. In a C-RAN architecture, one centralized location (the "C-RAN Hub") houses and manages multiple baseband units as the intelligence is in the Hub and serves multiple remote radios in the field. By centrally locating the equipment that can be shared across multiple cells-sites, it reduces costs while at the same time using a dynamic allocation model improves network performance such as reducing latency. As such, the C-RAN is a logical location to deploy edge compute/storage gear. The actual location of a C-RAN Hub can vary widely, but requires secure space for the network gear as well as power and back-haul to the network core. A basement of an enterprise building that may already support a rooftop cell site is one example.

- **Digital Twin –** a simulated, virtual model of an actual working product in the field. The ability to take a virtual representation of how elements and the dynamics of a device operates come from sensors that are mounted on the physical product combined with the use of Machine Learning algorithms to develop "deep physics" simulation models to accurately predict how the asset behaves.

- **Distributed Cloud –** The business model whereby cloud services are hosted and implemented in a variety of physical locations and optimized for the customer or end user. This can be a combination of edge and centralized cloud computing.

- **Edge Cluster –** An edge cluster is usually a general-purpose IT computer that is located in a remote operations facility such as a factory, retail store, hotel, distribution center or bank. It is common to find clusters of Edge servers with 8, 16, or more cores of compute capacity, 16GB of memory, and hundreds of GBs of local storage. An Edge cluster is typically used to run enterprise application workloads, like point-of-sale, manufacturing or supply chain systems.

- **Edge Computing –** The trend of moving computing resources closer to the end devices that are utilizing them. Edge computing is a subset of distributed

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computing with the goal of reducing latency and network loads by keeping IT resources more local than a centralized cloud environment.

- **Edge Fabric –** Is essentially the network topology that allows data to be transported between edge servers, end devices, and the core network connected to hyperscale cloud environments. This can allow end devices to connect to each other or to a cloud or core network environment depending on the application.

- **Edge Gateway –** An Edge Gateway is typically used for services that perform network functions such as protocol translation, network termination, tunneling, firewall protection, and/or wireless connection. And since this is where the initial processing of data occurs, Intelligent Edge Gateways packed with more software can be created to deploy data-intensive applications including Analytics, real-time data processing and Deep Learning AI models.

- **Edge Node –** A set of computing resources, such as a server, that is part of the edge infrastructure. By definition, this compute resource is therefore closer to the end device than a traditional hyperscale cloud datacenter.

- **Edge or End Device –** The “consumer” or “user” of computing resources. This generally describes a piece of hardware that is performing action based on computing that is performed on the device or in an edge or cloud environment. Edge devices also collect data to be utilized across the network.

- **Edge Servers –** Edge servers are an evolving subsect of the server market that are responsible for collecting, processing and delivering data to an end device closer within the network data producers and consumers than traditional public or hyperscale cloud environments. These servers are often placed within the “last mile” or access layer of a network. Edge servers can include standard server configurations in a typical datacenter type environment, or in a **micro datacenter** which has its own local power and cooling. **Modular datacenters** describe a group of servers designed to be installed in multiple locations and scaled appropriately.

- **Information Technology (IT) –** The flow of digital information, otherwise known as data. This includes aggregating as well as analyzing the data with specific software (applications and OSs) and presenting it in a way that it becomes useful and generates value. It also encompasses the required infrastructure behind this, namely servers, networking equipment, storage etc.

- **Latency –** The time it takes a unit of data to travel from its origination to its intended device. **Jitter** is a measure of latency variance.

- **MEC –** Multiaccess Edge Computing; the network architecture and open application concept (for developers) that enables cloud computing and IT services to be deployed at the edge of the network. MEC was initially planned for *wireless* edge networks is but now expanding to include other access technologies. Also, the facilities running the computing is also commonly called a “MEC”. A “MEC” facilities could be a cellular base station, a C-RAN Hub, a signaling access point (SAP, a regional node to get to the internet), or effectively any edge point-of-presence (PoP). A “MEC” could be a “public MEC” (accessible to any customers/developers) or a “private MEC” (a private edge network for a single customer, for example edge computing needed for manufacturing IoT on a factory floor).

- **MSC –** Mobile Switching Center; a facilities in a traditional wireless network that aggregates traffic from multiple cell sites. Serving as the aggregation node for cell

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sites, it essentially the equivalent of a Central Office in traditional wireline telco, and is responsible for routing voice calls and other services.

- **Network Hop –** The point when data that is in transit undergoes switching or routing, therefore adding some amount of latency to the packet's transport.

- **Operational Technology (OT) –** Technology where one which monitors and controls physical devices processes in an industrial workflow like machines and robots that are used to produce a specific good. This could be a discrete process like an automobile or a continuous process like a chemical compound. Examples of these are PLCs, actuators, drives, motors, valves, machine vision cameras and sensors.

- **SDN/NFV –** Software Defined Networking and Network Function Virtualization; a next-gen network architecture that allows the network to be "programmable" using software applications at a centralized location, as opposed to network functions being dictated by expensive/proprietary hardware throughout the network. SDN allows for far more agility in the network such as dynamic capacity (dialing up or dialing down capacity in real-time) and allows a customer to prioritize traffic (such as prioritizing voice traffic or healthcare data over less critical traffic), or re-route traffic in real-time. As such, the network functions become "virtualized" with software, eliminating hardware elements, and allowing for far more rapid deployment of new network features/upgrades.

- **Switching/Routing –** Switching is the moving of data traffic between devices/users on the same network. Routing is the moving of traffic off of one network and onto separate networks, such as internet traffic moving from network to network.

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Figure 61 Companies Mentioned In This Report

Company	Ticker	Price	Cowen Analyst	Rating
Accenture	ACN	$193.50	Bryan Bergin	Outperform
Activision Blizzard	ATVI	$72.47	Doug Creutz	Market Perform
Alphabet	GOOG	$1,402.80	John Blackledge	Outperform
Amphenol	APH	$90.21	Joseph Giordano	Outperform
Apple	AAPL	$316.85	Krish Sankar	Outperform
Aptiv	APTV	$71.53	Jeffrey Osborne	Outperform
Cognex	CGNX	$61.18	Joseph Giordano	Outperform
Cognizant	CTSH	$51.74	Bryan Bergin	Market Perform
DXC	DXC	$15.85	Bryan Bergin	Outperform
Electronic Arts	EA	$117.36	Doug Creutz	Outperform
Emerson	EMR	$56.25	Gautam Khanna	Market Perform
EPAM	EPAM	$223.86	Bryan Bergin	Outperform
Facebook	FB	$231.39	John Blackledge	Outperform
Fortive	FTV	$58.28	Joseph Giordano	Market Perform
Honeywell	HON	$137.69	Gautam Khanna	Outperform
Infosys	INFY	$8.93	Bryan Bergin	Market Perform
Itron	ITRI	$61.48	Jeffrey Osborne	Outperform
Landis+Gyr	LAND.SW	$59.70	Jeffrey Osborne	Outperform
Lear	LEA	$105.61	Jeffrey Osborne	Outperform
Microsoft	MSFT	$183.43	Nick Yako	Outperform
Rockwell	ROK	$203.73	Joseph Giordano	Underperform
Roper	ROP	$365.06	Joseph Giordano	Outperform
Schlumberger	SLB	$17.79	Marc Bianchi	Market Perform
Sensata	ST	$35.35	Joseph Giordano	Market Perform
Take-Two	TTWO	$138.19	Doug Creutz	Outperform
TE Connectivity	TEL	$76.29	Joseph Giordano	Outperform
Teledyne	TDY	$339.22	Joseph Giordano	Outperform
Teradyne	TER	$61.74	Krish Sankar	Market Perform
Tesla	TSLA	$827.60	Jeffrey Osborne	Underperform
Ubisoft	UBI.FP	69.40 €	Doug Creutz	Market Perform
Universal Display	OLED	$147.89	Krish Sankar	Outperform
Visteon	VC	$73.64	Jeffrey Osborne	Outperform
Xylem	XYL	$61.97	Joseph Giordano	Market Perform

Source: Cowen and Company. Priced as of 5/21/2020

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VALUATION METHODOLOGY AND RISKS

Valuation Methodology

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.

Semiconductor Capital Equipment:

Our valuation methodology is primarily based on a P/E multiple applied to our out year EPS forecast. In some cases we employ a sum-of-the-parts (SOTP) calculation where an appropriate P/E multiple is applied to forward earnings projections for the different business segments, plus estimated excess net cash per share.

Computer Services & IT Consulting:

We use forward P/E and EV/EBITDA multiples to value the companies in the Computer Services industry. We support our valuation with cash per share analysis.

Video Games:

Our valuation methodology is primarily based on an ex-cash price-to-earnings (P/E) ratio, where for earnings we use after-tax non-GAAP operating income (to remove interest earnings along with cash). We also use a discounted cash flow (DCF) analysis to support our valuation targets.

Telecom Equipment/Wireless:

Our core valuation methodology is the analysis of a company's prospects to change its cash flow in future periods. Our primary tool to measure that expected change in cash flow – and the value of it today – is the 10-year DCF. Since earnings are typically a solid proxy for cash flow and are often more easily compared across companies and sectors, we also use Price-to-Earnings (P/E) ratios to value companies. P/E ratios compared to historical ranges and competitive companies can help to determine whether there is incremental value to be found in company shares.

Transportation Technology:

Our primary inputs to valuation are earnings and earnings growth (P/E and PEG) for the next two years. In cases where GAAP net income includes large, non-cash items (e.g., SBC or intangible amortization), we may use non-GAAP EPS. For companies with an emerging business model, we may use future-year earnings discounted back. As a cross check to an earnings multiple, we may also use a DCF analysis. For situations where earnings are not visible within our forecast horizon, we may use asset values (P/Book, P/TBV).

Sustainable Energy & Industrial Technology:

Our primary inputs to valuation are earnings and earnings growth (P/E and PEG) for the next two years. In cases where GAAP net income includes large, non-cash items (e.g., SBC or intangible amortization), we may use non-GAAP EPS. For companies with an emerging business model, we may use future-year earnings discounted back. As a cross check to an earnings multiple, we may also use a DCF analysis. For situations where earnings are not visible within our forecast horizon, we may use asset values (P/Book, P/TBV).

Investment Risks

Semiconductor Capital Equipment:

The semiconductor capital equipment (SPE) industry has a strong correlation to semiconductor industry capex and global GDP trends. We expect SPE industry revenues to be less cyclical in nature going forward given consolidation in the WFE customer base. However, the occurrence of chip supply-demand imbalances, the timing of process node transitions and the yields from WFE customer production lines, and chip technology design trends can have a meaningful impact on equipment demand from time to time.

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.

Computer Services & IT Consulting:
Global economic growth could impact discretionary spending
The IT Services industry is sensitive to global economic growth. During a downturn or a recession, clients tend to reduce discretionary spending, which would have a direct negative impact on revenue growth at global and offshore IT Services vendors.
Wage inflation
If wage costs increase at a faster rate than billing rates, IT Services vendors will experience a negative effect on margins and profitability. In addition, if wage costs will increase at a faster rate than the historical average, the vendors' services could become less attractive for N.A. and European clients, which will impact efficiency, utilization and profitability. In addition, the issuance of stock based compensation for IT professionals could result in dilution to shareholders.
Foreign exchange risk
While the companies' consolidated financial statements are reported in U.S. dollars, a portion of the revenues (varies by company) is generated in other currencies (euros, INR, British pounds, etc.). In addition, in most cases, costs are not incurred in U.S. dollars. For example, the offshore vendors incur most of their costs in INR. This creates a currency and hedging risk.

Video Games:

(1)The global macroeconomic environment worsens, impacting consumer discretionary spending on video games. (2) Availability of other entertainment options decreases time spent playing video games. (3) New government regulations impact the distribution of video games featuring mature-themed content. (4) New entrants into video game publishing disrupt the existing value chain, resulting in reduced revenues and/or compressed margins for our companies under coverage. (5) New technologies such as virtual reality increase R&D costs without yielding revenue growth.

Telecom Equipment/Wireless:

High subsidies on mobile smartphones are the result of high end-user ARPUs; if ARPU declines, we would expect mobile phone ASPs to decline, pressuring OEM profitability. Mobile voice has driven wireless ARPU for two-plus decades; if the industry cannot convince end-users to increase dramatically data and Internet application consumption then revenue (ARPU) would be impacted. CAPEX to support the roll-out of LTE, LTE-A, and other 4G networks must stay available for our forecasts to be maintained; if a decline in global GDP occurs, CAPEX likely would be impacted negatively.

Transportation Technology:

Demand for Automotive Technology is largely a function of global automotive production. A slowdown in sales would lead to lower demand by automotive OEMs for content from

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suppliers. The pace of adoption for connected vehicle, autonomous systems, vehicle electrification, and safety may be strongly influenced by government regulations, subsidies, and mandates. Share prices and financial results may be sensitive to policy changes and outcomes may be difficult to predict, due to the political nature of the process.

Sustainable Energy & Industrial Technology:

Demand for Sustainable Technology may be strongly influenced by government regulations, subsidies, and mandates as well as the overall health of the global macro economy. Share prices and financial results may be sensitive to policy changes and outcomes may be difficult to predict, due to the political nature of the process.

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ADDENDUM

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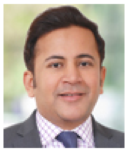

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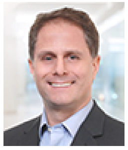

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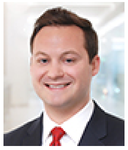

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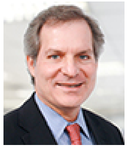

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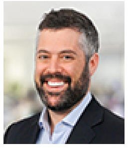

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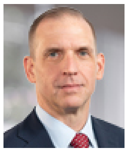

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