Copper in Data Centers: A North American Market Study

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Introduction and Objectives

Data Centers (DCs) are in high demand with the vast and various computing and data storage requirements throughout society, driven by continuing advancing technologies such as smart phones, computers, streaming, social networking, and now even blockchain, artificial intelligence, and quantum computing.

DCs will continue to grow, and even accelerate over time, enabling society's technological ambitions with more and more computing power, all while increasing computing speeds and densities. DCs are also expected to require significant amounts of varying forms of copper and copper alloys, as it provides superior conductivity for a given cross-section, facilitating energy and space efficiency. Both expectations of data center growth and copper content significance are verified and quantified through this study for the North American (NA) market, including the United States (U.S.), Canada, and Mexico.

DCs are described as facilities with large groups of networked servers used for remote storage, processing, or distribution of large amounts of data. Essentially, they are sophisticated computer rooms with many rows of computer racks that require megawatts of electrical power to operate, literally tons of wires to communicate and exchange information, and high amounts of cooling to remove generated heat to maximize computing speeds and longevity. DCs are often buildings or portions of buildings devoted to computers with their necessary infrastructure, including hardware from Information Technology (IT) equipment with computers and servers, industrial power controls like transformers and switchgear, and Heating, Ventilation, Air-Conditioning (HVAC) equipment for cooling. IT equipment is categorized across computers, servers, racks and enclosures, networking, and storage devices. Power controls hardware is categorized across cabling for power and data, power distribution panels and busways, and physical securities. Figures 1 and 2 exemplify typical views within DCs, noting aisle separation between "hot" and "cold" zones based on HVAC flows. DCs are categorized based on their use type, application, configuration, and tier rating, each of which will later be explained further.

Introduction and Objectives

Objectives of this research are to analyze the NA DC market in depth to quantify current and future trends over the next couple decades, including the market size and contents of its infrastructure, as well as the volume and forms of copper applied. Market segmentation is completed by DC type, application, configuration, tier rating, as well as region. Applied equipment and building infrastructure are categorized and quantified in both system value as well as copper content. How this information and data is collected is also described, including various roles and backgrounds from interviewees.

Figures 1 (left, cold aisle) and 2 (right, hot aisle): Racks of computing hardware in typical DCs

Market Engagement Methodology

Research to gain information was accomplished with individual interviews across a wide range of industry roles, responsibilities, and contributors, as well as basic online research looking through company websites, announcements, annual reports, and white papers. Leading names in the market were targeted, including data centers owners and operators, equipment suppliers and distributors, design and construction firms, government organizations, as well as copper semi- product manufacturers. Roles of individuals engaged included directors and mangers, purchasing heads, strategic decision makers, financial advisors and investors, and even senior leadership and board members. Each interview lasted around an hour with sample sizes over 150 individuals across more than 70 different companies. The interviewees resided in many different states across the U.S., as well as regions of Canada and Mexico. Interviews began by the end of October 2022 and concluded in February 2023. These engagements pre-date the recent AI boom which has significantly increased power and cooling demands, which will likely increase data center infrastructure value and copper content.

A questionnaire was designed to help the field team consistently engage the range of roles, understanding depth of knowledge across areas will vary.

Various market details were extracted and ultimately compiled. Surveys consisted of both closed and open-ended questions and ranged from general industry direction to detailed copper forms and content applied across various systems, dependent on the interviewees roles and knowledge. Titles of various interviewees ranged from Site or Chief Engineer, Project and Design Managers, Construction and Procurement. Managers, General and Operations Managers, Infrastructure Architects, and even some CEO/CIOs. Individuals involved represented a wide range of companies, including well-known names such as Siemens, Amazon, H5 Data Centers, Equinix, Verizon, and Turner Construction Company. Industry trends are also uncovered and described, including e-waste management, efficiency maximization, energy reduction, and supply chain availability and sustainability.

Data Center Market Results

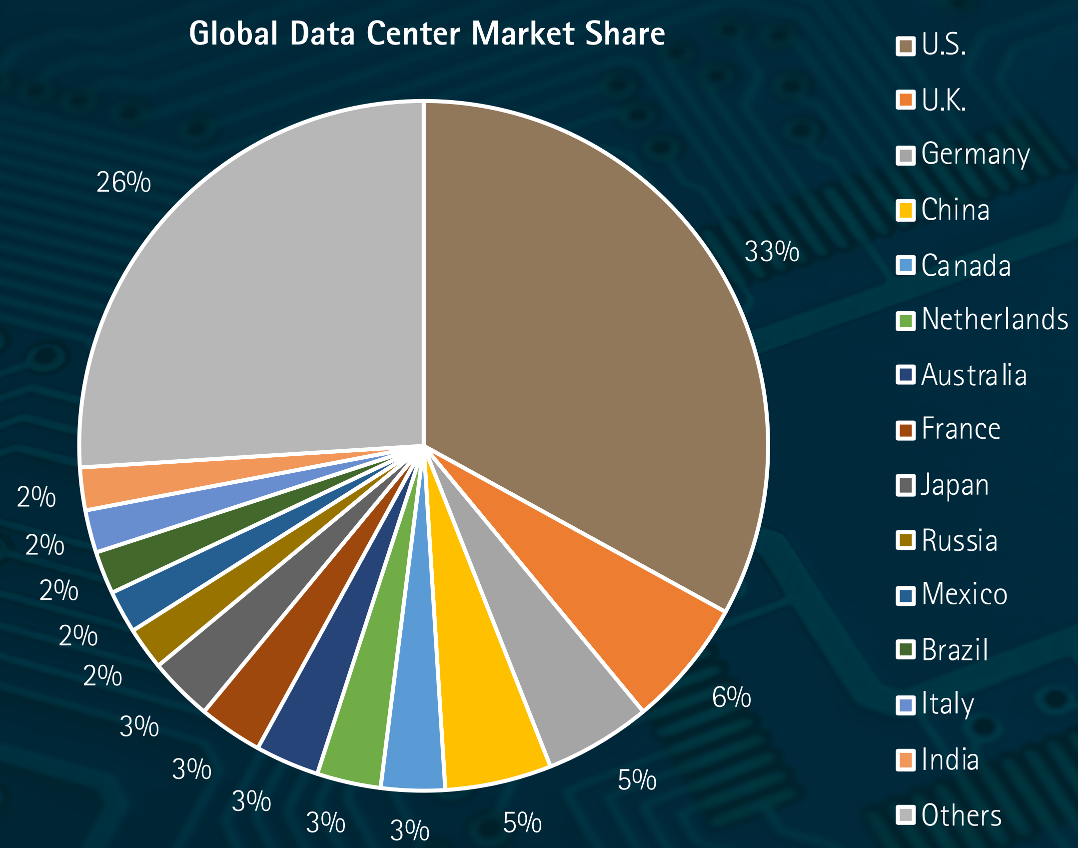
Global Market Share

The U.S. is the largest regional market for DCs in the world by far with a market share of 33% followed by the U.K. (6%), Germany (5%), China (5%), and Canada (3%). Figure 3 illustrates the country share of the global DC market based on applied computing power[1]. The global DC market is valued today between $280B and is expected to grow to $560B in 2032 at a Compounded Annual Growth Rate (CAGR) of 7.3%.[2] Although NA dominates the market share, Asia-Pacific is expected to grow the fastest during this next decade.

Within NA, the US dominates with 88% market share, while Canada is 9% and Mexico the remaining 3%. With a total third-party data center capacity of over 5 terawatts, which is more than half of the global capacity, the U.S. is the largest regional market for DCs in the world.[3] It is home to some of the largest data center markets by city, as well as three of the top four cloud service providers and the industry's powerhouse users and developers (Microsoft, Apple, Facebook, Google, Twitter). Inventory of the U.S. market has expanded by over 10% annually over the last 5 years, with the top five operators being Lumen Technology, Verizon, Digital Reality, AT&T, and Equinix.

Canada is expanding at 9% CAGR with over 181 colocation DCs throughout 26 cities. Mexico, however, is 11th on the list at 2% global market share, just behind Russia and ahead of Brazil. Nearly a quarter of the market is diversified across other countries not listed.

Figure 3: Global Data Center Market Share by Country

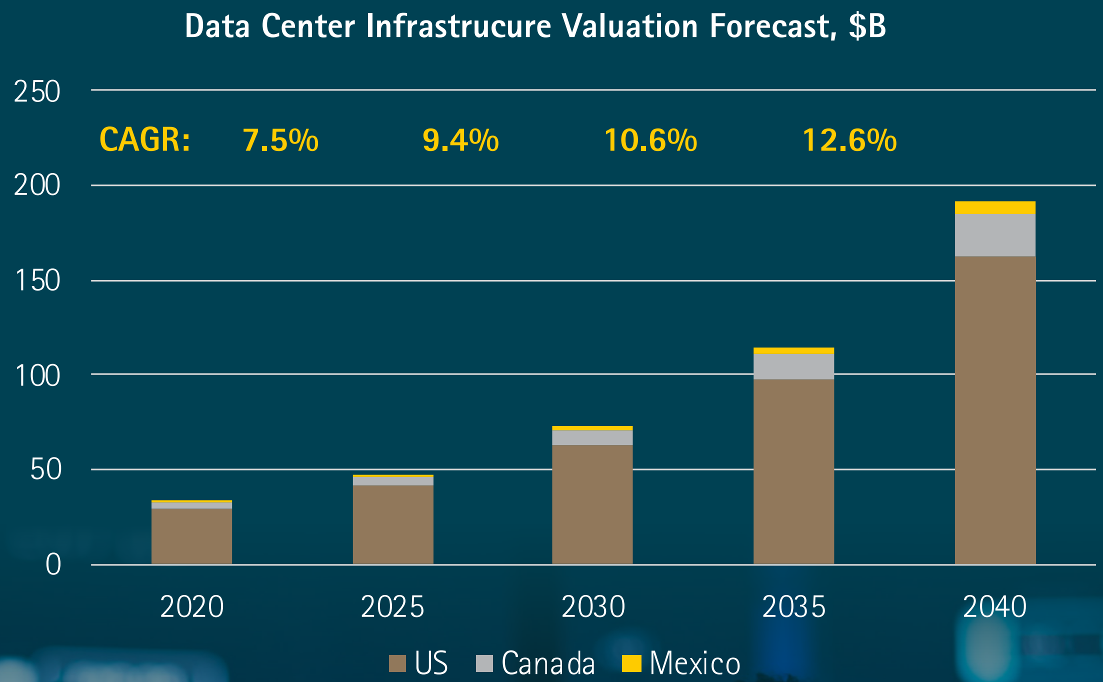


Data Center Market Results

NA Market Valuation

The market is sized based on a compilation of value from infrastructure assets across the three regions, U.S., Canada, and Mexico, forecasted through 2040, as illustrated in Figure 4. These values are then split across several DC descriptors, such as product systems, types, applications, configurations, and tiers. As these trends are looked at regionally, only minor variance is acknowledged. The value of the market's assets as of 2020 was just over $33B and grows at increasing rates to over $185B by 2040. CAGR grows from 7.5% this 5-year increment to over 12% after 2035 without an end in sight as society continues to become more reliant upon computing infrastructures.

Figure 4: NA Data Center Infrastructure Valuation Forecast with 5-year CAGRs



Data Center Market Results

Regional Market Share

Breakdowns of DC infrastructure value across states in the U.S. as well as across provinces in Canada are summarized in Figures 5 and 6. Within the U.S., data centers have concentrations in several key states, however they are diversified across most. The largest share is with California at nearly 13%, which makes sense with Silicon Valley's influence. Other states with significant shares include Texas (10%), Florida (6%), New York (5.7%), and Virginia (5.4%). Over time California's share slightly decreases a percent while other states shift upwards less than 1%. Within Canada, Ontario holds the most at nearly 40% of their data center infrastructure value share followed by Quebec (22%), British Columbia (13%), and Alberta (8%). Over time a couple percent shifts from Ontario to British Columbia.

Figure 5: U.S. States DC Value Share

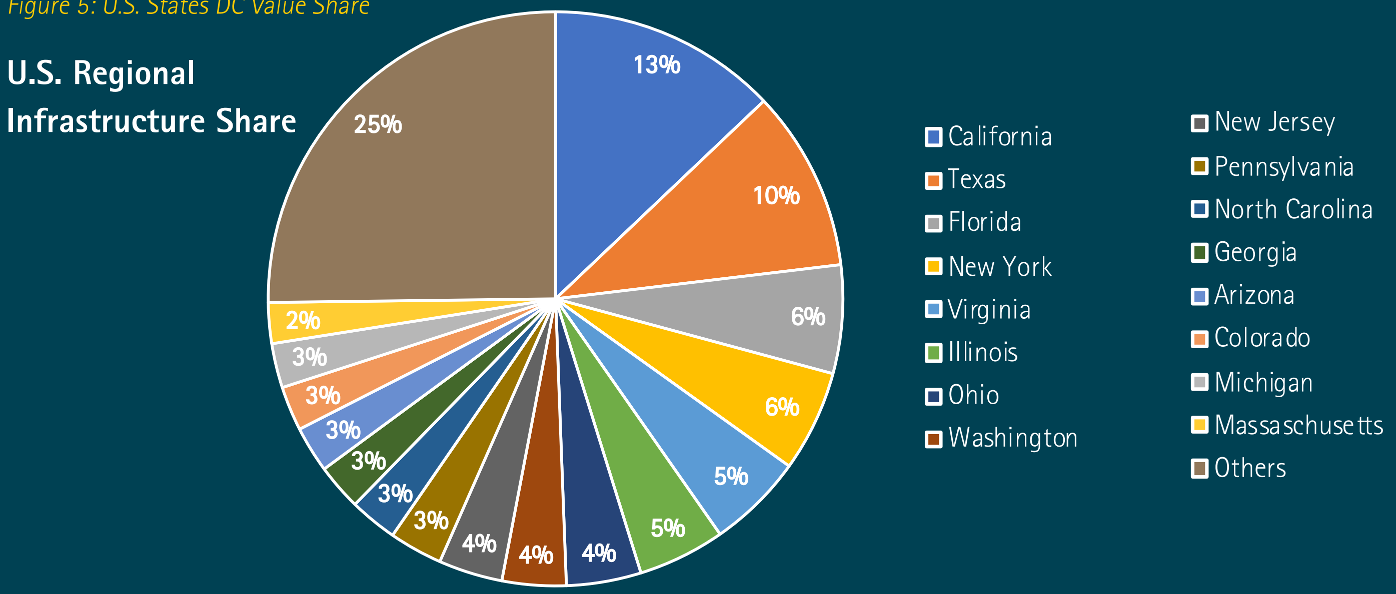
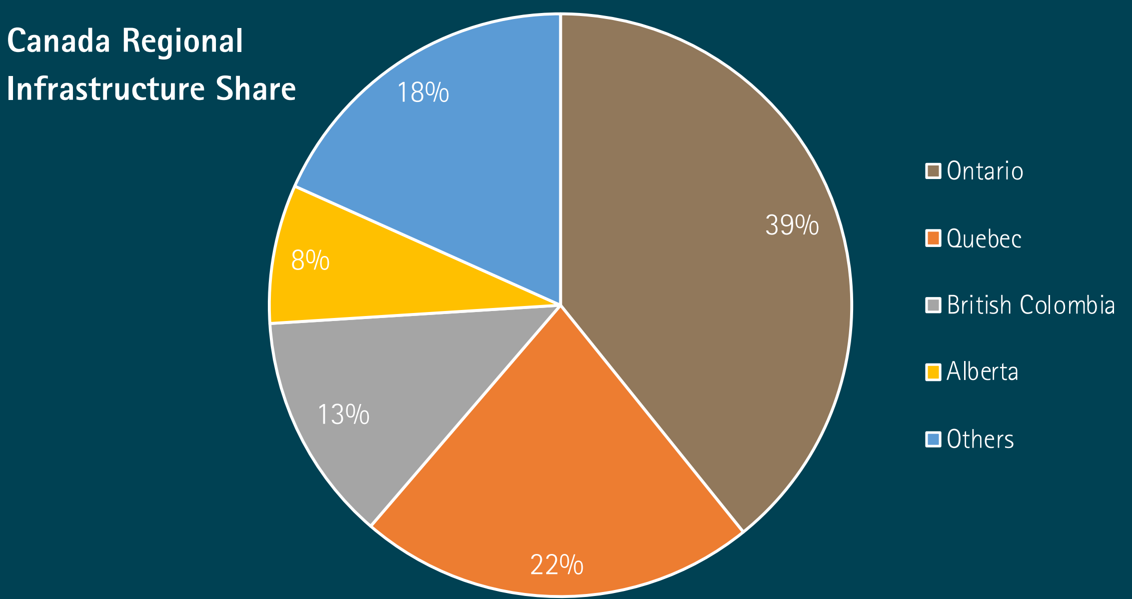


Figure 6: Canadian Province DC Value Share

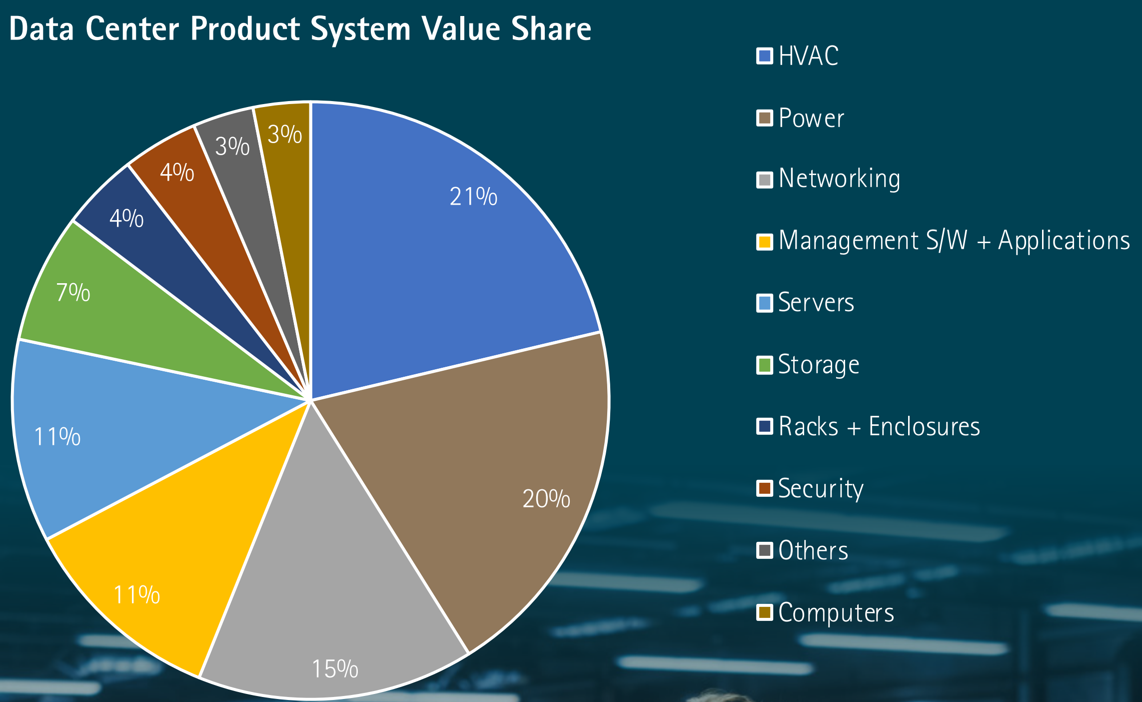


Data Center Market Results

Product System Valuation Splits

Figure 7 illustrates the splits across product systems, including HVAC, Power, Networking, Management S/W Applications, Servers, Storage, Racks / Enclosures, Security, Computers, and Others. Presently, HVAC holds the greatest value at 21% of the market infrastructure value followed by Power at 20% and Networking at 15%. Surprisingly, computers are one of the lowest valued categories at 3%. Over time, HVAC reduces 1% due to transitions to immersible cooling, reducing HVAC demands by cooling with non-conducting liquids. Power also drops 1% and Networking drops 2% as value increases for Management S/W Applications, Servers, and Storage.

Figure 7: DC Value across Product Systems



Data Center Market Results

Types and Applications Splits

DC Types are split across four, including Enterprise, Colocation, Managed, and Cloud / Edge, defined based on ownership and user relationships. Enterprise DCs are owned and operated by a company for its own use, while Colocation operates by renting out space. Managed DCs are third-party providers, and Cloud / Edge DCs are smaller and located close to the population being served to minimize latency while also being connected to a larger facility. Figure 8 illustrates the infrastructure value split across these types, with Cloud / Edge having the greatest value at 35% followed by Colocation at 28% and Managed at 21%. Over time Cloud / Edge and Colocation DCs increase a percentage point while Managed and Enterprise DCs each decrease one.

DC Applications are split between seven categories who make up the users, described in Figure 9. Over half of the market is applied to IT / Telecom (32%) and Banking, Financial Services, and Insurance (BFSI) (21%), followed by Manufacturing (13%), Healthcare (11%), Government (8%), and E-commerce (7.5%). Over time, IT / Telecom decreases to 26% as other industries apply more, as Manufacturing increases to 15%, Healthcare increases to 12% and E-commerce increases to 9%.

Figure 8: Value Share across Types

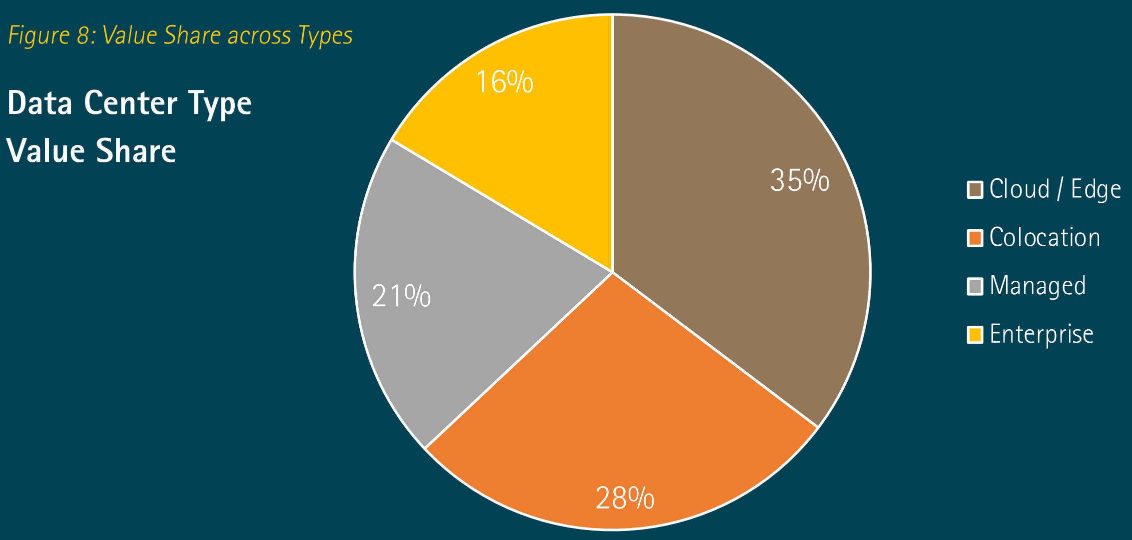
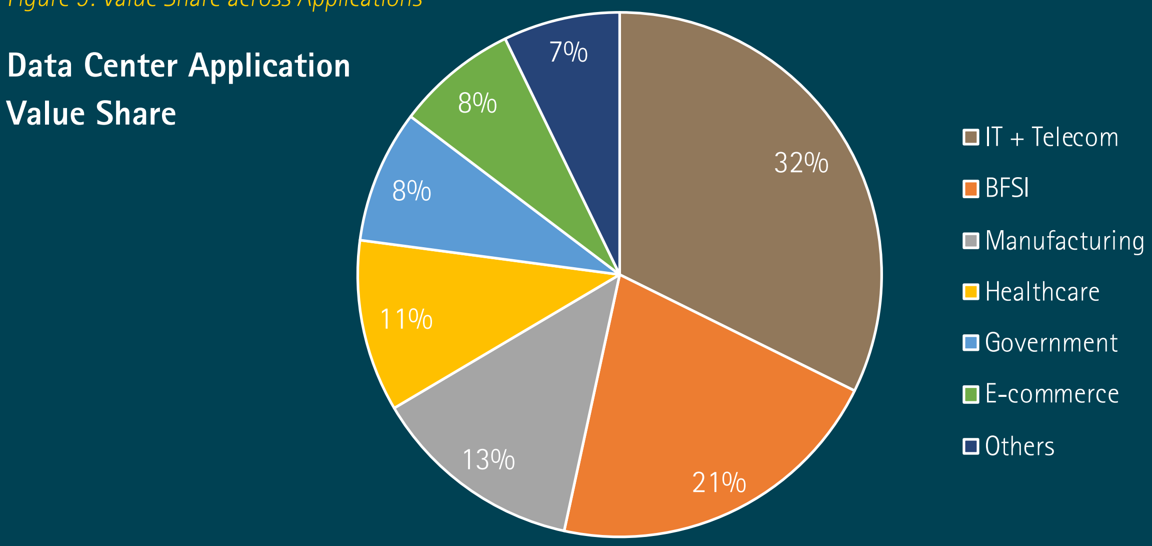


Figure 9: Value Share across Applications



Data Center Market Results

Configurations and Tier Splits

DC Configurations are split between three categories describing how they are setup and arranged, included in Figure 10. Storage Area Networks (SANs) are block-based storage, leveraging high- speed architectures connecting servers to their logical disk units, with a focus on high performance and low latency. Network-Attached Storage (NAS) focuses on ease of use, manageability, scalability, and lower overall ownership costs, as it dedicates file storage and enables multiple users and devices to retrieve data from centralized disk capacity. Direct- Attached Storage (DAS), on the other hand, attaches directly to a computer without going through a network. Over half the market are Storage Area Networks (SAN, 55%), while Network-Attached Storage (NAS) is 31% and Direct-Attached Storage (DAS) is 14%. Over time, SAN grows to 59% while each NAS and DAS drops a couple points.

Figure 10: Value Share across Configurations

Data Center Configuration Value Share

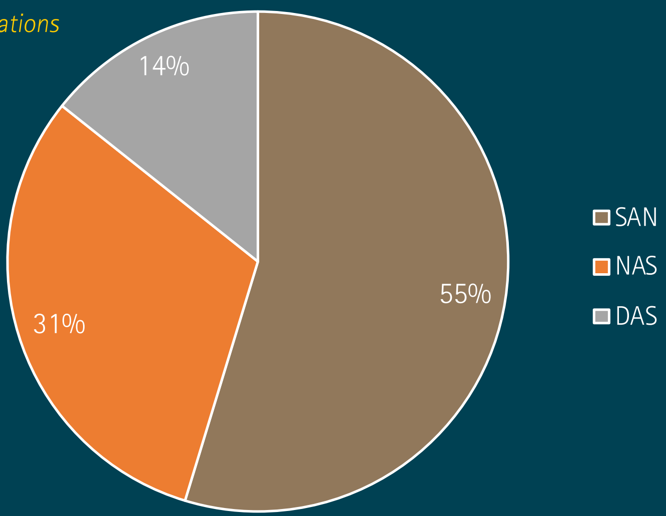
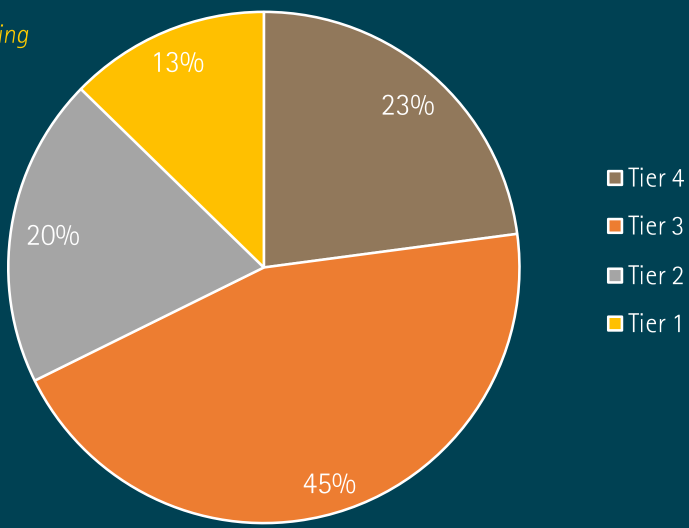


Figure 11: Value Share across Tier Rating

Data Center Tier Rating Value Share



Data Center Market Results

DC uptime is often important, but it is more important in some cases than others as it has associated costs, resulting in a tiered approach based on uptime expectations. Tier 1 is the lowest level with the least redundancies to ensure uptime under various circumstances and only a single path for cooling and power, resulting in uptime predictions of 99.671%. Uptime increases with each tier, achieving 99.741% with Tier 2, 99.98% with Tier 3, and 99.99% with Tier 4. Tier 4 has perfect fault tolerance and redundancy, including backup diesel-powered generators for power during outages, resulting in less than 1 hour of downtime per year. As shown in Figure 11, most of the infrastructure value supports Tier 3 DCs (45%), as they are not as costly and complex as Tier 4s while maintaining less than 1.6 hours of downtime. Tier 4, 2, and 1 follow at 23%, 20% and 13%, respectively. Over time, however, Tier 4 increases a couple of percentage points while Tiers 1 and 2 each decrease one, exemplifying the importance of uptime in upcoming applications.

DC Market Summary

In summary, the infrastructure value of the current DC market across NA is approximately $33B, by far the largest share in the world. This value is expected to grow at increasing rates through 2040, resulting in infrastructure value of over $185B with 88% of it concentrated in the U.S. with concentrations in California, Texas, New York, and Virginia. HVAC, Power, and Networking comprise over half of the infrastructure value while computers hold the least. Cloud / Edge and Colocation are the largest types and should continue to grow shares. Over half of the applications include IT / Telecom and BFSI with growth foreseen in Manufacturing, Healthcare, and E- commerce. SANs are the largest configuration type currently and are expected to continue growing. And, finally, Tier 3 is the largest group followed by Tier 4, requiring downtime per year of less than 1.6 and 1 hour, respectively. DCs are a very large market that drives significant technology volume in computing systems and necessary cooling systems, all requiring significant amounts of controlled electrical power, and the market continues to grow at accelerating rates.

Data Center Copper Content Results

Copper Forms and End-uses

Copper is a critical material applied in DCs, as its electrical conductance makes it ideal for efficiently transferring electrical energy and short-distance communications, and its thermal conductance likewise makes it valuable in transferring heat. Furthermore, its malleability makes it useful in forming products such as connectors, bridging the incoming power without losses from the cable to the application using it. Many of the forms of copper are on display at DC conferences with expositions, where many product suppliers in the industry display cutaways of various equipment and offer local tours to enable a closer view inside the stacks of racks. Figures 12 – 19 illustrate many of these copper forms on display and within a typical data center, including electrical, communications, and thermal applications. End-uses include power cables and wires, coaxial cables, communication patch cords, busbars, busways, and other flat electrical conductors, electrical connectors, foils as within PCBs and electromagnetic and radio frequency shields, heat sinks, heat exchanger tubing, grounding and bonding systems, and plumbing.

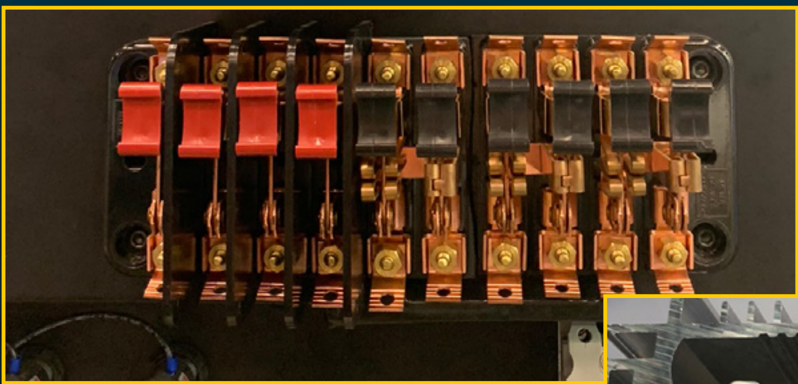


Figure 12: Contact Switches

Figure 13: Busway Cross-Section

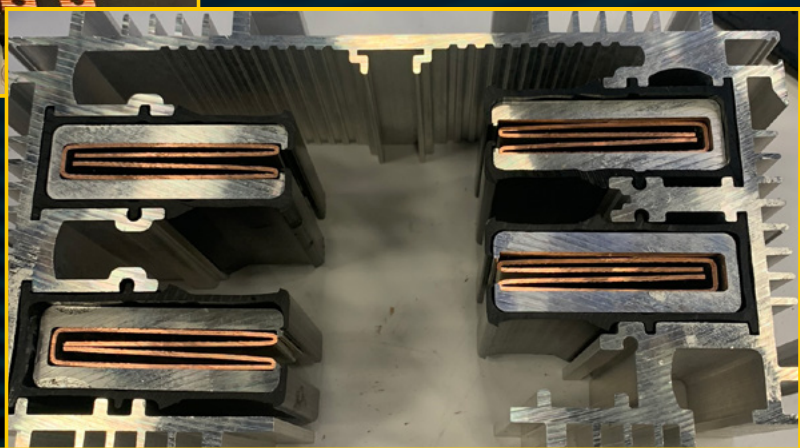
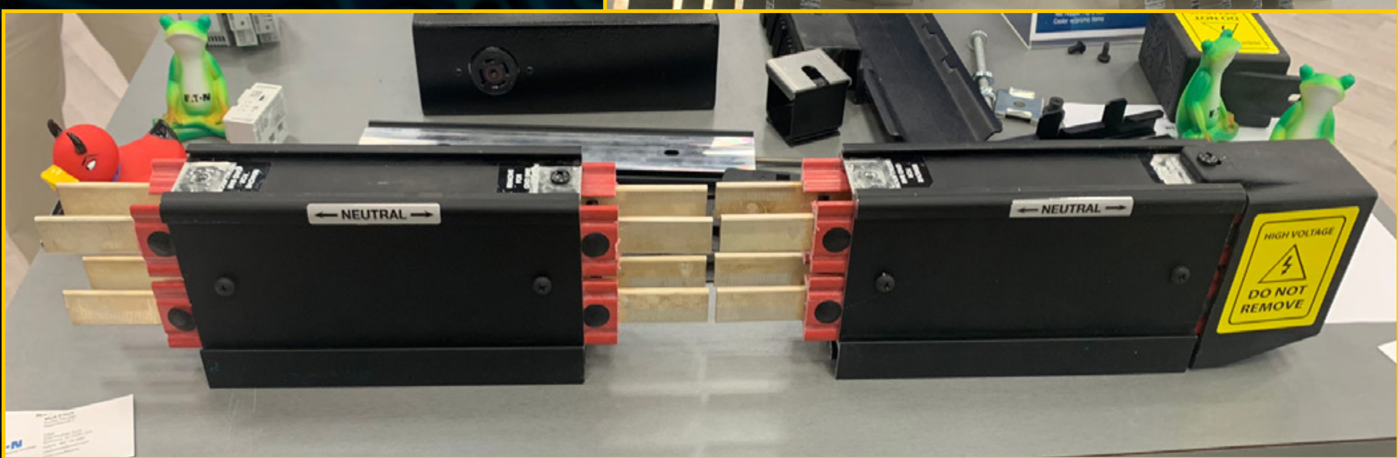


Figure 14: Busway Systems



Data Center Copper Content Results

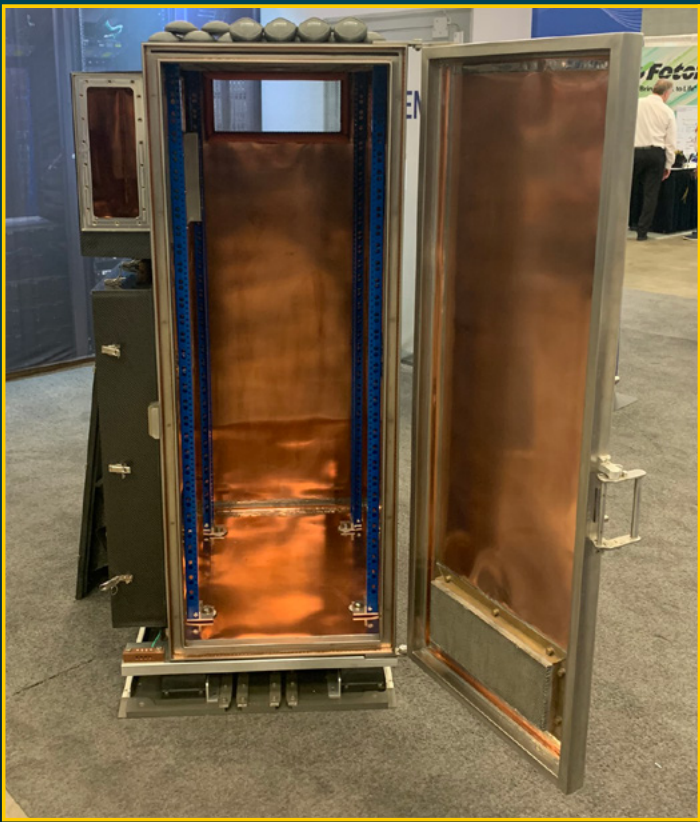


Figure 15: Rack Enclosure

Figure 16: Heat Exchanger

Figure 17: Covered Heat Sink

Figure 19: Plated Busbar conductors within Switchgear

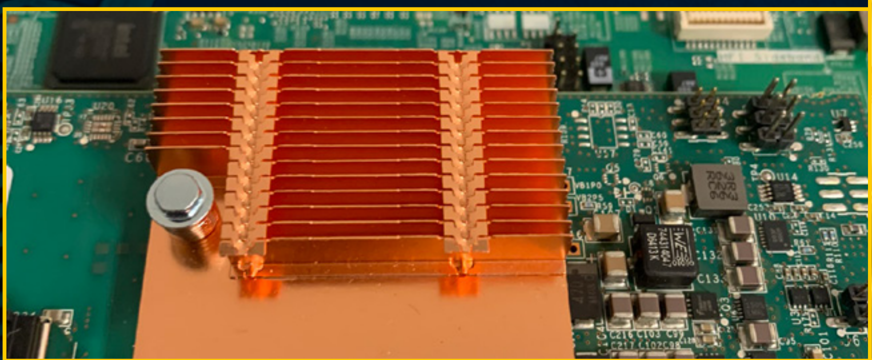


Figure 18: Open Heat Sink

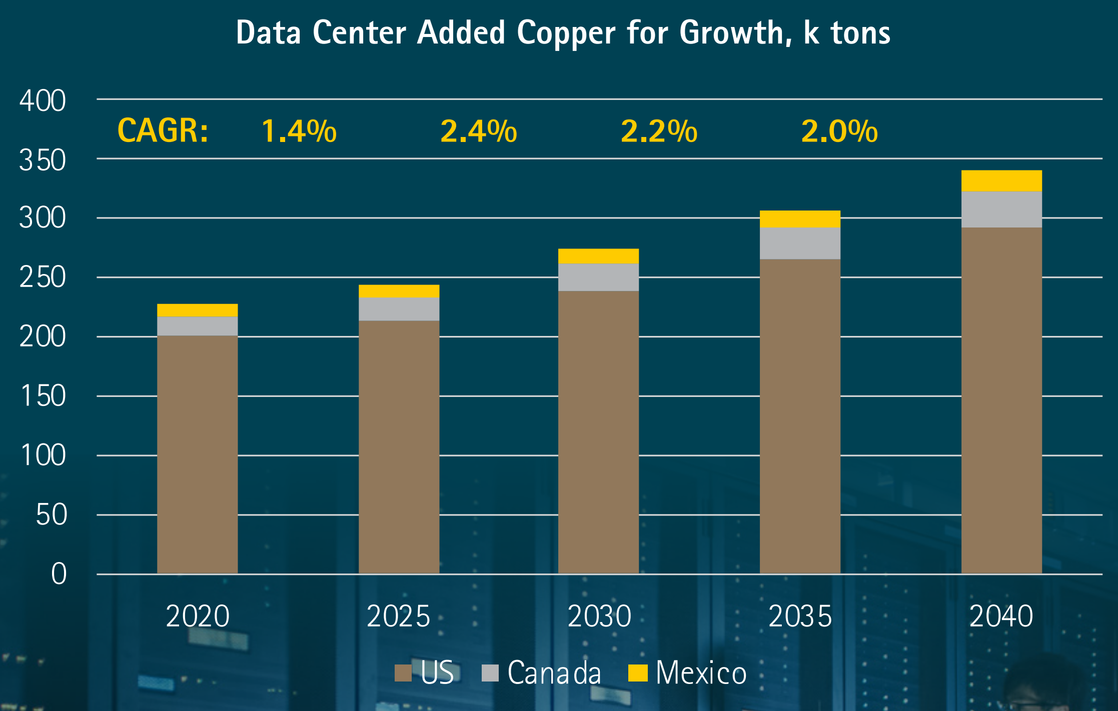
Data Center Copper Content Results

Copper Volumes in NA Data Centers

Significant volumes of copper are applied within DCs in total across its wide variety of applications. Figure 20 quantifies the annual copper volumes in each NA region applied within DCs as they continue to grow, expand, and upgrade systems. In 2020 nearly 217,000 tons (metric) of copper were used in DCs, and by 2040 this grows to 323,000 tons with CAGRs over 2%. The copper volumes for DCs grow, but not at the same pace as their total infrastructure value. Some of the growth comes from facility expansions that already have some of their infrastructure, not requiring some of the heavy areas of copper. Substitution and miniaturization are expected for some of the copper materials as well, also contributing to reduced growth rates.

It is now acknowledged these volumes are likely low as a result of the recent AI boom that is significantly elevating power and cooling demands.

Figure 20: NA Data Center Additional Copper Forecast to Support Industry Growth

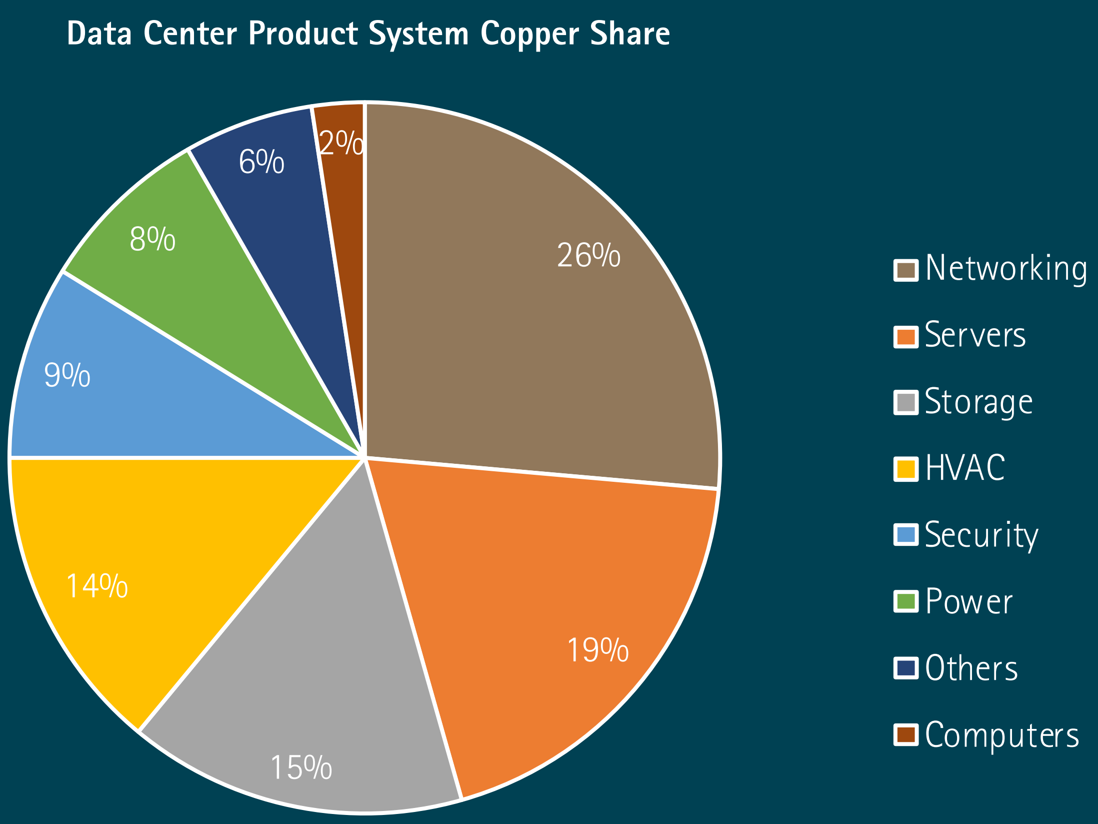


Data Center Copper Content Results

Copper Volume Valuation Splits

Figure 21 summarizes how this amount of additional copper volume applied each year in the DC industry as it grows is spread across the various product systems as previously described. A couple of the categories are not included, as they contain minimal copper, specifically Management S/W Applications and Racks/Enclosures (those on display in Figure 15 are not typical but demonstrate offerings to protect information and operations). Over a quarter (26%) of the applied copper is in networking equipment, followed by Servers (19%), Storage (15%), and HVAC (14%) systems. Surprisingly, Power is only 8% of the applied copper, and computers are one of the lesser copper-intense systems making up only 2% of the total applied copper. Over time, slight increases of less than a couple percentage points occur in Power and HVAC systems, offset with small reductions in most others.

Figure 21: Copper across DC Product Systems



It is worth noting the differences in order of value between Figures 7 and 21, acknowledging how much copper content is spread across each system and how this is not dependent on system value. For instance, HVAC and Power systems are the two greatest overall infrastructure values, but surprisingly they are fourth and sixth out of eight for copper content. And again, the heart of the DC, the computer, is the least of all categories in both system value and copper content. This demonstrates it is not the computers that drive DC costs, but rather all the infrastructure to power, communicate with, and cool the many applied computers.

Data Center Copper Content Results

Copper Volume Valuation Splits (Cont.)

Copper content splits based on DC classifications are illustrated in Figures 22 – 25, including Type, Application, Configuration, and Tier Rating. How copper content is spread across the DC Types is not much different than the infrastructure values (Figure 8 vs. 22). Likewise, little difference is evident in the DC Applications (Figure 9 vs. 23), as well as DC Configurations (Figure 10 vs. 24). DC Tier ratings also have little difference between infrastructure systems value (Figure 11 vs. 25). Similar trends occur over time between infrastructure value and copper content for each of these classifications, suggesting copper content is not too dependent upon DC Types, Applications, Configuration, or Tier Rating, as all of them require the necessary equipment with copper content.

Figure 22: Copper across DC Types

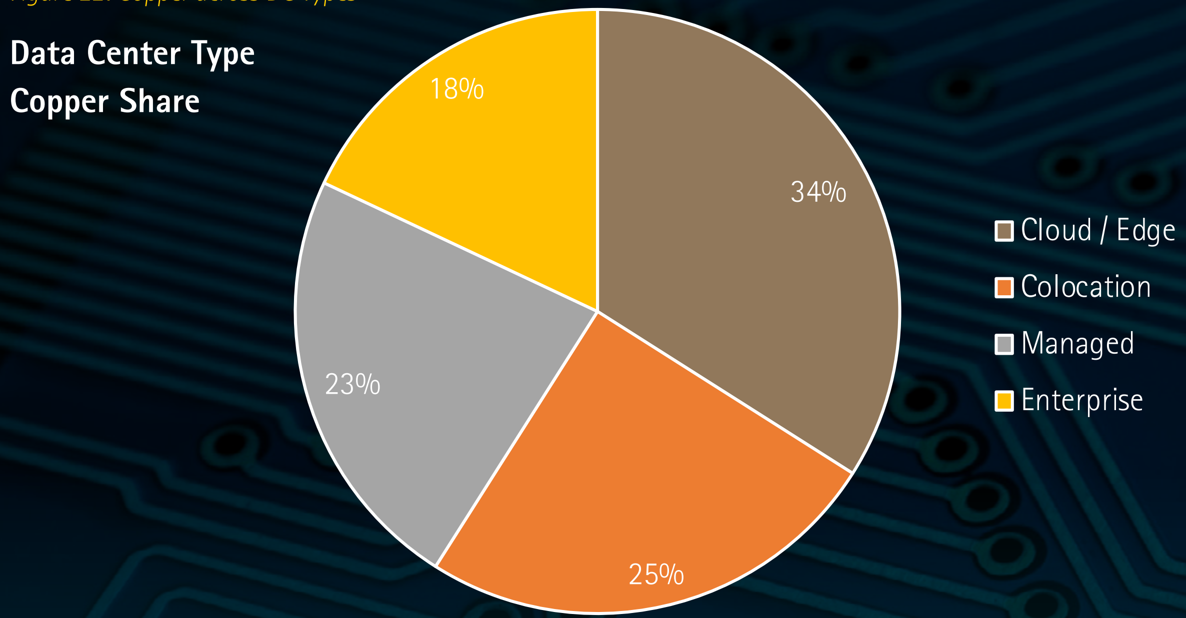
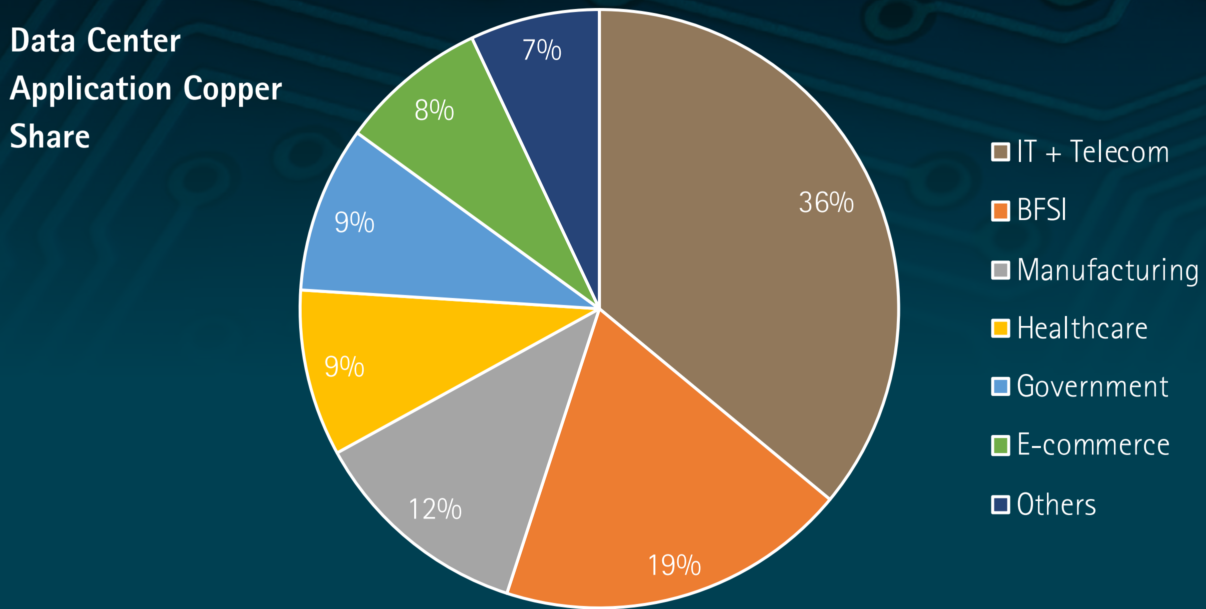


Figure 23: Copper across DC Applications



Data Center Copper Content Results

Figure 24: Copper across DC Configurations

Data Center Configuration Copper Share

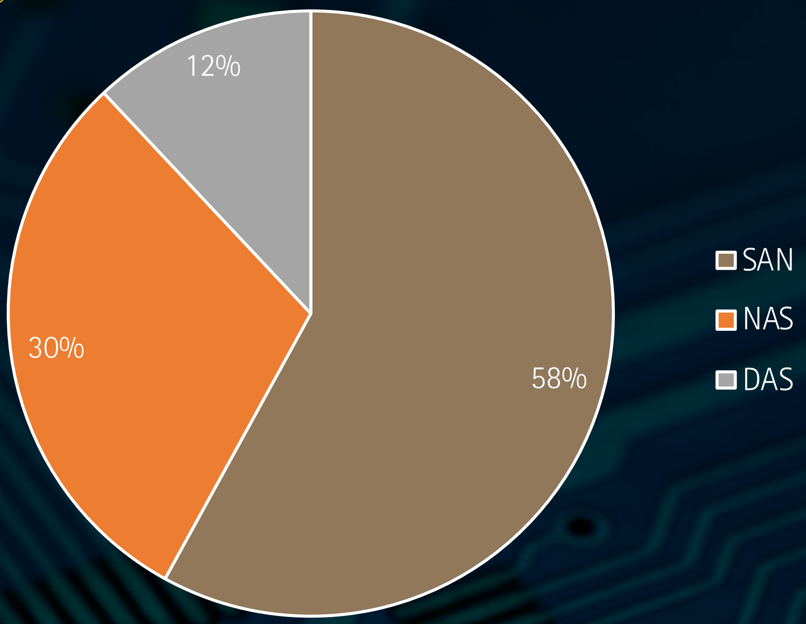
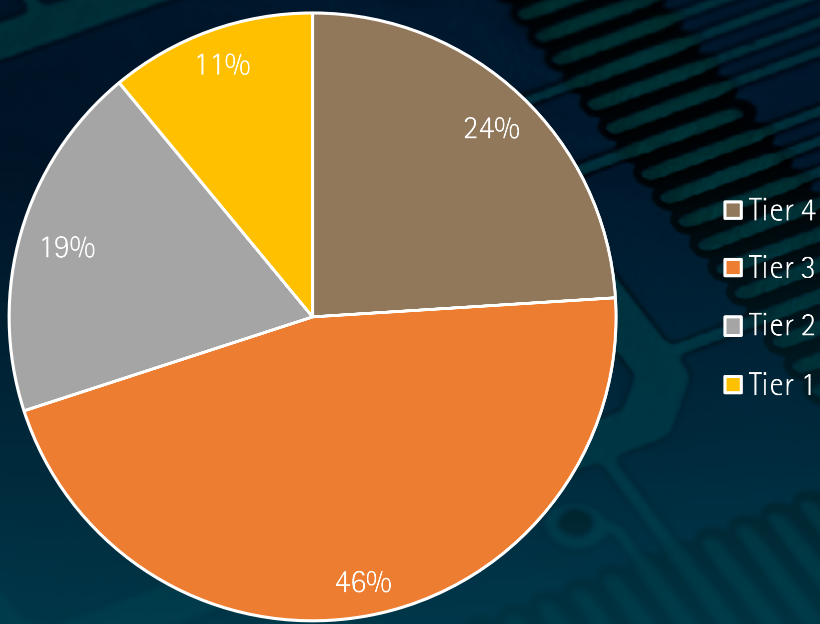


Figure 25: Copper across DC Tier Ratings

Data Center Tier Rating Copper Share



Data Center Copper Content Results

Copper Volume Valuation Splits (Cont.)

Copper content within DCs can be quantified for many of the common components and systems, particularly for a given size, such as its number of racks. Most of the copper volume is in the form of cables as applied in power distribution, pipes as applied in plumbing and HVAC, and wires, strips, bus strips, and bus bars as applied in interconnection and grounding systems. Copper is used in many other applications, but the consistent volumes of significance are across these areas. Figure 26 illustrates how the copper volume is split between these various end uses, as most of it (75%) is in power distribution, while the remaining is in Grounding and Interconnections (22%) and Plumbing & HVAC (3%). Figures 27 – 29 further detail the copper content for each of these end-use systems. Cables and wires volumes are mostly for the larger power cables (185mm, 74%), followed by smaller communications (Cat6, 20%) and electrical (3x6mm, 6%) wiring. Grounding and Interconnections are mostly large main grounding cables (185mm, 90%), followed by Earth Point and bus strips (~ 2% each), grounding wire (~ 1%), and bonding kits and busbars (~ 0.1% each). Finally, Figure 30 provides a summary of what forms of copper are ultimately applied throughout the DC, breaking them down between product forms of cable and wire, pipes and tubes, and flat products. Cables and wires make up most of the copper share within DCs at 96%, followed by tubes and pipes (3%), and flat products (1%).

Figure 26: Copper within DC Systems

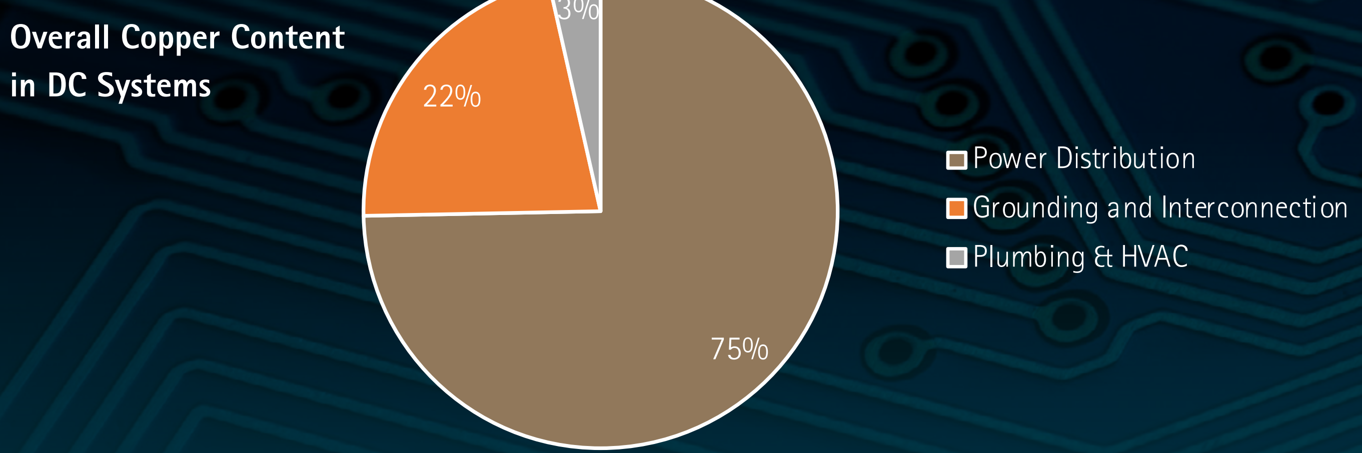
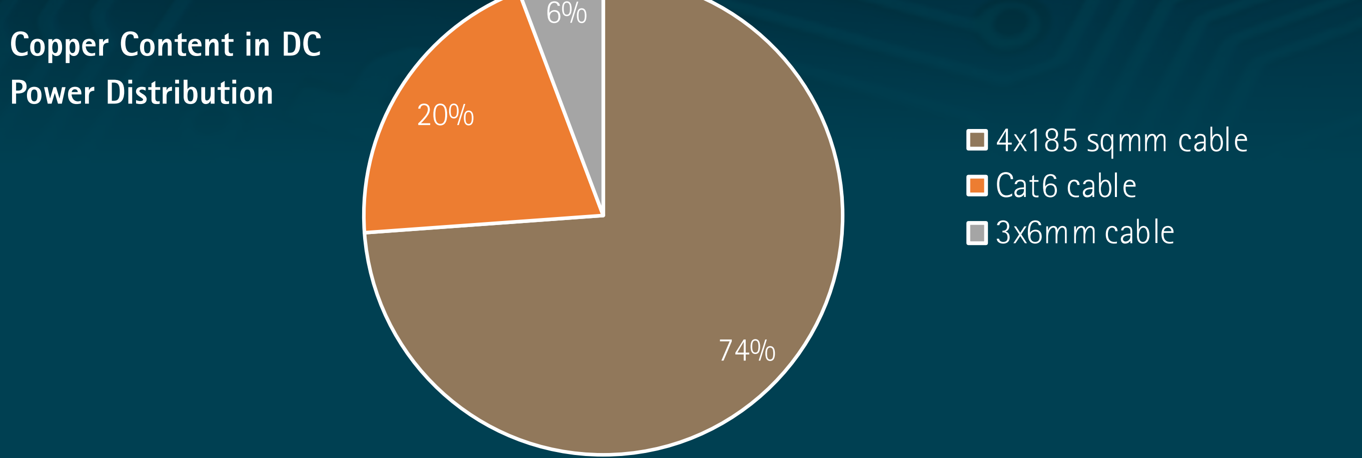


Figure 27: Copper in DC Power Distribution



Data Center Copper Content Results

Figure 28: DC Grounding and Interconnections

Copper Content in DC Gounding and Interconnections

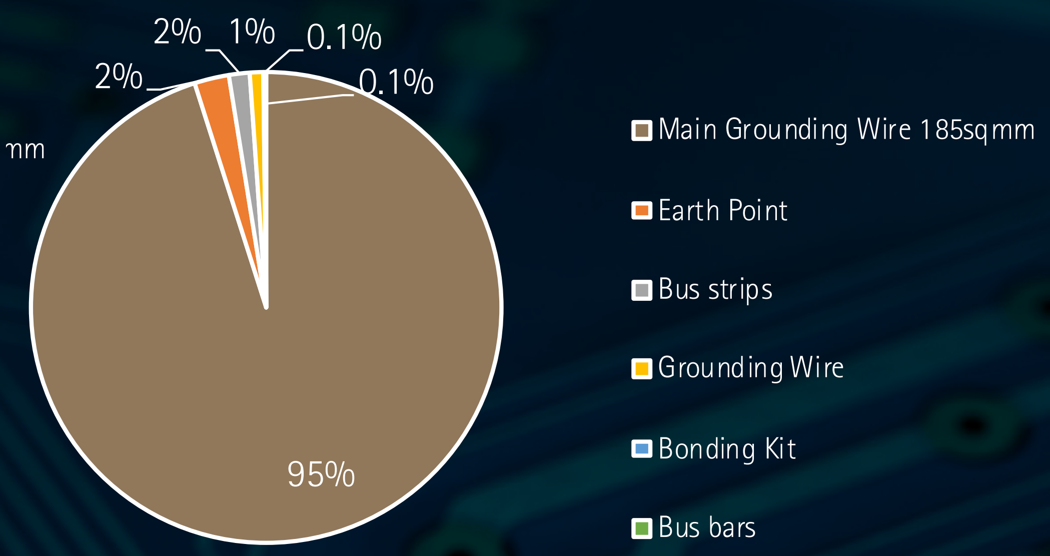


Figure 29: Copper in DC Plumbing and HVAC

Copper Content in DC Plumbing & HVAC

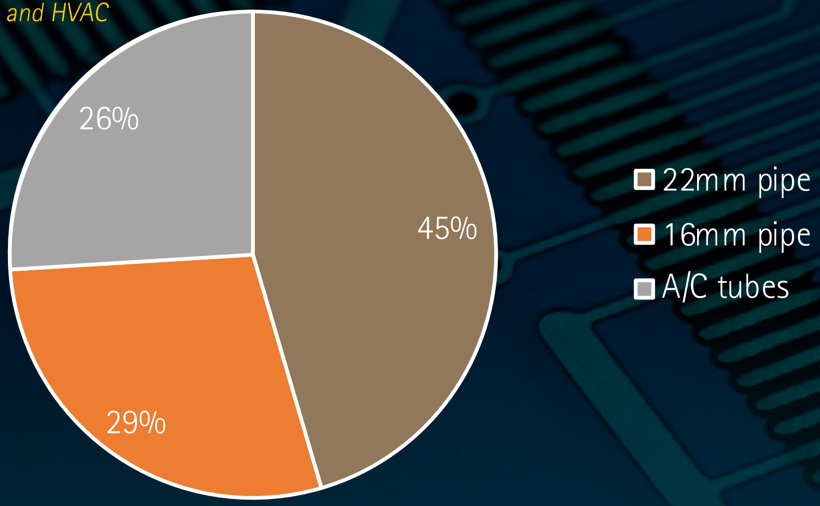
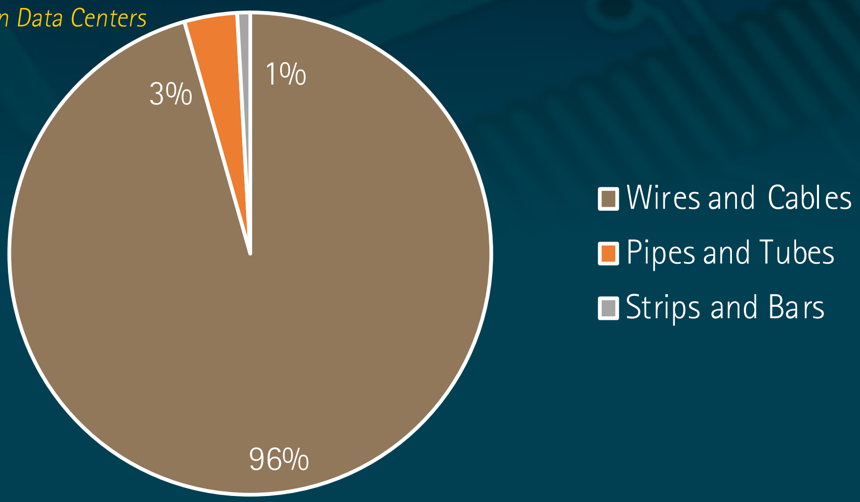


Figure 30: Copper Forms applied in Data Centers

Copper Content Forms in DCs



Data Center Copper Content Results

Copper Density in Data Centers

The total amount of copper applied in a DC is highly dependent on its size, often summarized using numbers of racks applied, required power demand, or square footage of applied space. A 90 rack DC is a rather small system, yet requires 34 tons of copper, while a 1250 rack DC is much larger, demanding 488 tons of copper according to this study. A rack may demand varying amounts of power dependent upon computing densities, typically requiring 10-20 kW4. And space required for typical DCs also varies, but 150W per square foot (SF) is typical.[5]

The research for this report began in late 2022 and was completed in early 2023, and since then AI power and cooling demands have significantly increased rack and server power. NVIDIA, for instance, recently announced 120kW racks launched in 2025 followed by 600kW racks coming in 2027. Their 120kW rack alone contains over 300kg of copper, which is nearly 3 tons/MW of copper intensity.

With this information, it is possible to calculate copper density based on

- **Racks (400kg/rack)**
- **Megawatts (20-40 tons/MW)**
- **Square footage (3-6 kg/SF)**

Conclusions and Recommendations

The criticality of copper in Data Center systems is demonstrated by quantifying volumes applied across their various infrastructure systems and describing the various forms in which it is applied. The DC industry is poised for significant growth as both uses and users increase and demand more computing and data storage. A series of interviews with industry experts of varying backgrounds was coupled with secondary research to unveil how their infrastructure is valued and how much and what forms of copper are applied where. Its infrastructure value is quantified and split across its various systems and is forecasted through 2040 to grow nearly six times in size. Various classifications are accounted, such as Type, Application, Configuration, and Tier Rating, for both infrastructure value as well as copper content. The infrastructure of the DC market in NA is valued at $33B in 2020 and $185B in 2040, and the copper volumes used in 2020 were 217,000 tons with 323,000 tons projected for 2040. When DC copper volumes are compared with the total amount of copper used within the U.S. across all end-use applications (2.5-2.8 million tons), they are 7- 8%, which is significant and may be considered high. Past efforts investigating Data Centers published by the International Copper Association (ICA) from 2019 forecasted the move to Edge applications in support of the many IOT applications requiring low latency.[6,7] And, it also acknowledged nearly 525,000 tons of copper were applied globally within new data centers in 2018, and just under half of the copper applied globally in new data centers by 2030 will be in North America.[8] Since the U.S. is currently one third of the global market, this means at least 175,000 tons is within the U.S., which is not far from the 217,000 tons applied in 2020 based on this most recent study. Nevertheless, it is clear the NA DC industry continues to rapidly grow and inevitably apply significant volumes of copper across a range of forms and uses.

A Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis is included below on copper as applied within DCs, which helps understand its potentials and risks.

Strengths Electrical Conductivity Thermal Conductivity Peak Temperature Malleability Antimicrobial Compactness Risk Reduction	**Weaknesses** Material Cost Weight
Opportunities DC Operating Efficiencies increasing DC Power Availability tightening Circularity, Recycling, and Sustainability prioritization Total Cost of Ownership	**Threats** Substitution Availability Perceptions

Figure 31: Copper in Data Centers SWOT

Conclusions and Recommendations

It is recommended for the copper industry to continue monitoring DC trends and technology shifts, as these may influence copper densities. Copper manufacturers also are recommended to participate in DC conferences and expositions to advocate on behalf of copper's high conductivity performance, space saving benefits, and recyclability. There is much attention in this industry to reduce power consumption and losses, optimizing efficiencies to reduce carbon footprints, which copper often helps enable. It is also suggested for copper industry representation to become involved in DC trade organizations, such as the Association for Computer Operations Management (AFCOM), to network and better become acquainted with application and industry specifics. It is also important to support industry with help driving technical standards to guide future system designs with better performance and efficiency.

DCs undoubtedly have a bright future, and copper is a critical material that continues to make them high performing and efficient.

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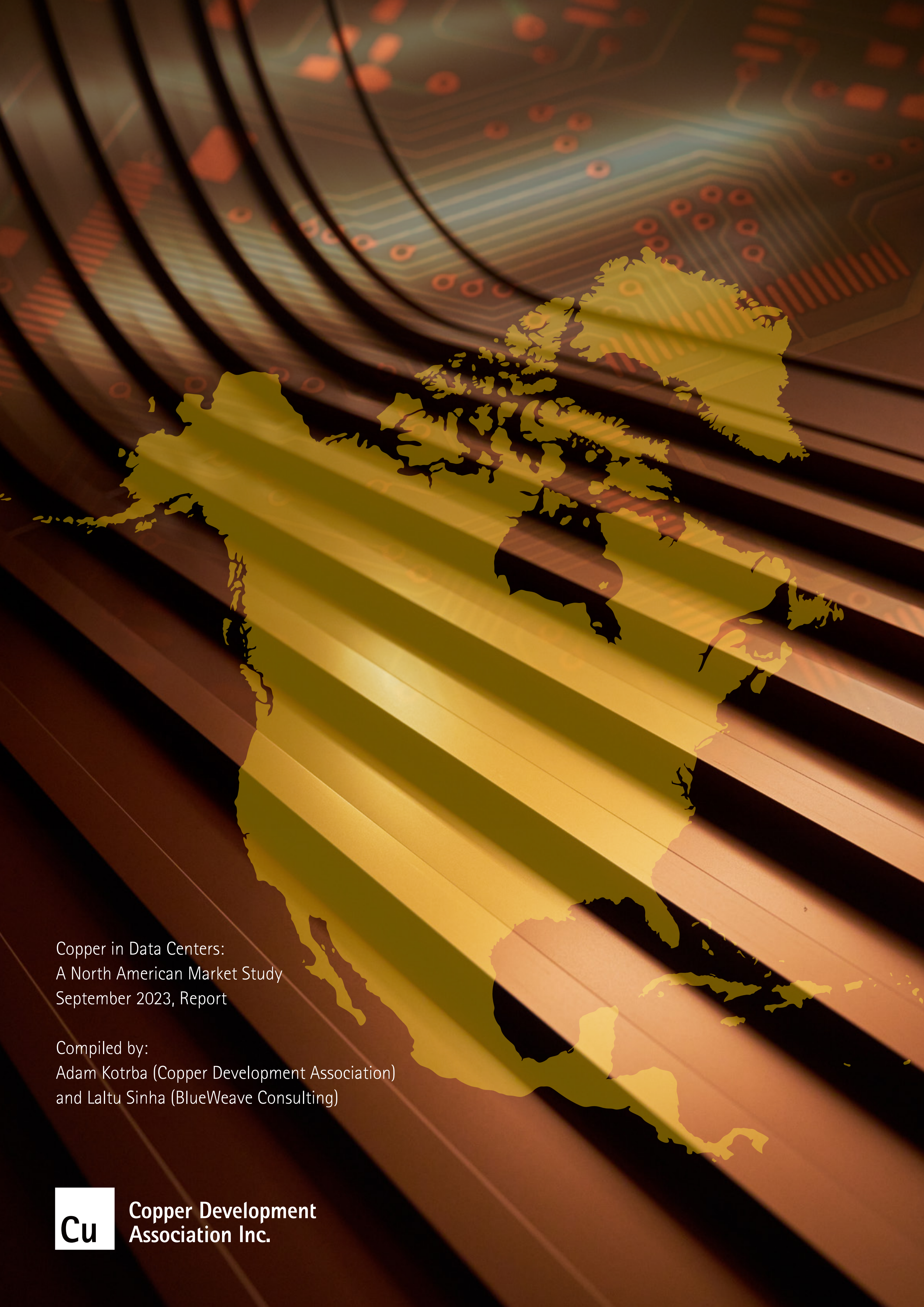
Summary of Figures



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