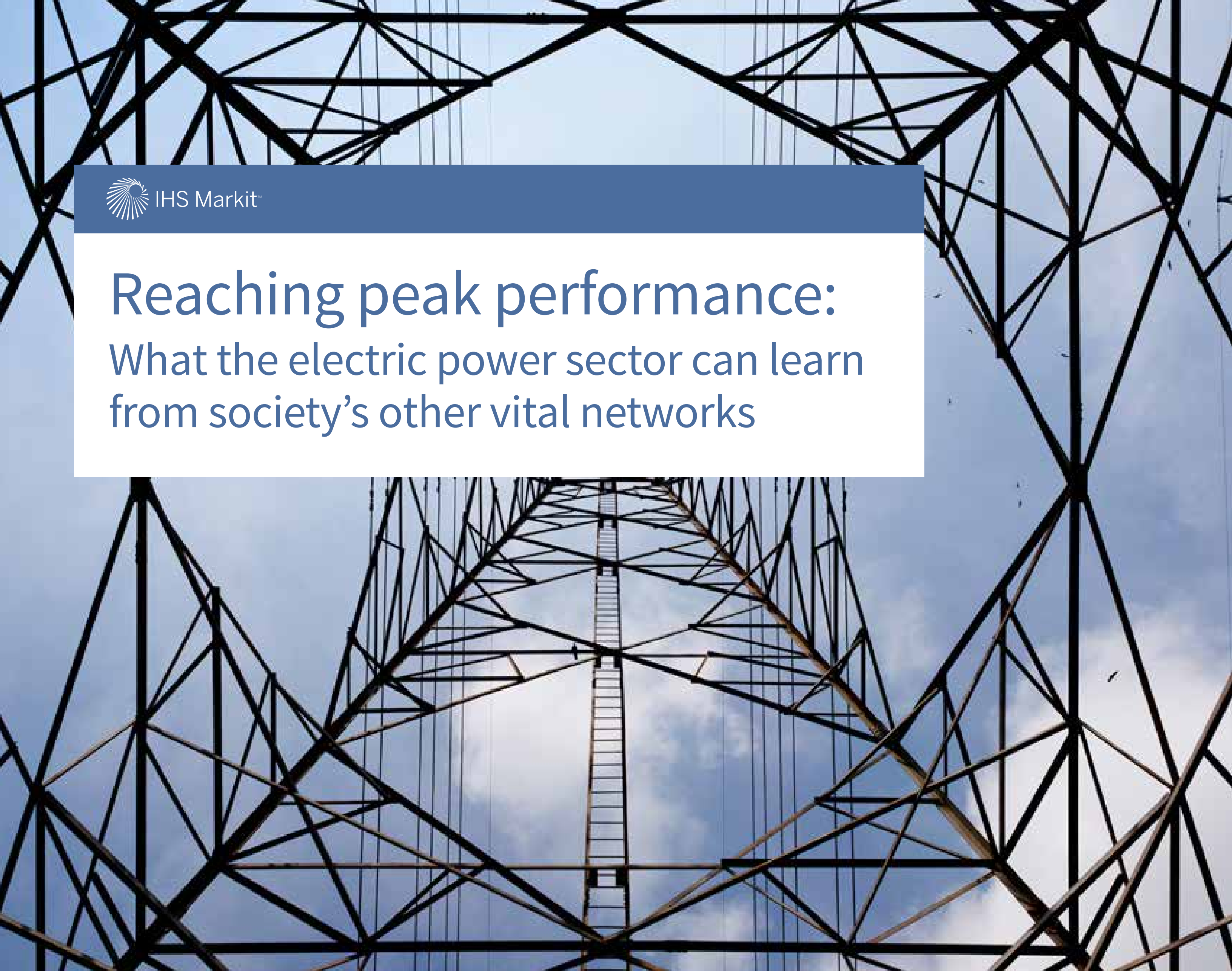


IHS Markit

Reaching peak performance:

What the electric power sector can learn from society's other vital networks

The role of storage in transforming systems into robust, resilient, and cost-effective networks

by Sam Wilkinson, IHS Markit Senior Research Manager - Solar & Energy Storage, in partnership with AES Energy Storage

Building networks to accommodate peak demands—or lulls in supply—requires overbuilding of infrastructure that leads to extra costs and system inefficiencies. This paper aims to uncover how the electricity grid can learn from the way other systems address the common challenge of balancing supply and demand, and how these systems are made more efficient with the introduction of new communications and storage capabilities.

This paper focuses on comparisons with the data, gas, travel, and perishable goods networks because, like the electricity network, they have a near-global reach and are embedded within the everyday life of most people. This exercise could be expanded to include many other networks, such as the transition from the pre-internet telecommunications grid to the internet we know today, all of which would likely be characterized by similar challenges.

Key findings

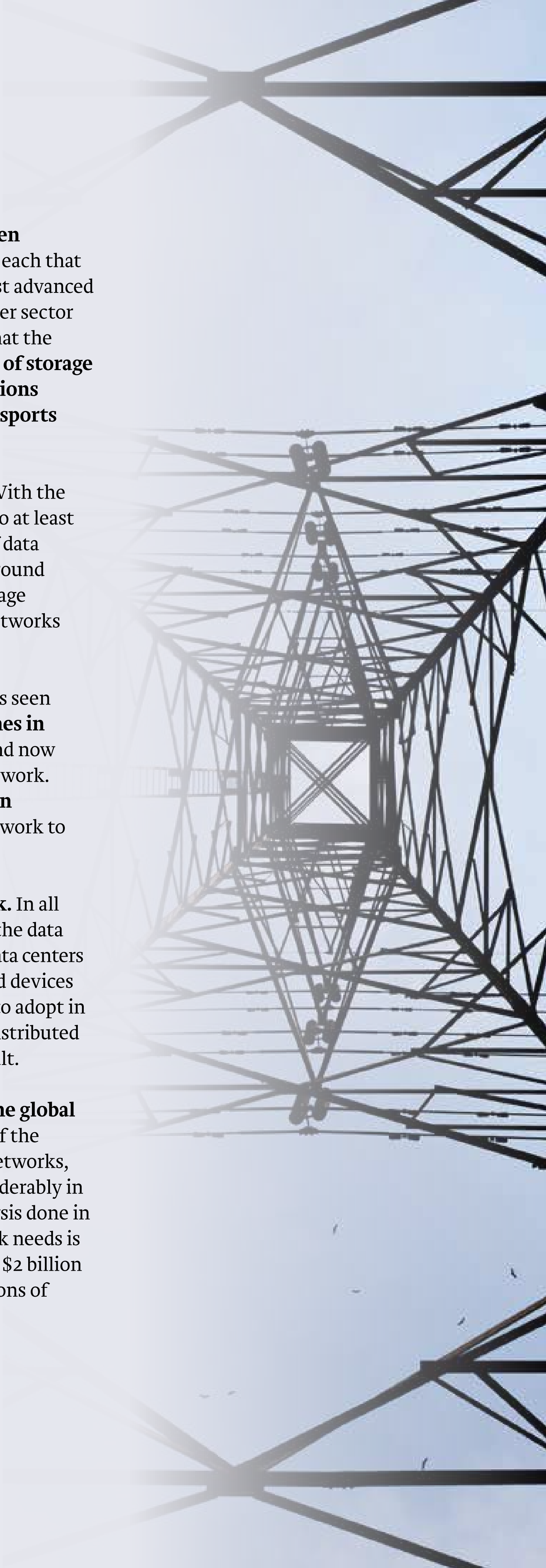
- **Storage and a common communications standard strengthen networks.** Of the five networks studied, there are elements of each that are worth consideration. However, the data network is the most advanced and robust, and it provides the most insight to the electric power sector as the latter adapts to new market changes. Our study shows that the data network has incorporated **not only a significant amount of storage to provide flexibility and resiliency, but also a communications standard that enables the bidirectional flow of what it transports** (i.e., information).

- **The electric power network has a distinct lack of storage.** With the exception of electricity, all networks have storage amounting to at least 4 days' worth of demand (and significantly more, in the case of data networks). The electricity grid currently has storage equal to around 20 minutes' worth of demand, and significant additions of storage would be required for the electricity grid to match the other networks in storage capacity.

- **Declining costs in storage enable system transformation.** As seen most prominently in the data network, **significant cost declines in data storage**—first in technology for hard disc drives (HDD) and now in solid-state drives (SSD)—underpin growth in this robust network. **Lithium-ion battery technology has a similar cost-reduction profile as SSD data storage,** and will enable the electricity network to incorporate multiple hours of storage.

- **Storage can be placed at many points throughout a network.** In all sectors studied, storage is located throughout the network. In the data network, we found that storage is growing at both centralized data centers that are far from the end user as well as in laptops and handheld devices that are located with the end user. We expect the electric grid to adopt in similar fashion, with growth in mass-centralized storage and distributed storage alike to be embedded throughout the network as a result.

- **Addressing peak power in an efficient manner could save the global electric industry hundreds of billions of dollars each year.** If the electric power sector were to incorporate lessons from other networks, particularly the data network, electricity grids could gain considerably in terms of flexibility, efficiency, and reliability. Based on an analysis done in New York, paying for idle capacity that is used just to meet peak needs is an expensive proposition, costing customers in the state about $2 billion each year. This suggests that on a global scale, hundreds of billions of dollars could be saved each year.



The importance of networks and their common challenge

From social networks such as Facebook and LinkedIn to transportation networks that move commuters every day, technology advancements in storage and communications have played a critical role in the transformation of some of our most critical global networks.

For example, the scale-up of data storage devices, such as HDDs in the 1980s and then SSD storage this decade, have had profound impacts on the evolution of data networks and computing around the world. Similarly, the rise of the cloud and improvements in digital communications and navigation systems have given rise to ride-sharing and ride-hailing platforms such as Lyft and Uber, which provide access to available seats that were previously inaccessible.

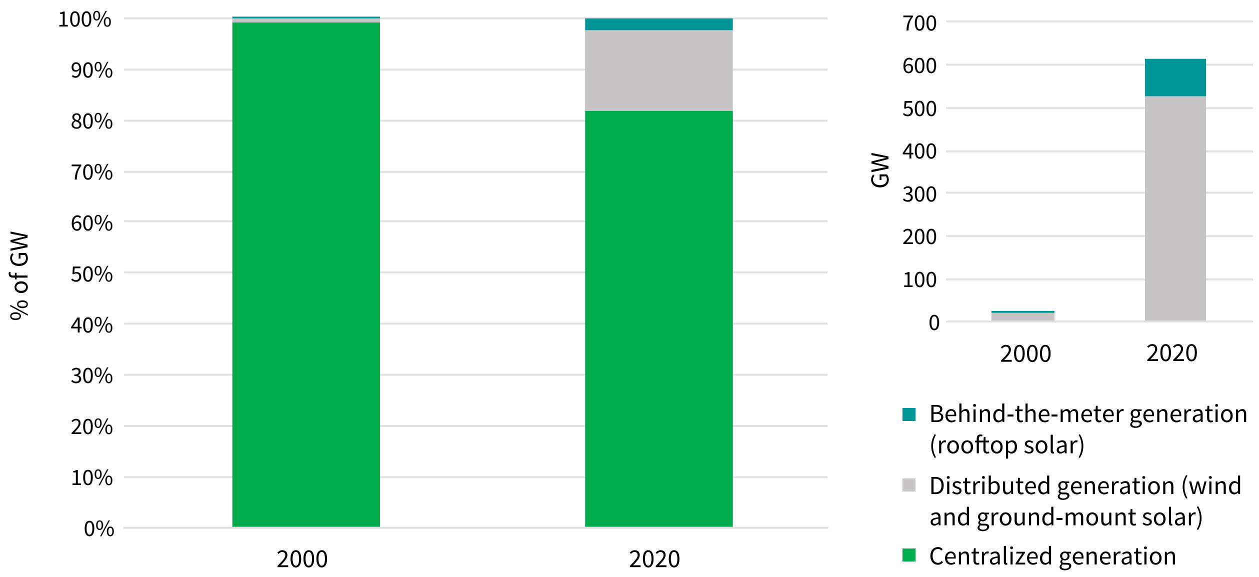
This phenomenon is seen again and again in numerous industries, including liquefied natural gas (LNG) storage in the natural gas industry, refrigeration and cold storage in the perishable goods industry, and pumped hydroelectric storage for the electric grid.

Today networks play an essential and fundamental role in our society, as everyone is increasingly connected in some way. Whether physical or digital, impossibly complex or basic at their core, artificial or organic, networks of some kind are involved in everything we do. Many parts of our lives depend on unfettered access to several types of networks, and continuing to improve the availability, resiliency, and efficiency of these networks is critical. While the industries and technologies differ across the different types of networks, at its heart every network shares a common challenge: balancing supply and demand to maintain reliability in the most efficient manner possible.

This challenge is becoming particularly acute for the electricity grid, where both supply and demand are evolving rapidly. Originally designed more than 100 years ago, the grid has mostly operated in one direction, "pushing" energy produced in central power plants to customers through a regional transmission and local distribution system. However, the rise of low-cost distributed generation—in particular, renewable sources that can provide energy both to the end user and back to the electric grid—combined with changes in the way that people are using and interacting with the grid, is placing strain on the current system.

Similar to the rise of wind and solar generation in the last 15 years, we are now starting to see exponential growth in the deployment of battery-based energy storage systems, thanks in part to a rapid decline in pricing for lithium-ion batteries. Over the past five years, the cost of lithium-ion battery modules has decreased by nearly 75%, and is projected to halve

Installed electricity generation capacity in Europe by type



Source: January 2017 IHS Markit European Power Planning Scenarios over the next four years. By the end of the decade, IHS Markit predicts that the installed base for battery energy storage will grow to nearly 16 gigawatts (GW) in its base case—equivalent to an assumed annual growth rate of over 60% from 2012 and 2020—with the clear potential for much greater expansion. Along with these new projections has come a growing understanding of the importance and value of energy storage to the electricity grid, and how this new technology might reshape the grid in order to reduce costs and improve reliability.

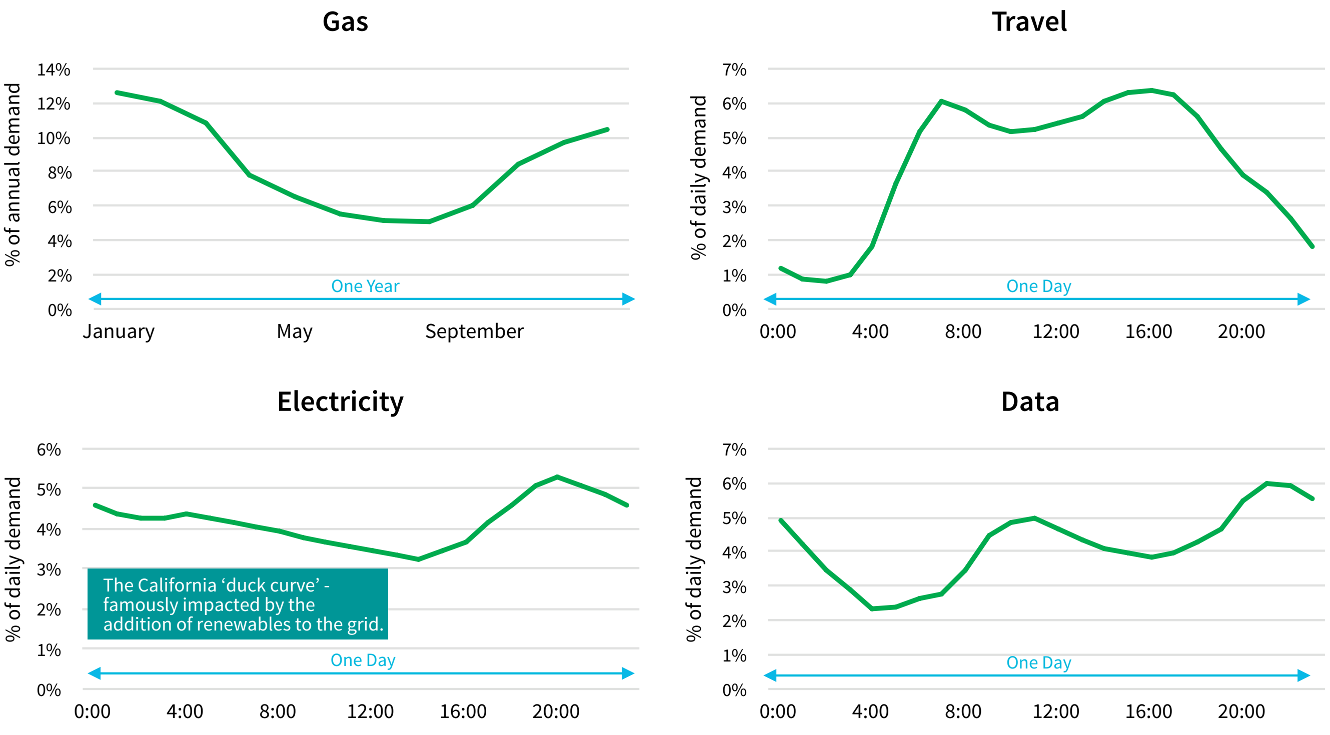
Peak demand: the network design principle

In general, the infrastructure behind each network is built to support the most extreme mismatch between supply and demand, which in most cases is caused by peaks in demand, but can also be created by lulls in supply. The reliability of a network is typically judged on its ability to meet demand, often considered critical to the network's end users.

In the event that supply falls short of demand in the electricity sector, the result is a blackout, where consumers lose access to electricity. This can have consequences ranging from a minor inconvenience (e.g., homes/businesses losing power) to severe and even life-threatening in more mission-critical industries (e.g., health care, telecommunications). The failure of other networks has similar consequences to both individual lives and to overall economic well-being.

While ensuring enough physical capacity in a network may safeguard reliability, rapid upticks in demand on a network and its users can have far from a desirable impact, particularly on the cost of building and operating the network.

Comparison of typical demand on networks



The California 'duck curve' - famously impacted by the addition of renewables to the grid.

All charts represent the percentage of daily/annual demand that occurs during each hour/month. Transport based on vehicle miles traveled in California in 2016 (Source: California Department of Transport). Gas based on monthly consumption in Germany and UK in million cubic meters (IHS Markit interpretation based on several sources). Electricity based on load on California grid (IHS Markit interpretation based on several sources). Data is based on global megabytes consumed per day (IHS Markit interpretation based on several sources).

Take travel, as an example. The millions of riders aboard a Shanghai metro train at rush hour on a Monday morning would argue that capacity could—and should—be increased. Similarly, users of data networks often experience network speeds being "throttled" at peak times that restrict their usage, with other networks seeing price spikes during peak times.

Nonetheless, the end results of networks being designed to accommodate both peak demand and constant changes in supply and demand alike are overall lower utilization of a system and higher total system costs.

In the case of roads and rails located within a city, these are built to accommodate as much as possible the peaks experienced by the network, typically associated with commuters making their way to and from work. At these times, certain areas can become highly congested, restricting the speed of traffic and significantly restricting the performance of the network. However, traffic volumes in other areas or at less busy times of the day are much lower, and the network could then accommodate much higher numbers of vehicles without performance being impacted. The government of the Netherlands in recent years has launched a "Better Use Programme" that aims "to achieve better utilization of existing networks in an innovative way." Acknowledging that there will be increasing volumes of traffic, the programme aims to use a variety of initiatives—including sharing traffic data, encouraging travel at off-peak times, and improving connections among motorways, railways, and waterways—to allow existing infrastructure to be more efficiently utilized.

Aside from roads and railways being underutilized for a large part of the time, it is also clear that improvement is possible as to how the seats within vehicles are used. In New York City, for instance, some basic analysis suggests that even at peak times just 53% of seats are occupied, while average occupancy of the seats across a whole day is more likely closer to 25%. This means that on average, just one of four possible seats on the system is in use; and to make matters worse, for much of the time the roads and railways are capable of accommodating a greater number of vehicles or trains. The US Transportation Energy Data Book suggests that the average number of people traveling within a car in the United States is just 1.55, while the average number of people on board a bus is merely over 9.0 or less than 20% of total capacity. It might seem like an abstraction, but if one assumed that on average each car was used by one person for two hours each day and that each car could hold four people, then the vehicle is fulfilling only 3% of its overall potential. Undoubtedly, there is much room for improvement in the overall utilization of the travel network. This is the insight driving shared networks like Uber.

For the perishable goods network, the same principle of inefficiency is manifested in the large amount of produce that is wasted all around the world. This is due to insufficient storage, incorrect storage conditions, or having to balance variable seasonal supply with demand that has become broadly constant in most regions.

The electricity grid—also built in order to provide power at peak times—likewise records alarmingly low utilization statistics. According to the NYISO (New York Independent System Operator), the system is required to have to a minimum capacity of 39,198 megawatts (MW); the peak recorded in New York was 33,956 MW in the summer of 2013. Peaks in subsequent years have been slightly lower, but NYISO predicts that peak demand on average will grow, albeit at less than 1%, each year in the future. In comparison, average load has stood between 17,000 MW and 18,000 MW for the last six years. This suggests that the network is typically delivering less than half of what it is capable of. Such overbuilding, while necessary to meet reliability requirements based on available technologies, comes at a significant cost to the users of the grid.

Peaks and their impact on users

Network	Cause of peak	Impact of network users	Frequency/cycle length
Electricity	Peaks in demand generally occur in the **evening** (some variation by region). **Renewables** are increasing supply and decreasing demand at certain times, making the balance of supply and demand even more complex.	**Blackouts** are uncommon in most developed regions. However, grid infrastructure can be extremely stressed at certain times. Many regions employ time of use (TOU) pricing to discourage usage at peak times.	Typical usage patterns generally cycle on a **daily** basis, although some regions experience seasonality, with reduced usage in summer months.
Perishable goods	**Supply is not available year-round** in all regions, whereas demand remains relatively constant.	**Imports** from regions that are able to produce. Leads to higher cost and longer lags between harvest and consumption.	Supply seasons cycle on an **annual** basis.
Data	Relatively constant demand throughout the day, with an **increasing number of devices constantly accessing data**. Peaks in the evening driven by internet browsing and streaming.	Network speeds for end users can become **slow** or intermittent, with service providers 'throttling' speeds.	Usage patterns repeat on **daily** basis, with increases during events.
Gas	Seasonal peaks as supply is relatively constant, while demand varies significantly due to **heating requirements**.	No significant impact due to **ample storage** installed in order to ensure sufficient supply.	Principal usage cycle repeats on an **annual** basis, particularly in regions with a more diverse climate (as peak usage is driven by heating needs).
Travel	Peaks occur each day, typically in line with commuting **rush hour**.	Travelers **slowed down**, particularly when traveling on roads, Public transport routes become **crowded and uncomfortable**.	Typical usage repeats on a **daily** basis.

How networks overcome the challenges of peak demand

In all cases, a logical approach to coping with increased demand is to simply increase supply, where possible, although this can be expensive. Some networks have found other ways of addressing this challenge and managing the balance.

In order to make meaningful comparisons among the five networks and the ways in which they operate, it is necessary to define the metrics common to them. All told, each network has five important common physical elements: an item that is being moved; a source; a physical infrastructure to facilitate the exchange; a communications infrastructure; and a storage component. How these items are interconnected can vary, and other common items do exist, but these five fundamentals are key to the analysis in this paper.

The **perishable goods network** is intended to capture from their source the transportation of all goods possessing a specific shelf life, through to their end user. In reality this could incorporate many things, ranging from meat and fish to pharmaceutical products, but the analysis here is generally based around the idea

Common network metrics and definitions

Network (item transported)	Source	Physical infrastructure	Storage	Communications infrastructure
Electricity	All forms of generation (fossil, renewables, etc.)	The grid - transmission and distribution lines	Batteries, pumped hydro, compressed air	SCADA (supervisory control and data acquisition)
Perishable goods	Crops, farming agriculture	Transport links - road, rail, ferry	Cold storage, warehouses, etc.	Mostly ad-hoc communications through supply chain
Data	Computations and content	Data transmission lines, wireless	Hard drives/data centers, smartphones, etc.	Internet Protocol (IP)
Gas	Gas fields	Pipelines	Disused fields, aquifers, tanks (LNG), storage fields	SCADA (supervisory control and data acquisition)
Travel	Vehicles - cars, trains, buses, etc.	Road, rail	Seats	Multiple on-the-ground controls for each distributed network (e.g., air traffic control). Limited inter-mode communication

of fruit and vegetables being moved from their crop to the final consumer. Interestingly, peaks in this network are characterized not by increases in demand—which remain relatively constant, as most developed countries now expect all products to be available throughout the year thanks to mechanical refrigeration—but instead by variations in supply caused by different growing seasons. To overcome such seasonality, supplies are sourced from other regions having different climates where the relevant produce can be grown, or long-term cold-storage solutions are used as an alternative. As to the logistics of moving goods regardless of the distance involved, storage solutions are essential, with cold storage generally located close to both the source and end user, allowing smaller batches of goods to be distributed locally.

The **data network** has a variety of ways to manage peaks in demand, which occur reliably on a daily basis. YouTube, for instance, says it keeps duplicate pieces of content at multiple **data centers** for flexibility to stream required content from any location. By the same token, **data caches** are used to locally store frequently accessed data, precluding the need to download the data from scratch each time it is required. Other notable techniques that this network employs include **data compression**, a major area of investment in the industry, which seeks to reduce the amount of throughput capacity required to transmit the same piece of information; and data throttling, in which internet service providers intentionally limit the speeds at which end users can access data in order to control demand in specific areas at particular times.

> “Storage plays a critical role in satisfying incremental load during peak use periods. The highest load periods occur during the heating season, and storage withdrawals typically satisfy over 50% of the daily North American load during the highest demand days of the heating season.”
>
> – National Petroleum Council Transmission & Distribution Group Report

For the **gas network**, a key characteristic is its predominantly annual seasonality cycle. During peak months, this network is challenged with almost triple the demand of off-peak months. Given that supply from natural resources is relatively stable throughout the year and is not significantly ramped up or down to follow demand like that of a peaking plant in the electricity sector, large-scale storage solutions are key to ensuring reliability. In Europe, the gas system has enough storage to provide approximately 69 days of average daily usage, which is the equivalent to approximately four hours of storage for networks with daily cycles. Liquefied natural gas (LNG) is also stored in tanks, allowing easier transport and storage throughout the continent in much smaller volumes, before being injected into the network when required.

The **travel network** generally copes with rush hours by essentially increasing the number of seats in the system (i.e., having more trains, buses or cars running) or increasing roads over time in order to allow more people to complete their journeys. These peaks occur every day, although they are more predictable and pronounced on working days. While challenging to think of individuals as a commodity—for the purposes of this paper passengers are considered as the item being moved—the road and railways are deemed to be the physical infrastructure. In comparison, storage within the travel network is considered to be the seats within the system, as they offer a place where varying amounts of passengers can be held for a varying amount of time. The buildings themselves are another form of storage in the travel network as they house individuals during work and non-work hours, but in order to isolate the physical infrastructure, these forms of storage were not considered.

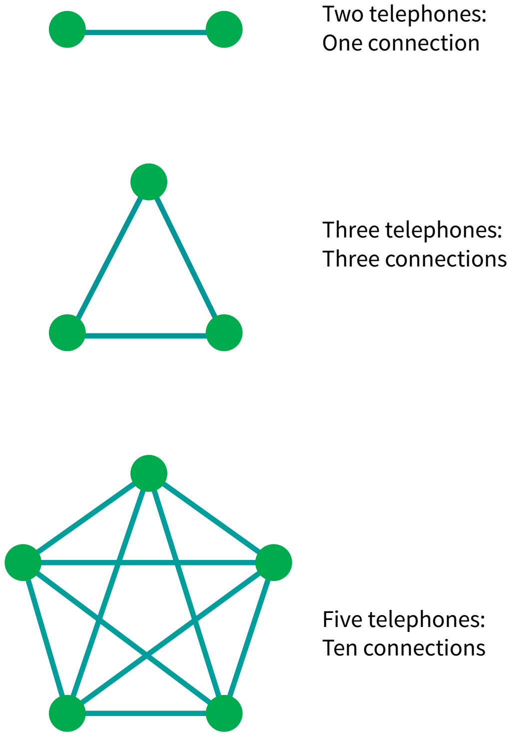
Given the low proportion of seats that are accessible at peaks times (as discussed earlier), increasing the number of accessible seats is important. Of particular interest here is the effect of ticketing. Modes of transport requiring customers to purchase tickets in advance, such as on particular train routes and air travel, typically enjoy average occupancy figures reaching 70% or more. However, “walk-on” services, such as those for regular trains and buses, typically see figures less than half in comparison. This suggests that the variable pricing typically employed that is based on availability of seats is an important way to increase seat occupancy in many instances, encouraging passengers to travel during those times when the network is less stretched. Such an approach has also been embraced by what is known as the new mobility services sector encompassing ride-sharing and ride-hailing, with operators like Uber resorting to surge pricing and applying premium rates to journeys taking place at the busiest times. The advent of autonomous vehicles including cars, now introduced by ride-hailing providers in certain places, also has the potential to considerably improve the occupancy of seats and utilization of the network.

The importance of being connected

Metcalfe's law (developed circa 1980) states that the value of a network grows proportionally to the square of the number of connected users. Although it was derived to apply to the telecommunications network, and then later for data networks, the fundamental principle holds broadly true: **that as networks grow in size, the value that they provide also grows at an exponential rate.** With that growth, the importance of the reliability of networks—as well as the impact resulting from their failure—grows as well.

Similar to the telecommunications network, increasing the number of connections or nodes in the electric grid will improve overall reliability, reduce the cost of operating the system, and raise the overall value of the underlying network. For example, system planners operate on a contingency planning principle, the most common being N-1, which means they have to design and operate the system to handle at least one major outage, by providing a back-up capable of replacing that loss. In a system with limited connections and large central power plants, this excess amount of standby power is significant, reaching over 1,000 MW in certain markets.

Metcalfe's Law



By ramping up the use of storage and distributed generation, the increased number of connections will not only transform the grid into a robust network but also will significantly reduce the cost of operations.

Storage technology improvements drive network changes

Technological improvements have enabled a complete transformation of many of our networks. The invention of mechanical refrigeration trucks in the 1940s, for instance, allowed produce and other perishable goods to reach markets well beyond where they were grown or produced. The World Trade Service estimates that last year alone, global containerized trade in refrigerated food amounted to some 7.3 million TEUs, or twenty-foot-equivalent units.

For its part, data storage technology has progressed so quickly that the cost and volume of a gigabyte of capacity—unthinkable several decades ago—is now almost insignificant. The result is abundant storage throughout the data network, conferring the ability to cope with extreme overall growth in demand driven partly by the increasing use of cloud storage and by the streaming of larger and higher-quality media, countering what would otherwise be a major threat to the reliability of a network.

Meanwhile, many new applications and use cases have emerged for data storage, with individuals and businesses increasingly demanding constant access to the network. A surge has also occurred in recent years in the number of devices connected to the data network, involving the almost constant exchange of data. This applies not just to smartphones embedded into daily life in developed countries, but also extends to internet-reliant services for cars, heating systems, and home appliances, as well as seemingly unrelated areas of activity like agriculture, in which livestock and crops could be connected to data networks in the future. Likewise, most media is now trending away from traditional broadcasting methods to streaming models over the internet, demonstrating persuasively that data networks must be readily equipped to cope with the dramatic increase in demand expected during the coming years.

Looking into these four networks, it becomes apparent that storage is the critical tool to ensuring that the networks are able to reliably meet both short-term and longer-term seasonal peaks cost-effectively. In contrast, the electricity network is far more reliant on adjusting supply in order to meet demand, which persistently follows a similar load curve each day.

In practice, this means that so-called flexible thermal power plants lay idle for the vast majority of the time, awaiting a signal to increase supply, thus contributing to significantly low overall utilization rates and a substantial cost to users of the grid. Moreover, the amount of electricity storage continues to be minimal, despite growing consideration toward using storage in the electricity network and increased scale in some recent battery projects. Even with the inclusion of pumped hydro—still the predominant form of storage in the electricity network, regardless of environmental and siting challenges—the United States has enough storage to provide power for only 20 minutes, a figure that drops to just 10 seconds if batteries alone were considered as the sole source of electricity storage.

Storage and digital communications as key to transforming networks

While storage is undoubtedly key to providing the flexibility that a network requires in order to operate efficiently and maintain high utilization levels, ample storage on its own is not a magical silver bullet that can transform a network. The travel network, for example, contains approximately four times as much storage—that is, seats—as it actually requires in a day, and the key to balancing the network lies in enabling users to access available idle storage. Thus, a digital communications network is equally important to ensuring that all assets within the network are used in the most efficient way. Supervisory control and data acquisition (SCADA) as well as smart technologies provide this communications network for the electric power system.

Following the example of how ticketed journeys enjoy higher passenger levels, the recent upsurge in ride-hailing and ride-sharing services bodes well for the overall travel network, as it means both seat occupancy and network utilization levels are set to improve. These new mobility services rely on smartphone applications to connect people needing to travel with empty seats in the system, with a variable or surge-pricing methodology applied to encourage as many passengers as possible to shift to off-peak periods.

Methods of managing peak demand

		Economic pricing	**“Local” storage**	**Reducing total usage**	**Cutting peak usage**
Network	**Electricity**	🟦 **Time-of-use pricing**	**Pumped hydro & battery-based energy storage**	**Energy efficiency**	**Demand-side management** (utility controlled)
	Perishable goods	**Variable pricing -** Premium for out-of-season	🟦 **Cold storage**	**Fuel efficiency, fleet management, route optimization**	
	Data	**Speed tiers -** Customers pay more for faster connections	🟦 **Local data caching**	**Data compression**	**Internet speeds ‘throttled’**
	Gas		🟦 **Gas fields & LNG**	**Efficient appliances & efficient gas plants**	**Eliminate inefficient “peaking” plants**
	Travel	**‘Surge pricing’** in new mobility services, congestion charging/tolls	🟦 **Individual private & extra public seats**	**Mode shift** (e.g., walking/biking)	

🟦 Most significant methods

Less significant methods

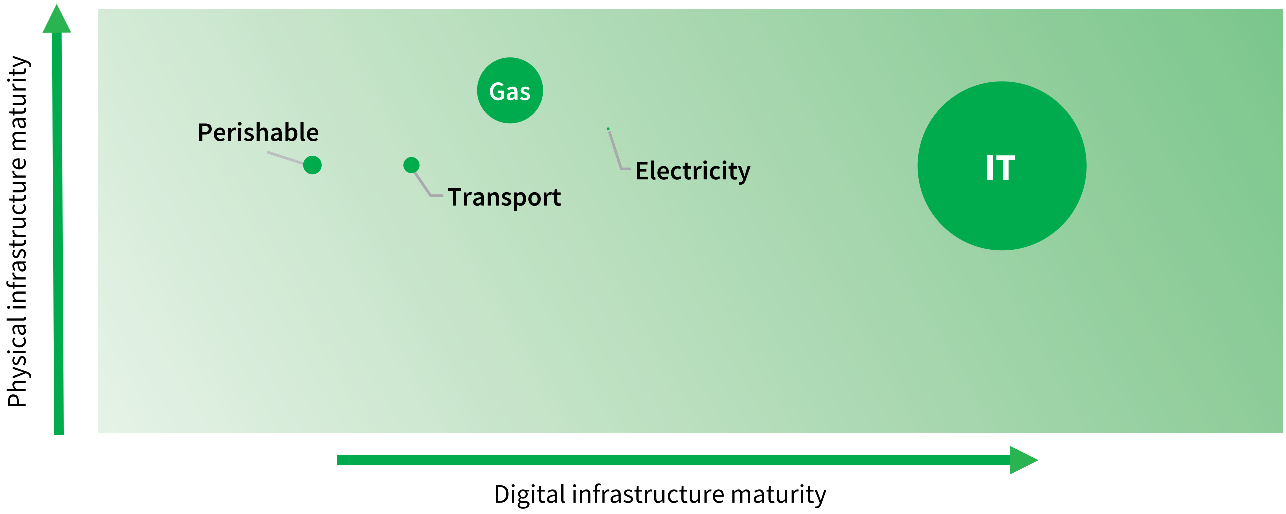
Recent IHS Markit analysis of the automotive sector included in the "Reinventing the Wheel" project notes the impact of such services in the United States on the use of vehicles, with base-case forecasts for vehicle miles traveled (or miles traveled per vehicle per year) increasing significantly, up 4% by 2030, and up nearly 20% by 2040. This suggests that each vehicle will be performing a greater number of trips, and when paired with higher levels of seat occupancy, will help drive greater utilization of the travel network.

In some cases, the information available from greater digital connectivity in the travel network has also begun to enable a mode shift, with users making more informed, intelligent decisions on when and how to use the network to travel. For example, applications such as Google Maps have already begun to offer users a range of information on travel options, including alternative routes, costs, and different forms of transport, based on the latest real-time data collected constantly from their many users and transport agencies. A passenger can assess information on road traffic, current pricing of ride-hailing services, and public transport options available, before making a decision. This should help lead to greater occupancy of seats in places where levels would otherwise be low, helping to increase utilization of the overall system.

In addition to storage and a developed digital infrastructure, a network will also require adequate physical infrastructure. Although ongoing maintenance and certain upgrades will be needed as a rule to ensure the network's ability to function, the availability of sufficient storage and the flexibility that it affords may reduce such needs. The physical infrastructure of the five networks analyzed here is relatively mature, and the mechanical means of moving items from one location to another are already in place. It is true that in the future the electricity grid will be expanded to cover new areas of the world, and with data transmission lines to be expanded and extended, but the systems in place today are generally adequate. Where networks are expanded to include new areas of the world, in less developed regions for example, the opportunity to build from the ground up may allow the latest technologies to be used well, such as for new rural electrification programs to rely more heavily on storage and renewable generation.

In comparing the maturity of the physical and digital infrastructure as well as the volumes of storage available for each network, it becomes clear that the real variation between each network is the amount of available storage and the maturity of the digital infrastructure, which should be addressed in order

Comparison of physical infrastructure, digital infrastructure, and storage volumes by network



Storage volumes are calculated as installed storage capacity divided by average daily demand. Gas = 69 days, based on installed storage capacity and annual demand in Europe in 2015. Electricity = 20 minutes, based on installed storage capacity and annual demand in North America in 2015. Perishable goods = 5-7 days, based on an estimate for required capacity according to typical lifespans of perishable goods. Transport = 4 days, based on number of seats and typical daily usage in New York City. IT = >100 years, based on installed global data centre capacity and typical daily global data usage. 'Maturity' scores are estimates based on an assessment of each network. A high score for maturity implies that the infrastructure is well developed, using the most up-to-date and relevant technology, with little room for improvement under today's technology landscape.

to increase the overall utilization or efficiency. For example, the transport system has ample storage, but the application of digital connectivity to enable seats to be more effectively used has only begun in recent years. Conversely, the electricity network has a reasonably developed digital infrastructure with remote signaling, control, and the monitoring of assets already a reality, but with the network itself encumbered by minimal storage. Adding increasing volumes of storage will facilitate an overall increase in system utilization.

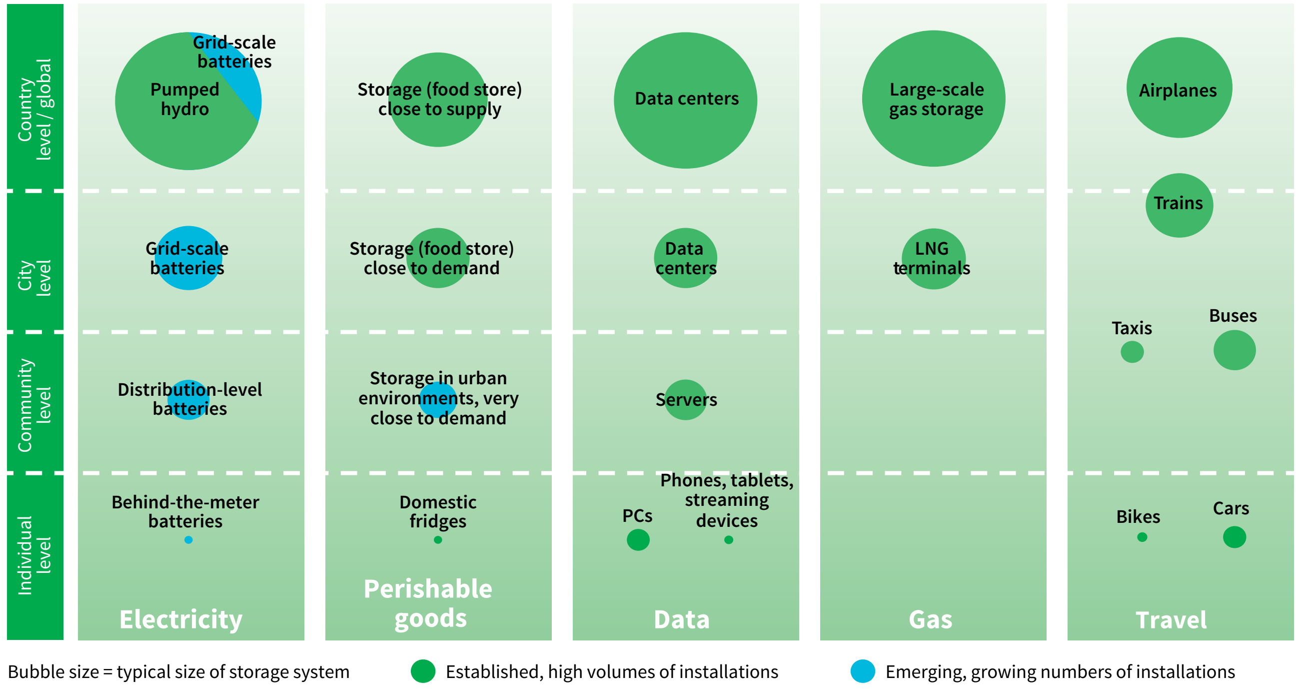
Equally interesting, however, is the question of where storage is installed in each network. While the use of storage in a wider variety of locations is emerging in other networks, the data network has the highest penetration, with high volumes of installations both located far from the end user (in data centers) and also situated close to the end user (in PCs, mobile devices). On the one hand, data centers enable mass central storage that can be accessed from all around the world, and even offer the possibility of duplicate data being stored in multiple places in order to increase reliability and allow flexibility as to where the required data is to be accessed. On the other hand, the smaller storage used in consumer devices allows greater flexibility in storing data locally to reduce the need for the constant exchange of data and bandwidth usage, or even makes it possible to go offline—similar to how batteries in residential and commercial buildings provide emergency back-up or enable people to temporarily disconnect or even go “off-grid.”

Technology and business model trends that accelerate transformation

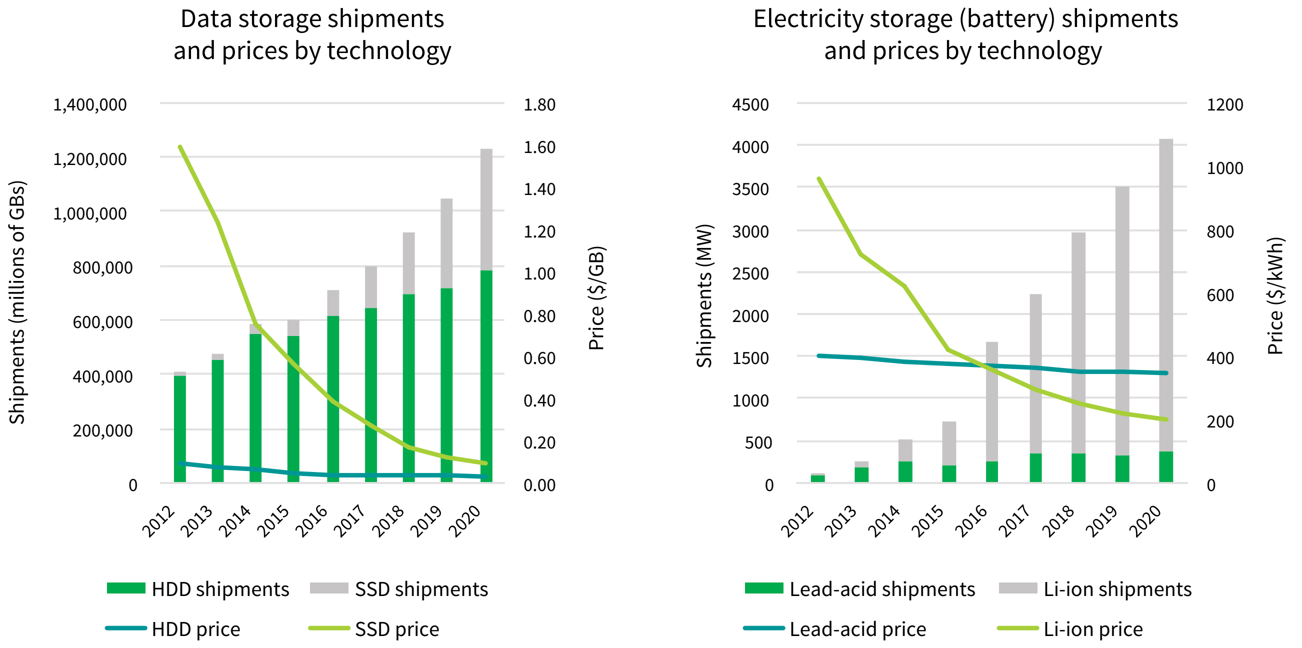
In the same way that distributed storage within the electricity network has largely been made viable by huge cost reductions in battery technology, dramatic improvements in data storage technology have enabled the build-out of one of our most sophisticated, far-reaching, and integrated networks.

The introduction of solid-state storage on a commercial scale, as well as the corresponding dive in its cost, has enabled storage to be embedded into a huge range of portable devices, at the same time beginning to displace conventional hard drives in more established applications, such as personal computers, servers, and data centers.

Location and size of storage systems by network



Comparison of data storage and electricity storage shipments and prices



Source: IHS Markit Energy Storage Intelligence Service, Mobile and Embedded Memory Intelligence Service, SSD and HDD Intelligence Service

The similarity to the story of lithium-ion batteries being introduced to the electricity network and competing with established lead-acid technology is striking, right down to the characteristics that define their value proposition. Both offer a faster-reacting, more efficient, higher-density product—amounting to more kilowatt-hours or megabytes per cubic meter—that is also capable of a greater number of cycles within its lifetime.

The electricity network of the future

The electric grid, designed originally as a one-directional “push” network, faces significant challenges as it moves to a bidirectional network with variations in both supply and demand. It is clear that for networks to not only address these challenges but also to maintain resiliency, efficiency, and universal access, they need greater flexibility. The incorporation of a comprehensive communications infrastructure and a sufficient amount of energy storage will ease this transition to the electric grid.

Considering the fluctuations in demand and generation that it must accommodate, the electricity grid currently includes an alarmingly small volume of storage, amounting to approximately 20 minutes’ worth of demand. It is extremely likely that this value will mirror that of other networks to become several days’ worth of storage, or even months or years in the case of gas and data.

One clear example for the electricity grid to follow is the data network, which has quickly become one of our most developed networks and is now central to everyday life, connecting almost everyone and everything, everywhere. As the cost of electricity storage follows a similar path to that of data storage, it will enable electricity storage to be embedded throughout the network in similar ways. Large-scale battery storage will offer flexibility and enable more efficient use of a leaner generation base, also allowing a greater contribution from new clean technologies such as renewables. More distributed storage solutions will likewise play an important role in offering end users greater flexibility in how they produce and use electricity, with the addition of advanced digital communications allowing this distributed storage to be collectively operated and to play a much greater role in the operation of the entire network.

Examples of this model are already visible in the travel network, which enjoys abundant storage distributed throughout the network but is also characterized by a physical infrastructure that is underutilized much of the time. Here, the growth of digital connectivity and real-time data analytics is beginning to make important improvements to the overall utilization of the system, by enabling users to make smarter choices around when and how to travel; and through the action of operators in their introduction of reactive pricing, such as "surge pricing," to further encourage better system utilization.

In the same way that more applications have become reliant on the data network, electricity will also grow in demand. While the pace of the change is subject to debate, transport will be increasingly electrified, and regions with limited or no access to electricity will begin to be connected. There is even potential for electricity to play a growing role in heating applications. Undoubtedly, renewables will generate more and more of the world's electricity as their cost continues to fall. The flexibility and reliability afforded by storage embedded throughout the system will be critical to enabling this transformation.

Ultimately, the networks that we have discussed will become seamlessly interconnected and increasingly integrated into our everyday lives, with data, travel, and electricity all intersecting. Electricity will be at the very center of this increasingly connected world, playing a critical role that demands a network that is far-reaching, flexible, and always available—a transformation possible only if accompanied by the significant implementation of storage.

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