NETWORK BUSINESS QUARTERLY℠

Telecom Edge Compute Market Forecast (2019-2024)

Annual

Publish Date: Feb. 28, 2020

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TBR

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Telecom edge compute taxonomy

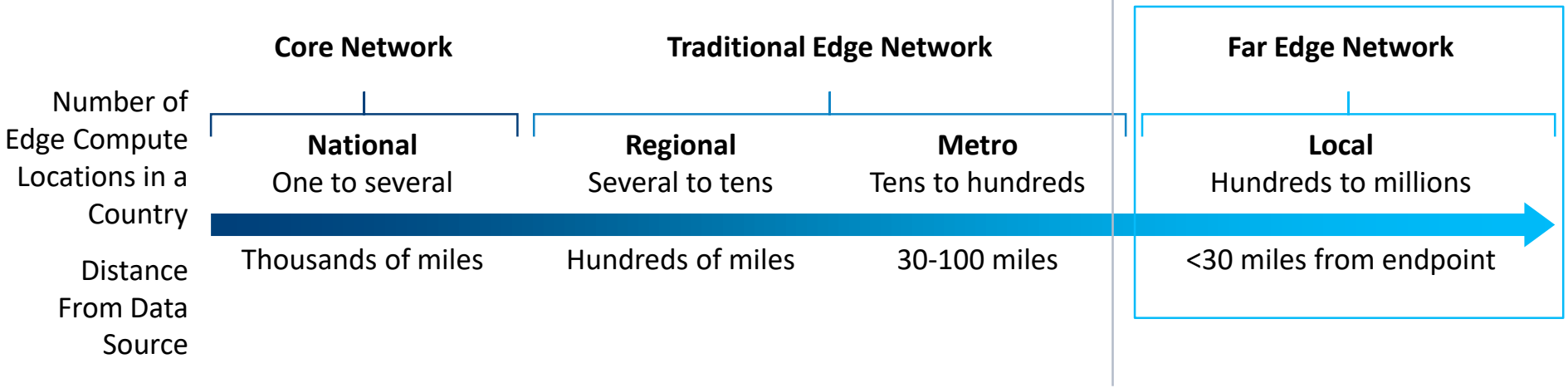
Edge compute environments are essentially data centers that reside in relatively close proximity to a data generation source. Data generation sources could be smartphones, IoT sensors or other devices that connect to a network.

Domains of the network can be understood by their proximity to the data source.

"Local" edge compute environments are typically less than 30 miles from data generation sources and reside next to (on premises) or close to the access layer (or last mile) of the network. Typical locations for local edge compute environments include central offices, headends, cable hubs, baseband hotels, and tower and rooftop sites. Edge locations could also be sited within the premises of a data generation source, such as in stadiums or airports.

Focus of Research

Note: The "far edge" is also known as the local edge, new edge, network edge, mobile edge, multi-access edge (MEC) or distributed new edge. All these characterizations refer to the same thing, which is locating mini data centers in closer proximity to data generation sources.



Telecom edge compute taxonomy

- TBR's telecom edge compute reports focus on edge compute opportunities specific to the communication service provider (CSP) industry, which includes telecom and cable operators as well as third-party infrastructure owners and cloud service providers (i.e., webscales). Edge compute infrastructure spend by nontelecom verticals is not covered in this report.

- The edge compute market size provided in this report only includes the technology inputs to build an edge environment, which TBR defines as sites being within 30 miles of data generation sources. Infrastructure utilized exclusively for the metro, regional and national domains of the network is not included. On-endpoint device compute is also excluded.

- Items in the edge compute taxonomy include data center equipment (servers, storage, networking, optical interconnect) as well as services attached to or related to this infrastructure. Close-to-the-box software such as data center infrastructure management software (including operating systems and virtual infrastructure management) as well as related platforms and analytics applications are also included.

- The distance between edge data centers and data sources is contingent on the speed of light and the number of hops the traffic must go through. To get below 10ms of latency in the network, which is the maximum threshold for low-latency services, edge compute resources must be within 30 miles of the data generation source.

COVID-19 impact on edge compute market

- The COVID-19 virus will significantly impact the ICT infrastructure supply chain, and, more broadly, the global economy. This dynamic and evolving situation prompted TBR to revise its telecom edge compute market size in the recently published *Telecom Edge Compute Market Landscape*.

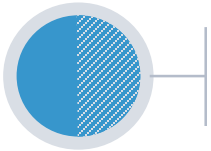
- Though the virus will delay the ultimate build-out of the edge, the cumulative market size during the forecast period is expected to be larger and grow faster than originally anticipated once the dust settles from the virus.

- TBR expects the virus to delay edge spend in 2020 and a portion of 2021. By mid-2021 TBR expects the supply chain to be fully operational again, at which time the industry will attempt to catch up to align with pent-up demand.

- TBR expects governments and businesses around the world will reassess their disaster response and risk profiles to mitigate future risks to their societies and operations. This will drive investment in surveillance, drones, industrial automation, blockchain, AR/VR and other use cases that require edge resources to operate. As such, TBR increased the cumulative market size for edge infrastructure as it is expected that many governments, not just the U.S. and China, will justify these investments for national security and business resiliency purposes. It is expected that CSPs will be key beneficiaries of this addressable market to support government and business initiatives in these areas.

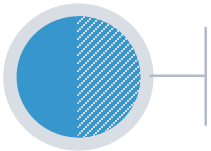
Executive Summary

The U.S. and China will lead the world in edge compute infrastructure deployment, driven by domestic webscales and telco transformations



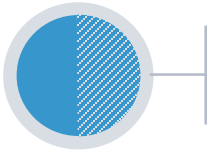
Most CSP edge sites will be located in the U.S. and China by 2025

- TBR estimates over two-thirds of global far edge sites that are owned or leased by CSPs will be located in the U.S. and China by 2025. This heavy concentration of sites will be due, in part, to webscales pushing the ecosystem into the edge to realize their distributed computing initiatives, which encompass migrating mission-critical and latency-sensitive enterprise workloads into their clouds as well as enabling and supporting their digital lifestyle initiatives.
- Telecom and cable operators in these two countries will also be active participants in building out their own edge infrastructure, but this will mostly be to transform their networks into automated, virtualized and cloudified systems.
- CSPs in other countries will also build out edge compute infrastructure over the next five years, but the scale will be dwarfed by what stakeholders in the U.S. and China intend to pursue.



Webscales will utilize ODM gear for their edge stacks

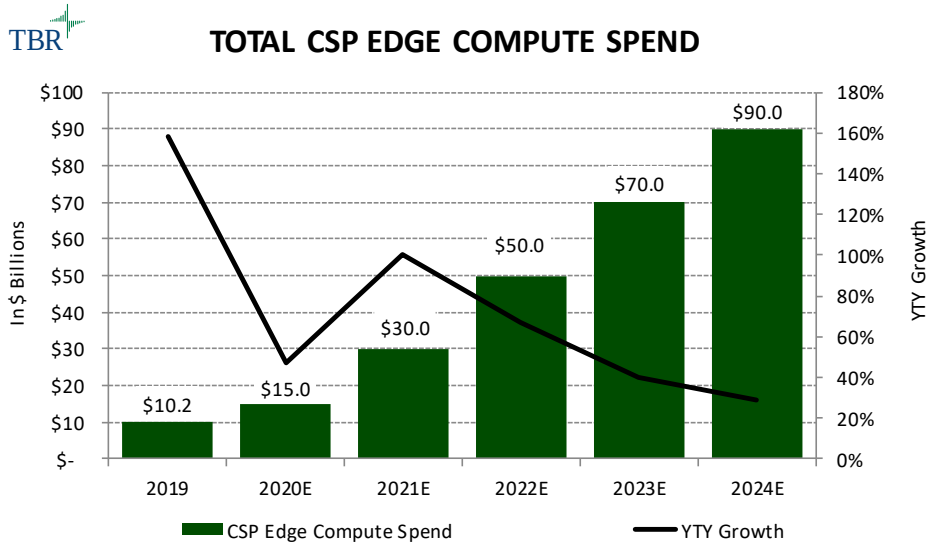
- Webscales intend to evangelize the use of commodity-based hardware platforms for their edge stacks. ODMs will be the primary beneficiaries of this trend, and this ecosystem of suppliers will provide a range of x86- and ARM-based data center equipment, as well as open infrastructure-based telecom equipment to flesh out webscale edge environments.
- Leading webscales have been actively investing in R&D to build standard reference designs for edge stacks that can be modular, ruggedized and cost-optimal for edge environments. These designs are likely to become widely available to the ecosystem to align with. Webscales view hardware as a commodity and believe their real value-add is in the software layer.



vRAN will push telecom edge infrastructure spend into overdrive

- CSPs will ultimately migrate to a vRAN architecture, which is a key aspect of the new networks they are evolving toward. vRAN requires edge compute resources to be within 10 miles of the remote radio unit (RRU) to get the latency to 200 microseconds, which is the maximum threshold required to support vRAN traffic.
- The vRAN market will ramp up in the early 2020s as leading operators push the industry forward. Due to the requirements for a vRAN architecture, the number of edge sites will greatly increase, and those sites will primarily be at the base of cell sites or at aggregation hubs that are in relatively close proximity to those cell sites.

CSP spend on edge compute infrastructure will grow at a TBR-projected 54.5% CAGR from 2019 to 2024 to reach $90B by 2025



SOURCE: TBR ESTIMATES

Spend Assumptions:

Spend includes capex and external opex from telecom and cable operators as well as webscales on edge compute infrastructure.

CSPs must procure the edge infrastructure for it to be included in the market size.

Edge compute infrastructure that is procured by non-CSPs is excluded from the market size.

TBR Assessment

TBR estimates over 1.2 million network sites and cell sites will become mini data center (edge) locations globally by 2025, up from nearly 9,000 sites globally at the end of 2019. The primary driver of edge build-outs during the forecast period is telcos' and cablecos' network transformations, which entail migrating to a cloudified and virtualized network, and webscales' edge initiatives to support their cloud businesses and digital lifestyle endeavors. In this new architecture, network functions will be virtualized and housed in NFVI, which is essentially a data center. Network sites, such as central offices, have been the primary edge compute locations to date, with cell site builds expected to ramp up significantly in 2021 and become the primary locations for the CSP edge by 2025. For more information pertaining to the edge ecosystem, see TBR's *Telecom Edge Compute Market Landscape*.

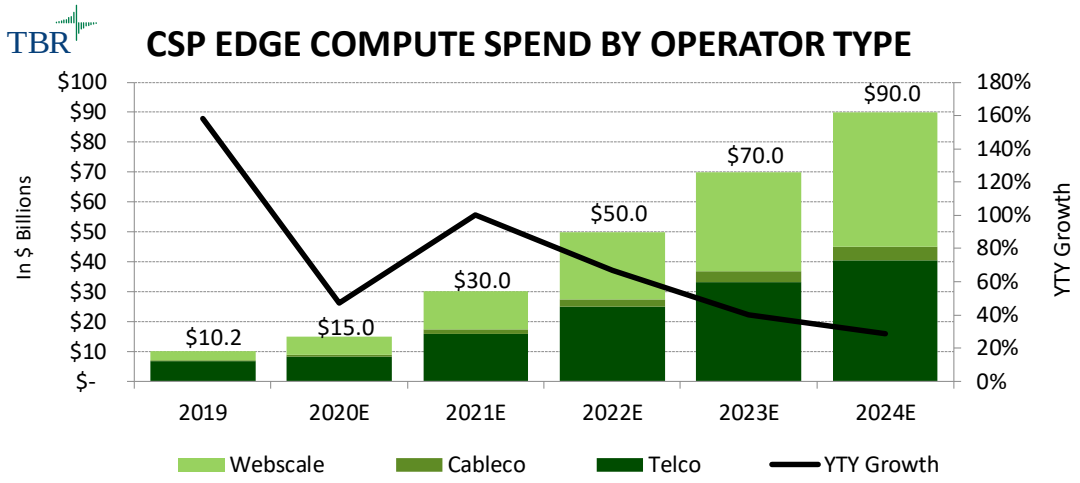
TBR believes over half of the estimated $15.8B spent by CSPs on edge computing from 2015-2019 came from 7 companies

CSPs that have spent at least $1B cumulatively on edge compute infrastructure from 2015-2019

AT&T
China Mobile
China Unicom
China Telecom
Rakuten
Telefonica
Verizon

- Leading telcos that have been investing in edge infrastructure have been doing so as part of their network transformation toward a virtualized and cloudified network, which requires data centers to run virtual network functions. These telco-owned edge data centers reside in a range of network sites, such as central offices, aggregation hubs and at the base of cell towers, as well as on customers' premises, which typically have CSP-owned uCPE, such as AT&T Flexware.
- The big three CSPs in China have been major investors in edge compute infrastructure as part of their involvement in government initiatives, such as the social credit system.
- Rakuten has spent the most on edge infrastructure of any webscale globally as of the end of 2019 as part of its mobile network build-out in Japan. Though the network build has encountered delays, infrastructure build-out continues, just at a lengthened timeline from the original plan.
- TBR expects the list of companies that will have spent at least $1 billion cumulatively on edge infrastructure will grow significantly over the next three years as the largest CSPs in the world ramp up their investments to catch up to leaders. Amazon and Microsoft especially are expected to invest billions of dollars in their edge build-outs as they aim to carve out a leading position in this nascent space.

Telcos drive edge investment in early years of forecast as part of network transformations; webscales go big on edge in later years of forecast

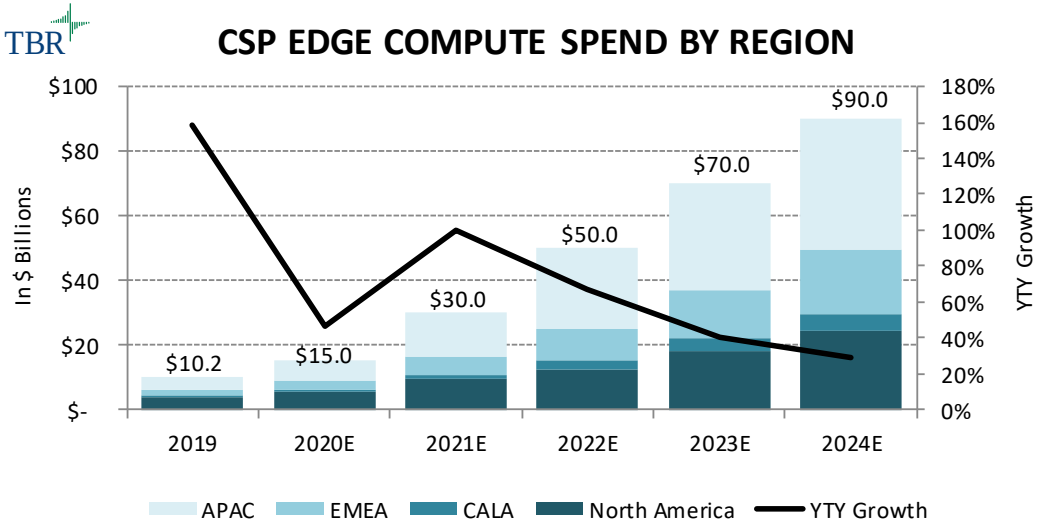


SOURCE: TBR ESTIMATES

TBR Assessment

- Telcos will spend the most, collectively, on edge infrastructure each year through 2022, at which time there will be an inflection point in 2023 whereby webscales become the largest investors in edge infrastructure starting in 2024.
- Webscale spend will be dominated by Amazon, Microsoft and Rakuten, with Google, Alibaba and webscales in the Big 9 spending a relatively lower amount. Amazon and Microsoft have global ambitions for edge, and both webscales intend to partner with and or compete against telcos and cablecos in the edge space.
- Amazon and Microsoft will ultimately become the largest spenders on edge infrastructure in the world as their dominance in the public cloud market and influence in the economy naturally extend into the edge space. It is expected that some telcos and cablecos will ultimately put some or all their networks into the public cloud, which would transfer the infrastructure procurement and operation responsibilities to the webscale that is hosting the network.
- Compared to telcos and webscales, cablecos will be relative laggards in edge compute investment through the early 2020s but will gradually catch up as the technology and business models mature over time. Comcast has invested the most aggressively in network transformation among cablecos thus far, a fact that is expected to hold.

Edge usage will surge after COVID-19 subsides as governments and businesses worldwide leverage new technologies and CSPs to mitigate risks



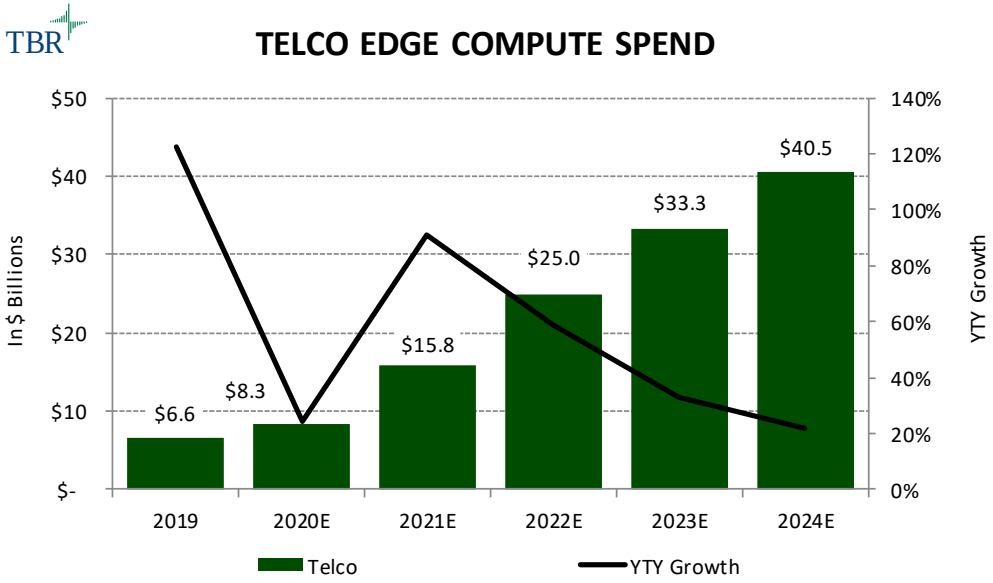
SOURCE: TBR ESTIMATES

TBR Assessment

- Many governments and businesses across all regions, particularly in developed countries, are expected to increase demand for edge computing after the fallout from the COVID-19 virus subsides. CSPs will be key beneficiaries of this increase in demand for edge computing.
- The U.S. will drive the edge market in the early years of the forecast period, led by telco network transformations and Amazon's and Microsoft's initial foray into the space with Outposts, Wavelength and Azure Stack, respectively.
- APAC will be the region hit hardest owing to the COVID-19 virus, and delays will impact APAC CSPs' ability to invest in the edge in 2020 and part of 2021, shifting more spend into 2022.
- Despite these delays, China is expected to outspend the U.S. on edge infrastructure starting in 2022 to support government-sponsored initiatives.

Telecom Edge Compute Spend by CSP Type

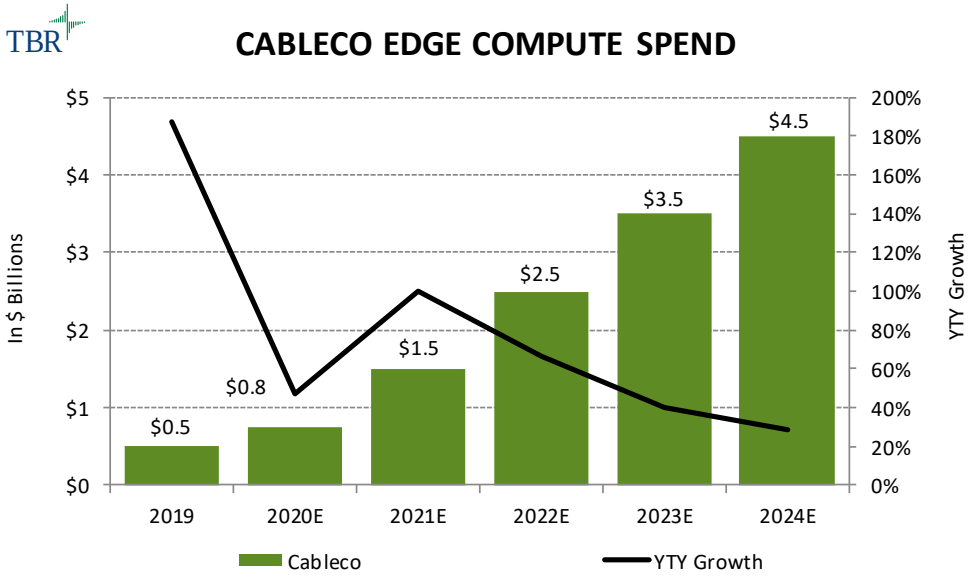
The bulk of telco spend on edge compute will be for network transformations toward a virtualized and cloudified architecture



SOURCE: TBR ESTIMATES

- NFV/SDN and 5G will drive telcos to invest in their own edge computing resources to run their virtualized and cloudified networks.
- vRAN will compel CSPs to build edge sites at the base of cell towers or at aggregation hubs in the access layer of the network.
- Some telcos will opt to put some or all of their network into a webscale's cloud, similar to what AT&T intends to do with Microsoft.

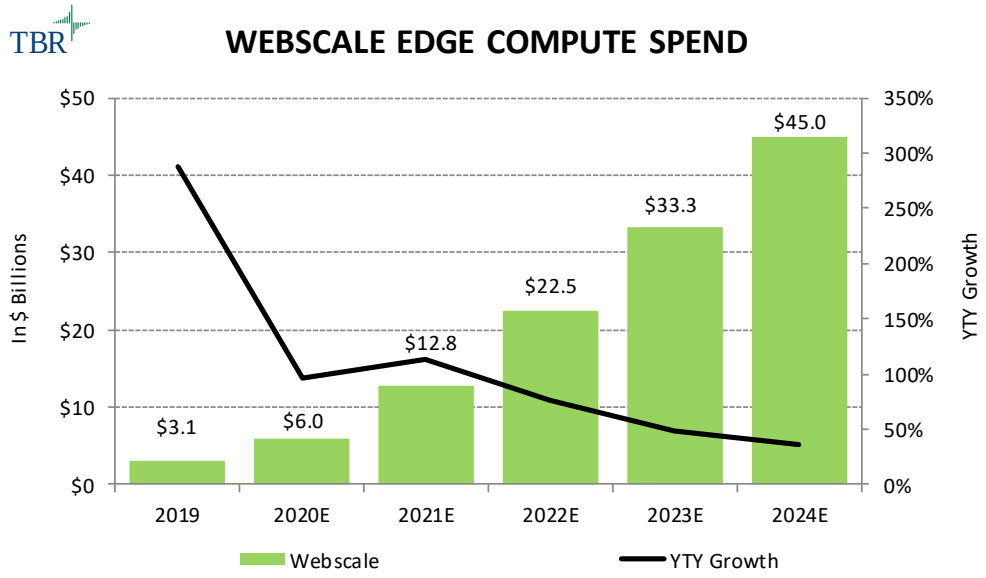
Comcast will lead cablecos globally in edge infrastructure spend through the forecast period; network transformations are primary driver of spend



SOURCE: TBR ESTIMATES

- The majority of cableco spend on edge compute is predominantly for existing site transformations to NFV/SDN technology.
- Comcast has spent far more than other cablecos on edge infrastructure as the operator pushes forward with its network transformation. A significant portion of this spend is related to universal CPE (uCPE), virtual converged cable access platform (vCCAP) and virtual distributed access architecture (vDAA), which implicates the operator's aggregation hub sites and requires the use of data center infrastructure in those sites.
- Other cablecos, such as Charter, Cox, Altice and Liberty Global, are expected to follow in Comcast's footsteps during the forecast period.

The Big 9 webscales will ultimately own a large portion of edge infrastructure resources globally, led by Amazon and Microsoft



SOURCE: TBR ESTIMATES

Webscale segment includes the following nine (aka Big 9) companies:

Alibaba

Alphabet (Google)

Amazon

Apple

Baidu

Facebook

Microsoft

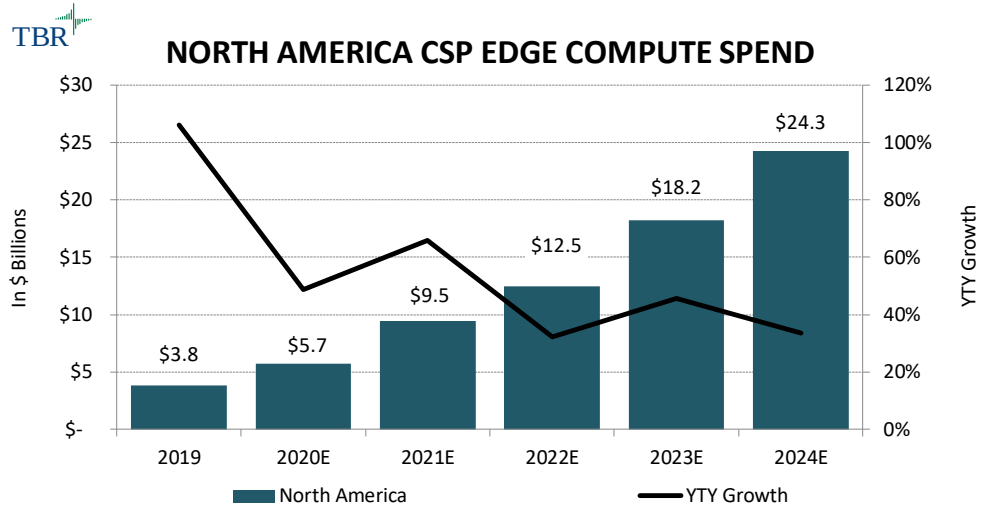
Rakuten

Tencent

- The world's largest webscales are all likely to extend their cloud footprints closer to endpoints by the mid-2020s. These companies will drive significant innovation in the edge space, contributing design references, technology standards and best practices to facilitate ecosystem development.
- Webscales will utilize the most cost-effective means of deploying edge compute infrastructure, and these companies are building their own standard reference designs for edge compute infrastructure that is intended to be simple to install, automated, and use low-cost hardware. This push to extend open infrastructure is a key reason the edge market will scale quickly.
- Webscales will push the ODM industry forward via initiatives such as the Telecom Infra Project (TIP) and OCP and will have ODMs manufacture ICT gear to their customized specifications to minimize their costs and align with their strategic objectives.

Telecom Edge Compute Spend by Region

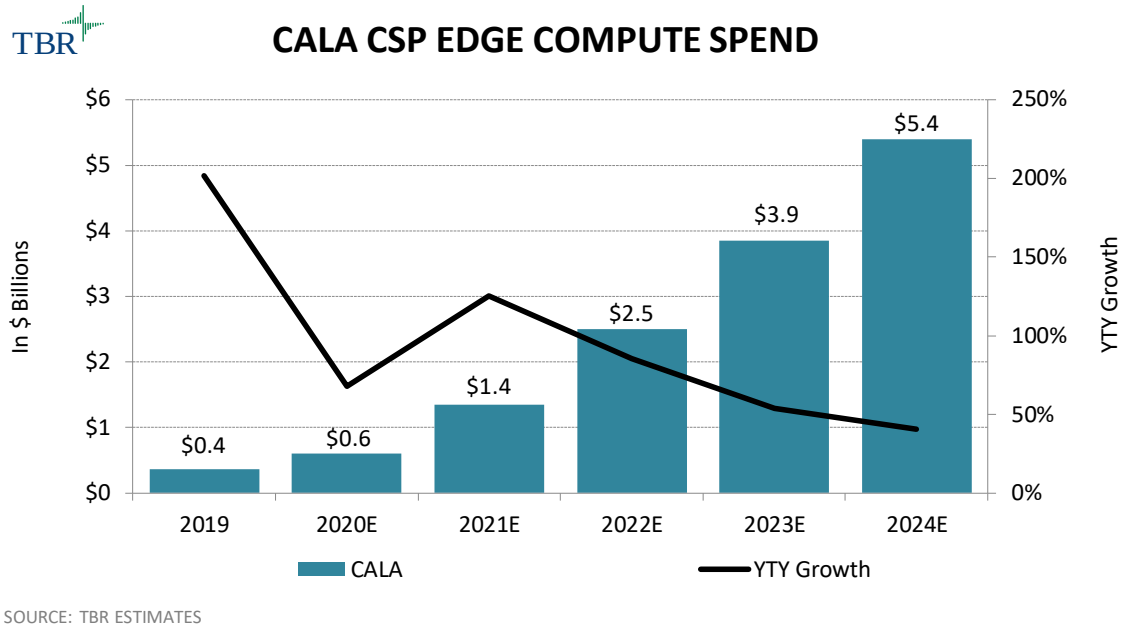
The edge ecosystem in the U.S. will be dynamic and robust, whereas Canada is expected to lag other developed countries in edge investment



SOURCE: TBR ESTIMATES

- AT&T, Verizon, Amazon and Microsoft will spend the most on edge infrastructure in North America through the forecast period.
- Comcast, CenturyLink, T-Mobile and Dish are also expected to invest in edge infrastructure, but it will be at a much lower scale compared to the four aforementioned companies.
- Canada-based operators are likely to take a wait-and-see approach before spending significantly on edge infrastructure. Canadian operators will want to see a clear business case for 5G and network transformation via virtualization and cloudification before committing capital to these endeavors. Canada will account for around 5% of North America spend on edge infrastructure through the forecast period.
- Google will also participate in edge build-outs, but the scope is expected to be relatively low as the company figures out its play in this space.

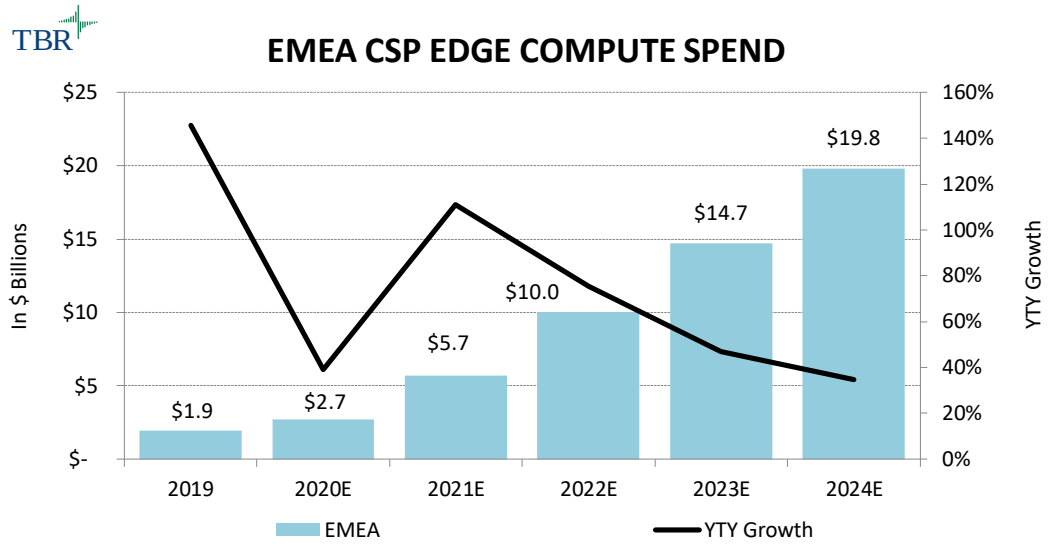
America Movil, AT&T Mexico and Telefonica are likely to be the biggest spenders on edge infrastructure in CALA through the forecast period



SOURCE: TBR ESTIMATES

- Edge infrastructure spend in CALA will lag other regions due to economic and financial challenges that are pervasively impacting the region.
- The bulk of the edge spend in this region will be tied to telco and cableco network transformations toward a virtualized and cloudified network architecture; vRAN will be a key use case for these edge investments to help CSPs reap cost savings from building and operating their networks.
- Webscales are not expected to invest heavily in edge infrastructure in CALA during the forecast period.

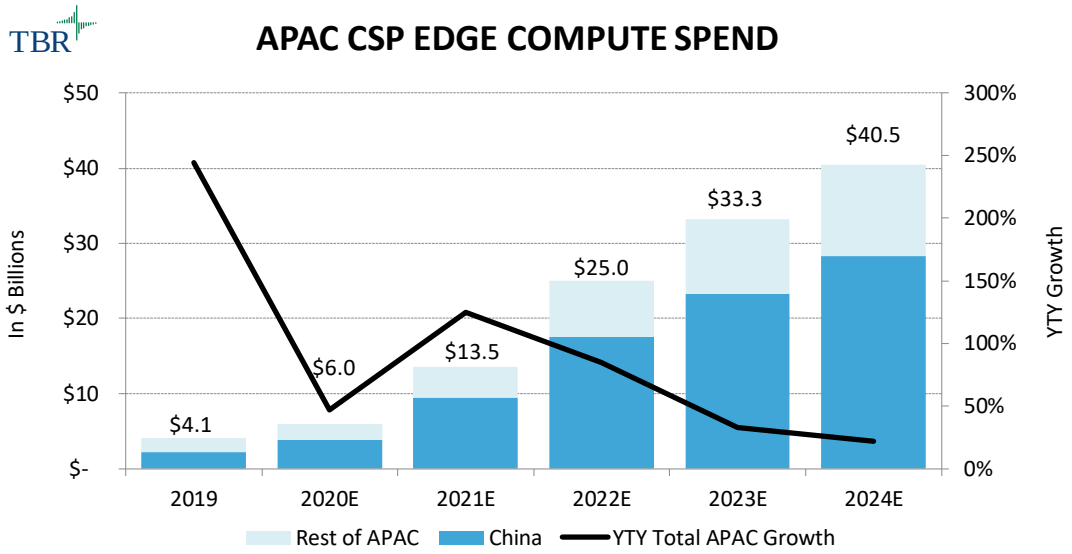
Europe holds the most opportunity in EMEA for edge, but has significant challenges that will cause the region to lag other developed markets



SOURCE: TBR ESTIMATES

- Europe-based, Tier 1 CSPs are likely to spend the most on edge infrastructure during the forecast period, most notably BT, Deutsche Telekom (DT), Telefonica, Orange and Vodafone.
- However, Europe will lag other developed markets in edge development due to prohibitive regulations as well as financial and business case limitations.
- Webscales will be active in Europe, but the bulk of their investments will be centered in the U.S. and China.
- MEA CSPs will lag in edge infrastructure build-out due to economic, geographic and other considerations.

China, South Korea and Japan spend the most on edge infrastructure in APAC; other APAC countries comprise around 15% of region spend



SOURCE: TBR ESTIMATES

- China-based CSPs will dominate edge infrastructure spend in the APAC region, most notably China Mobile, China Unicom, China Telecom, Alibaba and Tencent.
- Baidu will also invest but at a relatively lower amount.
- CSPs in South Korea and Japan will also be major investors in edge infrastructure through the forecast period.
- South Korea-based telcos invested in edge infrastructure in 2019 as part of their 5G networks. These operators' VR offerings are being offered via those edge sites and these sites also house some NFVI that is part of their virtualized networks.
- Rakuten was also a major edge infrastructure spender in 2019 as part of its mobile network build-out in Japan.
- Other developed countries in the region will also invest in edge computing, but at a much lower level compared to China, South Korea and Japan.

Appendix

Telecom Edge Compute-related Definitions

CDN	A content delivery network (CDN) is a geographically distributed group of servers that work together to provide faster delivery of internet content, typically video.
CORD	Central office rearchitected as a data center (CORD) is a means of modernizing existing central offices into data centers that are capable of supporting CSPs' network virtualization and edge computing requirements. CORD leverages NFV, SDN, open software and commoditized hardware to achieve its goals.
NFV	Network functions virtualization (NFV) applies IT virtualization technology to the network and consolidates physical network functions onto industry-standard, high-volume servers, switches and storage, which could be located in central data centers, at the edge, or on the end user's premises. NFV involves the implementation of network functions in software that can run on a range of industry-standard server hardware and that can be moved to, or instantiated in, various locations in the network as required without the need to install new equipment.
NFVI	Network functions virtualization infrastructure (NFVI) includes hardware (predominantly data center equipment such as servers and storage) and close-to-the-box software such as operating systems and infrastructure management platforms that compose the physical layer in which VNFs are housed.
SDN	Software-defined networking (SDN) is an approach to networking in which control is decoupled from the physical infrastructure, allowing network administrators to support a network fabric across a multivendor environment.
uCPE	Universal customer premises equipment (uCPE) includes commercial off-the-shelf (COTS) x86-based hardware appliances that are used to deliver virtualized network services to the end user's premises. Also includes webscales' on-premises CPE, such as AWS Outposts and Microsoft Azure Stack.
VNF	Virtual network functions (VNF) are individual network functions, such as firewalls and routers, that exist in a software state and are instantiated in a data center.
vRAN	Virtual radio access network (vRAN) — virtualizing and decoupling elements of the radio access network, such as the baseband unit (vBBU); includes macros, small cells and distributed antenna systems (DAS)

TBR initiates models with reported information, then expands on reported figures via interviews, company interactions and secondary research

TOP-DOWN

Regularly reported data

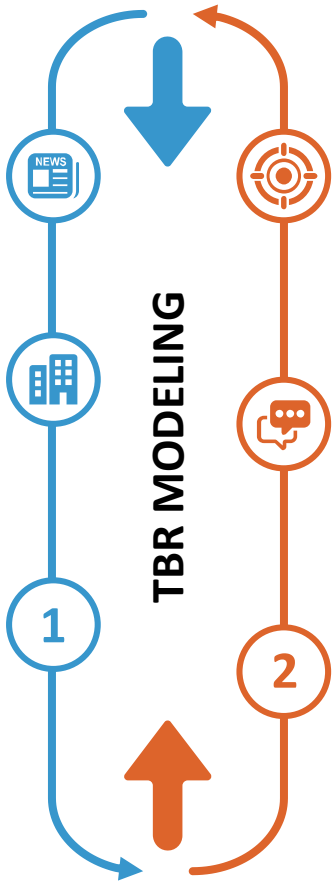
Capture regularly reported financial and earnings information as model foundation

Company guidance

Break down reported figures by layering in growth, mix and directional financial information delivered by the company

Quantitative primary research reports

Refine model by integrating adoption, switching, pricing, volume, and incentive figures captured in TBR's survey research of customers and partners



BOTTOM-UP

Targeted company briefings

Layer in substantiations built on answers to questions that are specifically targeted at supporting and refining modeled figures

Regular company interactions

Strengthen model substantiations by leveraging strategic, roadmap, and directional information delivered by each company

Secondary research

Build in most recent information regarding product releases, organizational/resource changes, and investments

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