Guidehouse

# From Smart Grid to Neural Grid

## Industry Transformation and the Top Five Technologies Poised to Bring the Grid into the Cloud

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# From Smart Grid to Neural Grid

**Industry Transformation and the Top Five Technologies Poised to Bring the Grid into the Cloud**

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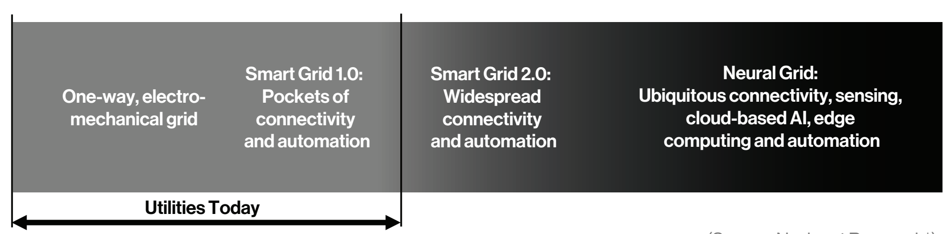
## 1. Introduction

### 1.1 Neural Grid Takes Smart Grid into the Cloud

The Neural Grid represents more than Smart Grid v2.0—much more. Today, the smart grid implies the legacy mechanical power transmission and distribution (T&D) networks enhanced by pockets of automation, connectivity, and centralized IT systems. The Neural Grid implies a vastly more powerful platform of hard and soft assets leveraging ubiquitous connectivity, the cloud, robotics, artificial intelligence (AI), edge computing, and pervasive sensing to perform a variety of energy and non-energy applications. It is the end game for grid modernization, transforming legacy infrastructure into a platform that will support a fully mature Energy Cloud[1] environment.

**Figure 1.1 Grid Transformation Is Underway**




(Source: Navigant Research*)

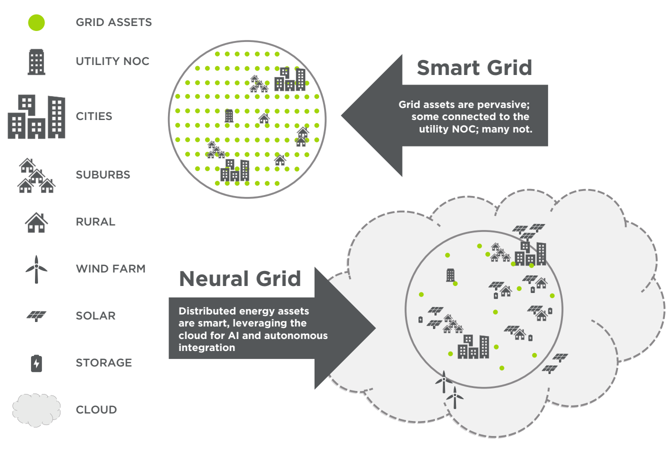
In the Neural Grid, data and intelligence reside largely in the cloud, managing the intersection of generation assets and distribution networks with energy customers, buildings, transportation infrastructure, city systems, and distributed energy resources (DER) assets (solar, wind, microgrids, EVs, demand response programs, etc.). Asset ownership is diverse and utility grid data and assets work with third-party data and assets to coordinate energy supply and demand.

In a nutshell, the Neural Grid takes the world's largest machine—the grid—and gives it a brain. It replaces dumb network assets (poles and wires) with intelligent, multifunction infrastructure that interacts with cloud-based intelligence for energy and non-energy purposes.

1. Navigant Research, Navigating the Energy Transformation, 2016.

*Navigant Research is now Guidehouse Insights (April 2020). Guidehouse LLP completed its acquisition of Navigant Consulting Inc. and its operating subsidiaries on October 11, 2019. https://guidehouse.com/news/corporate-news/2019/guidehouse-completes-acquisition-of-navigant

**Figure 1.2 Smart Grid vs. Neural Grid**




(Source: Navigant Research)

Imagine, for example, if poles in the distribution grid integrate small cells for 5G networks, enabling ubiquitous low latency, broadband communications throughout the network. This then makes possible a multitude of new applications and revenue streams for asset owners. In the Neural Grid, a reconfiguration of distribution grid assets enables new network functions and eliminates assets rendered obsolete by widespread distributed solar, community microgrids, or virtual power plants (VPPs).

The Neural Grid enables deep customer involvement and choice and sets the stage for premium services and pricing. Both energy and non-energy tied service offerings will be offered by a variety of actors in the ecosystem that leverage their access to customer and market data.

Utilities, but also third parties such as telcos, tech giants, DER service and product vendors, and new startups, will maneuver to grab market share. Meanwhile, residential and commercial end users will also participate. Those with their own generation capabilities will be enabled to provide energy or other micro services, much as Uber and Airbnb have enabled new revenue streams to individuals with cars or a spare bedroom.

As the Neural Grid evolves, the incumbent status of utilities does not guarantee them a dominant role. The unidirectional value chain that serves a captive audience in the utility model of today will be replaced by a multidirectional Neural Grid platform that allows a wide diversity of market participants and asset owners to benefit. The Neural Grid platform has the potential to empower utilities as the Energy Cloud paradigm, described in Section 2.1, emerges. Those that ignore these longer-term trends, however, risk marginalization.

## 1.2 Neural Grid Growth Markets for Today and Tomorrow

Navigant Research forecasts indicate that DER such as solar and energy storage, but also microgrids, VPPs, and more, could provide enough energy capacity to meet global demand by 2035. Theoretically, when this point is reached—if not in 2035, then in 2040 or 2045—the legacy grid will no longer be necessary.

In practice, the evolution of the market and changes to energy infrastructure will be lumpy, with some regions taking technology to its limits early while others remain dependent upon a certain level of legacy infrastructure for decades to come. In Hawaii, Guidehouse expects the combination of solar and storage to reach parity with utility power prices within the next few years. In most markets, this parity may be much further off—but the day will come.

The challenge for owners of legacy infrastructure in the interim will be to upgrade their networks with dynamic, intelligent, and autonomous features that enable more than the transport of electrons. The Neural Grid platform must support an open environment for new services creation; these services may be the only way in which utilities can safeguard the stickiness of their customer base in the long run.

The International Energy Agency (IEA) currently projects investments in T&D grids over the 2012-2035 timeframe to be $7.2 trillion, 40% for replacement of existing infrastructure and 60% to build new infrastructure. If even a third of that new infrastructure will not be needed within 20 years, nearly $1.4 trillion is freed up for investment in infrastructure and capabilities that help transition the smart grid efforts of today to the Neural Grid platform of tomorrow. This is a significant number, and the opportunities it could support will also be significant.

This white paper defines the Neural Grid and identifies critical components of the ecosystem. It describes the conditions necessary for accelerated market expansion and highlights informative parallels which can be found in the mobile industry. It also identifies the top five growth markets that stand to benefit as the smart grid investments of today transform into the Neural Grid market of the future.

### 1.2.1 Neural Grid Enabling Technologies

Guidehouse has identified the following five technology segments as offering sound investment opportunities today and even greater upside in the longer term:

- **Connectivity:** Fiber, low power wide area (LPWA) technologies, and licensed spectrum solutions (i.e., private 4G, 5G) will be imperative to formation of the Neural Grid. In the meantime, existing connectivity solutions support smart grid deployments occurring today. Connectivity to the billions of grid and energy assets worldwide will present a large and growing market opportunity for decades, although the purpose of that connectivity—and favored networking technologies—will evolve.
- **Sensing and measurement technologies:** Low cost sensors integrated into virtually every element of grid and energy infrastructure will provide the data that allows for analytics and AI to manage every layer of the Neural Grid.
- **Drones and cloud robotics:** When unmanned drones and robots are able to learn via vast stores of data in the cloud and interact seamlessly with humans thanks to natural language processing, they will be able to perform repetitious maintenance and monitoring tasks. They will also have the intelligence to tackle new problems, reduce human error, and keep people safe.
- **AI:** AI takes analytics and the cloud's ability to store a virtually unlimited arsenal of information, images, and more to allow for machine learning and intelligent automation. Ultimately, cloud-based AI is the brain in the Neural Grid.
- **Cybersecurity:** Ubiquitous connectivity and data collection heighten the already clear need for vigilance with data security for customers, systems, assets, etc. As the Neural Grid forms, widespread, holistic cybersecurity solutions will be critical.

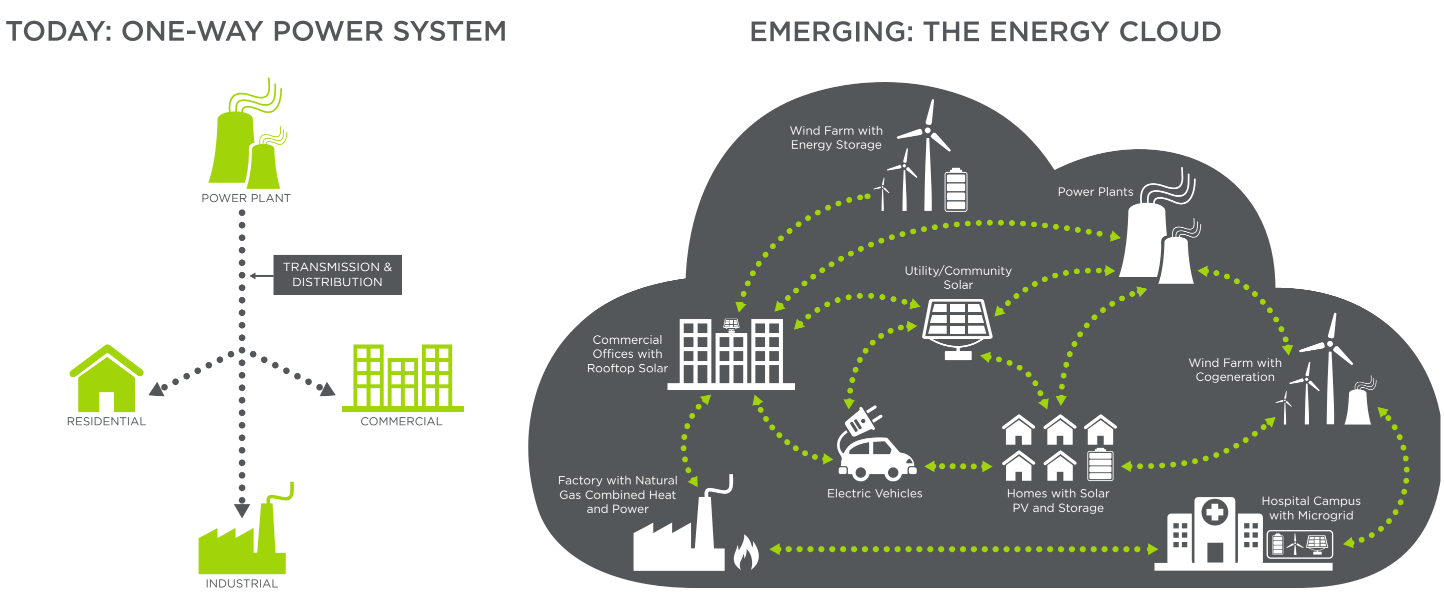
Each of these technology areas are rich with opportunities for market growth in the near term as first-generation smart grids deploy. These five segments are poised for accelerated (hockey stick) market expansion as the Neural Grid platform comes to be.

## 2. The Neural Grid and the Energy Cloud

### 2.1 The Energy Cloud

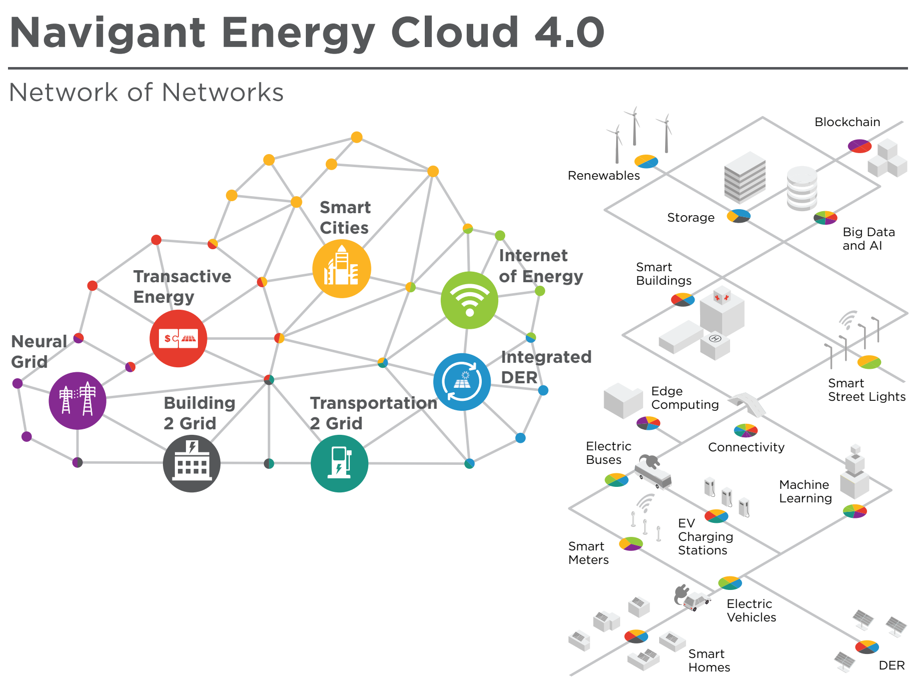
The Neural Grid is one of several platforms identified by Guidehouse as underpinning the Energy Cloud, which in turn defines a highly distributed, networked, and dynamic energy environment. In the Energy Cloud, multiple interrelated platforms connect end users to a diverse set of products and services, with grid-sourced power provision just one of several value streams.

**Figure 2.1 The Emerging Energy Cloud**



The Energy Cloud is already forming, fueled by technological advancement, falling costs, changes in customer demand, and regulatory shifts. Between $1 trillion and $2 trillion in new revenue opportunities will be created in the Energy Cloud by 2030, according to Guidehouse estimates. These transactions will flow through multiple overlapping customer-oriented growth platforms such as integrated distributed energy resources (iDER), building-to-grid (B2G), transportation-to-grid (T2G), the Internet of Energy (IoE), transactive energy (TE), smart cities, and Neural Grids.

**Figure 2.2 Energy Cloud Platforms**






The trend toward platforms goes beyond the energy industry. Enabled by a new era of digitization across the global economy, emerging platforms are replacing linear value chains in which successive value is added to core raw materials before distribution to the end consumer. Upstart companies and customers now have greater access to alternative solutions that may compete on efficiency, price, customization, or any combination thereof.

In this shifting landscape, volumetric sales—number of goods sold, units shipped, kilowatt-hours—face unprecedented competition. When emerging technologies or platforms combine, so-called second and third order effects emerge, which enlarge the potential value pool further.

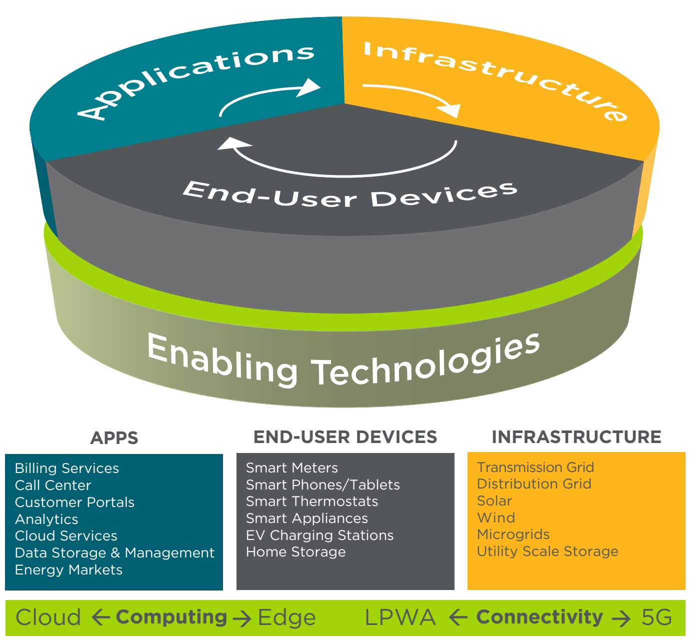
Today's most profitable organizations are no longer so much a collection of resources and capabilities as a set of platforms. Value is increasingly created through stickiness of a platform rather than differentiated products. Actors may play one or several roles across platforms, but those actors that control the platform have greater opportunities to scale their business rapidly and will have more success insulating themselves from competition.

## 2.2 Neural Grid Platform Components

As described in Section 1, Guidehouse defines the Neural Grid platform as an autonomous grid leveraging artificial intelligence (AI), connectivity, cloud robotics, and sensing technologies across grid and non-grid energy assets. The Neural Grid supports ubiquitous automation, self-healing, seamless DER integration, customer engagement and involvement, and ultimately, the integration of dispersed markets for TE.[2]

The Neural Grid ecosystem can be thought of in terms of both emerging and evolving technologies, products, and services that can be grouped into four component categories: infrastructure, end-user devices, and applications and services, all of which are layered on top of enabling technologies. This representation of the Neural Grid ecosystem and some examples of category components (not exhaustive) are illustrated in Figure 2.3. Further description of each category follows.

**Figure 2.3 Neural Grid Platform Components**




(Source: Navigant Research)

- **Enabling technologies:** Computing and connectivity enable the Neural Grid. The rise of powerful, affordable computing—from tiny distributed devices to the cloud—combined with a wide range of connectivity options, also increasingly affordable, are powering massive transformation across all industrial verticals. In the coming decade, 5G networks in particular will provide a powerful backbone for Neural Grid applications.
- **Infrastructure:** In the energy sector, enabling technologies have given rise to Smart Grid 1.0 applications for grid infrastructure such as smart metering and real-time monitoring and management of transmission and distribution (T&D) substations or solar and wind farms. Going forward, smart, multifunction infrastructure replaces the electromechanical devices of the past with assets that gather and process data and share it in the cloud for a multitude of use cases, in addition to performing their legacy functions. Smart infrastructure combines previously separate assets into more efficient, multipurpose forms, such as utility poles, which provide multifunctionality like lighting, communications cells, or digital display technologies.

  Smart infrastructure, combined with other Neural Grid platform elements and seamlessly integrated DER will ease the path to going off-grid. They will also enable new applications and services that leverage their geographic pervasiveness, established rights of way, and the massive amount of data collected by each asset.
- **End-user devices:** End users will have a growing number of touchpoints—devices or interfaces—they use to interact with their energy usage, services, and providers. These smart end-user devices will include smart meters, appliances, EV charging infrastructure, smartphones, and more.
- **Applications and services:** Standards and the ubiquity of smart infrastructure and elegant, plug-and-play end-user devices will give rise to a plethora of applications and services—both energy and non-energy related and designed for both consumers and enterprises.

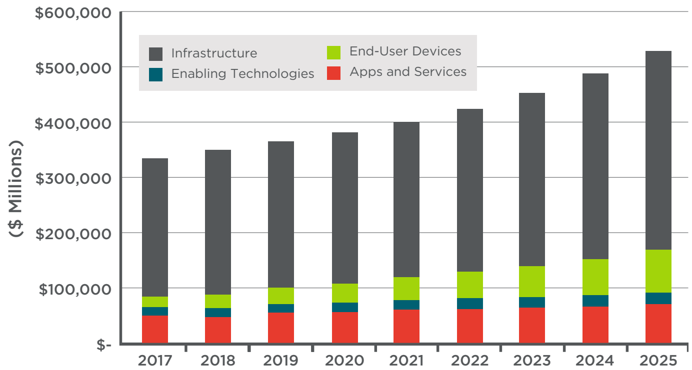
The interplay of smart infrastructure, end-user devices, and applications and services, all of which arise on the back of next-generation computing and connectivity technologies, is what takes the smart grid of today into the Neural Grid future. It will be adaptive—in real time—and leverage AI in the cloud to perform not only the functions of today's electric utility, but also many, many more.

### 2.2.1 Neural Grid Markets Represent a $3.8 Trillion Opportunity—in the Near Term

Guidehouse estimates that products, services, and technologies identified in the Neural Grid ecosystem will see their annual revenue grow by nearly 6% annually through 2025 to more than half a trillion dollars. On a cumulative basis, that is a nearly $4 trillion opportunity—and it does not include apps or technologies that have not matured enough yet to measure. It also does not show the market acceleration expected post-2025.

2. Navigant, Navigating the Energy Transformation, 2016.

**Chart 2.1 Neural Grid Ecosystem Revenue by Category, World Markets: 2017-2025**




(Source: Navigant Research)

Included in this analysis are the following products and services depicted in Table 2.1 for which Guidehouse has developed market forecasts.

**Table 2.1 Neural Grid Ecosystem Market Components: 2017**

| ENABLING TECHNOLOGIES | INFRASTRUCTURE | END-USER DEVICES | APPS AND SERVICES |
|---|---|---|---|
| Connectivity | Distribution System Upgrades | Smart Meters | Billing |
| Cybersecurity | Transmission System Upgrades | Smart Thermostats | Web |
| Data Storage and Management | Supergrids | Smart Appliances | Outage Solutions |
| | Drones and Robotics | EV Chargers | Call Center |
| | Solar | Home Energy Storage | IT Systems |
| | Wind | Smart Solar Inverters | Analytics |
| | Microgrids | | |
| | Utility-Scale Storage | | |

(Source: Navigant Research)

But the real market expansion—the hockey stick growth curve—comes after 2025 and includes devices, applications and services, and smart infrastructure that are either very early stage or have not yet even been invented.

In an upward spiral of innovation, the proliferation of smart infrastructure and additional end-user devices increases the utility and variety of applications and services. These, in turn, will increase demand for more/smarter infrastructure and new end-user devices.

A similar upward spiral has taken place in the mobile industry over the last decade. The perfect storm that arose in the mobile vertical, described in more detail below, has not yet formed in the energy space—but it will.

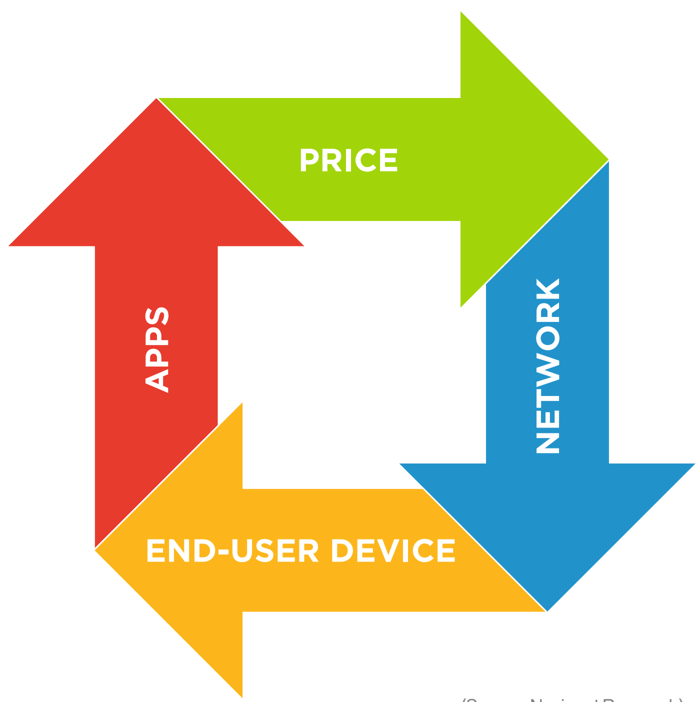
## 2.3 The Perfect Storm for Mobile Platform Expansion

Given society's collective dependence upon smartphones today, it can be easy to forget that the current wireless device, with a plethora of capabilities and applications and data, is less than a decade old. As cellular telephone usage grew in the late 1990s, no one could have foreseen the massive expansion that was to come. The mobile platform replaced watches, books, credit cards, gaming devices, PCs, and so much more—not to mention plain old telephone service (POTS).

There were many who predicted the rise of the mobile data industry. Investors, engineers, and entrepreneurs started companies and gave talks at conferences throughout the nineties; it was, for at least a decade, a "zero billion dollar" business, as one industry analyst called it. Many of those investors and entrepreneurs failed miserably—they were too early to market with ideas dependent upon technology that was not yet mature.

Around 10 years ago, however, a perfect storm of technology, pricing, and market conditions began forming, which ultimately resulted in the nearly tenfold growth of mobile industry revenue that has occurred since 1997. The four key factors in that perfect storm were price, network, end-user devices, and applications.

**Figure 2.4 The Perfect Storm for Mobile Platform Expansion**




(Source: Navigant Research)

- **Price:** It was considered revolutionary when AT&T boldly did away with roaming and long-distance fees in 1998. However, counterintuitively, average monthly revenue per user for cellular service began to climb after this point, following years of declines, despite the lower prices. Monthly service plans got cheaper on a per minute basis and, as the carriers consolidated and the Federal Communications Commission (FCC) opened more spectrum over the next decade, network operators were eventually able to offer unlimited voice and data plans. These plans prompted their subscribers to spend double or triple the $40/month they had been spending. And this trend ultimately led to the cut-the-cord landline replacement trend that has eviscerated legacy telephone companies.
- **Network infrastructure:** It has been just 7 years since Verizon launched the first 4G LTE network in the US, bringing to market data speeds that truly supported applications like music and video streaming on phones. Wireless data was already growing on the 3G network, as texting, email, and web browsing grew in popularity, but it was the widespread availability of 4G data speeds that really catalyzed today's all-day-all-night smartphone fixation. Data usage has grown 3500% since 2010 and, in 2017, it was nearly double that of 2016.
- **End-user device:** The release of the first-generation iPhone in 2007 was truly a transformative event in the evolution of the mobile platform. Steve Jobs nailed it with a sleek, elegant interface and user experience that virtually every handset manufacturer has been emulating since.
- **Open application development:** Along with the iPhone came the App Store. The iPhone was great on day one, but its greatness grew exponentially as an amazing variety of applications, games, and other tools were created for the platform. There are 3.5 million apps available today, up from a few thousand in 2010, and app revenue worldwide is more than $50 billion.

Today, there are nearly 8 billion mobile devices in use worldwide—more than one for every human on the planet. In contrast, in 1997, penetration in the US was just 20%. In Western Europe, between 10% and 15% of people had a wireless device, while in other global regions, penetration was in the low single digits. Notably, penetration in 2017 far exceeded 100% in many developing regions of the world, and electrification in rural villages is often driven first and foremost by the demand for phone charging.

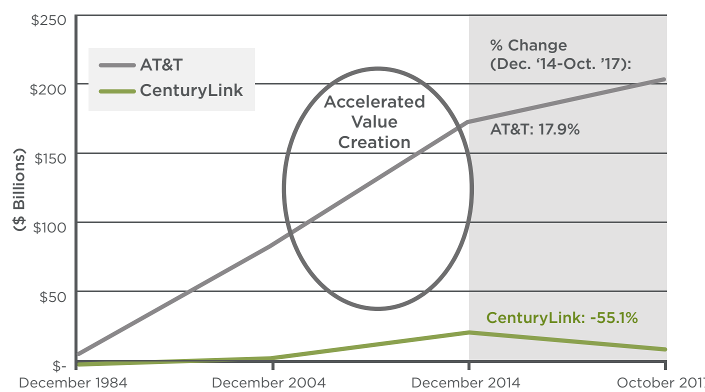
A substantial portion of that massive market expansion has occurred over just the last 10 years. This is even more notable considering that the largest global recession since the Great Depression occurred within this timeframe. The network infrastructure, end-user devices, and open application environment that prompted that massive mobile market expansion can be mapped directly to infrastructure, end-user devices, and applications and services in the Neural Grid ecosystem. As technology advances and prices fall, a similar explosion in market size and participation is poised to unfold.

### 2.3.1 A Perfect Storm Accelerates Tangible Value Creation

AT&T, along with Verizon in the US and many other telecoms' concerns worldwide, embraced wireless technology over the legacy wireline voice business. As Figure 2.5 shows, it has seen its value grow exponentially over the past 30+ years, particularly during the period in which the mobile phone revolution described above occurred. AT&T continues to seek growth opportunities, expanding its fiber footprint and adding media content via its DirecTV and pending Time Warner acquisitions.

Over the past 3 years, AT&T's public value has grown by 18%. In sharp contrast, CenturyLink, which divested its wireless operation in 2001 and opted to consolidate legacy landline telephone operators, has lost more than half its value since late 2014.

**Figure 2.5 Public Market Cap: Wireless vs. Wireline**




(Source: Navigant Research)

On announcing its intention to sell its wireless business, CenturyTel, as it was known in 2001, said: "While the wireless business continues to produce strong results, CenturyTel believes that attractive acquisition alternatives are developing in the wireline sector that could drive strong growth." As described more fully below, CenturyTel bet on the wrong horse. Electric utilities today that think that consolidation of legacy operations is their strongest bet for growth would do well to remember what has happened to the regulated monopoly telephone business over the past 20 years.

### 2.3.2 The Cellco/Telco Analogy—When, Not If

There are many in the electric power industry today who insist that while cellular service was a natural replacement technology for POTS, the electric power grid—and its utility owners—will remain indispensable, due largely to the intermittent nature of the most common sources of distributed generation (i.e., solar and wind). They argue that the grid will remain necessary, not only as backup to these intermittent sources, but also for continued movement of power from generation source to the site of consumption. Telcos, too, thought that their infrastructure and services would remain relevant for decades to come.

In fact, well into the 2000s, landline telephone companies, particularly those in rural markets, were confident that a combination of poor coverage and cellular's propensity to go out during major storms or other crises, or for the network to be overloaded (again during major crises), would ensure that their customers, for the most part, maintained their tried and true landline connection.

When Verizon began selling off major chunks of its landline business to private equity concerns and consolidators such as FairPoint Communications in the mid-2000s, deal values indicated a widely held belief that these were healthy, cash-generating machines with an attractive, sustainable (regulated) business model. Just a few years later, however, it became clear that the regulated telco business model was not a low risk opportunity.

Hawaiian Telcom, formed when Verizon sold its Hawaiian landline assets to private equity concern Carlyle Group in 2005, filed for bankruptcy protection in late 2008. FairPoint Communications, which acquired a large chunk of Verizon telco assets across New England in 2007, filed for Chapter 11 in late 2009, costing Verizon shareholders more than $1 billion of their original equity proceeds. FairPoint was in turn acquired by Consolidated Communications in late 2016; Consolidated's share price subsequently fell 23% through October 2017.

The decade-long telco consolidation trend arguably culminated with CenturyLink's $22 billion buy of Qwest, announced in April of 2010. Ironically, that is the same month and year in which Verizon launched the first 4G LTE network in the US.

A lot of smart people firmly believed in the wisdom of acquiring these old school, cash- and dividend-generating businesses. But, as noted earlier, CenturyLink's share price has fallen by more than half over the past 3 years. In 2016, AT&T, which did not divest its landline assets as aggressively as Verizon did over the last decade, asked California regulators to lift its requirement to provide a copper-based landline network at all. AT&T asserted that wireless and voice over internet services do the job better and more cost-effectively. The landline telephone business is slowly—but irreversibly—going the way of the buggy whip.

So, does the grid, as many power industry participants have argued, rise above this analogy? Will its relevance and necessity persist even as emerging technologies such as low cost solar panels, smart solar inverters, affordable home energy storage, community microgrids, and virtual power plants (VPPs) become a reality?

The answer is no, and anecdotal evidence suggests that the shift in mindset has already begun. For example, in October 2017, following the devastation of the Puerto Rican power grid as a result of Hurricane Maria, CEO Elon Musk stated that Tesla would be able to restore power to the island with a combination of solar and battery systems. He noted, "The Tesla team has done this for many smaller islands around the world, but there is no scalability limit, so it can be done for Puerto Rico too." The likelihood of an island wide project remains low and would require involvement of Puerto Rican government and regulators. Wholesale replacement of the grid in a non-island setting is no doubt many years on the horizon.

But as demonstrated above, the right combination of technical maturity, affordability, and demonstrable benefit of a new platform versus an old one can lead to an acceleration of adoption that turns conventional thinking on its head. Smart infrastructure will be deployed at the grid edge or where it can be used to connect utility-scale solar and wind farms to end users. But as these distributed assets proliferate, the need for dumb poles and wires everywhere will decline.

When—not if—that day comes in the electric power industry, utilities and distribution system operators will be forced to find ways to make end users—both consumer and enterprise—see greater value in remaining tied to the grid than in leaving. Without this added value, the traditional utility risks being marginalized. Plans for how to deliver that added value—likely in the form of services that leverage customer and other types of data that smart grid assets will collect—should be on the drawing board today.

There is an opportunity for incumbent utilities to leverage emerging technologies and, with their vendor partners, create a perfect storm of market expansion and value creation by building the Neural Grid platform. There is, however, considerable risk that third parties will enter the market, bypassing utilities and grabbing market share, influence, and value. Either way, it is 1997 in terms of maturity in the Neural Grid ecosystem and a tenfold—or better—increase in market value is up for grabs.

# 3. From Smart Grid to Neural Grid: Top Five Growth Technologies

## 3.1 High Growth Now, Higher Growth Later

Section 1 describes the Neural Grid and how it takes the smart grid efforts and investments being made by utilities today to their logical conclusion. That is, ubiquitous connectivity, the cloud, AI, and robotics will enable a platform that will support far more than the transport of energy.

Section 2 describes the convergence of low price, elegant user devices, fast networks, and diverse applications that catapulted the wireless industry from a growing voice and text communications business to a massive, broad-based mobile platform/ecosystem. This ecosystem supports individuals, companies, and governments with a cornucopia of communications and non-communications applications for business, social, entertainment, financial, and other purposes.

Four categories of products or services that can be found in the Neural Grid ecosystem have been identified: infrastructure, end-user devices, apps and services, and enabling technologies. Each category mirrors, in many ways, the key factors that led to platform expansion in the mobile examples described.

Guidehouse has also described how the lack of foresight shown by legacy wireline telephone operators has led to substantial value destruction. Electric utilities without very forward-thinking strategies will not only miss their opportunity to participate in the market expansion anticipated in the Neural Grid, but could ultimately suffer a fate similar to those telcos that bet on the legacy wireline business.

In the following sections, five key technology segments are identified. Each will offer measurable and growing opportunities in today's smart grid paradigm and evolve and increase in importance as the Neural Grid emerges.

### 3.1.1 Connectivity

Connectivity is a broad term that encompasses technology choices, chipsets, transport mediums (e.g., fiber), and spectrum for wireless communications. A wide array of technologies has been used for first-generation smart grid applications. As the smart grid of today evolves toward the Neural Grid platform, newer technologies are likely to replace some that have been widely used in the past.

#### 3.1.1.1 Connectivity Today: Smart Grid

Utilities have been connecting grid assets to their operations centers for decades. In the 1960s, it became common for transmission-level substations to be connected to network operations centers for SCADA purposes, often over phone lines. More recently, that connectivity is being upgraded, in many cases to fiber, and extended to distribution-level substations. Public cellular networks are often used for backup at more critical sites and other, usually unlicensed, wireless solutions are widely popular for smart meter networks, as is power line communications (PLC) technology. Grid edge monitoring of feeder assets is also increasingly done with either public cellular or private wireless solutions. Purveyors of low power wide area (LPWA) wireless solutions are promoting their equipment and services for widespread asset monitoring applications.

Navigant Research's analysis of the utility market for public and private, wired and wireless communications networking equipment and services, including early LPWA investments, indicates that nearly $86 billion will be spent by utilities through 2025. In-depth analysis of the markets for smart grid connectivity technology and services may be found in the Navigant Research reports *Networking and Communications for Smart Grids and Smart Cities*[3] *and Low Power Wide Area Networks for Power Utility Applications.*[4]

#### 3.1.1.2 Connectivity Tomorrow: Neural Grid

The large and growing market for smart grid connectivity over the next decade is expected to remain highly fragmented in terms of networking technology choice. Utilities for the most part are not deploying high bandwidth, low latency networks across their entire territories. Rather, they tend to deploy application-specific networks across small areas. The reasons for this range from limited budgets to regulatory constraints to utility insistence on owning and managing their own networks. None of these reasons will hold water in the Neural Grid environment.

In order to move from the smart grid paradigm into the Neural Grid, more advanced communications platforms, such as 5G or private 4G LTE networks, combined with low cost LPWA solutions are expected to become more dominant. Specifically, 5G networks are very likely to become the underlying connectivity in the Neural Grid era. 5G can be thought of as a three-pronged solution that provides very high bandwidth and very low latency along with LPWA networking for massive machine-to-machine connectivity. Both mobile and fixed 5G solutions are envisioned, each with slightly different requirements. The final standards for 5G networks will be released in 2018 and commercialization is still roughly 5 years away.

5G's very compelling capabilities, however, should be thoughtfully considered before large capital-intensive investments are made in private networking infrastructure, which also entail large teams of highly skilled workers. Unless a utility intends to become a telecoms provider in its market—often not possible due to regulations—it must carefully consider where investment will be most long-lived and provide support for new business models and service offerings.

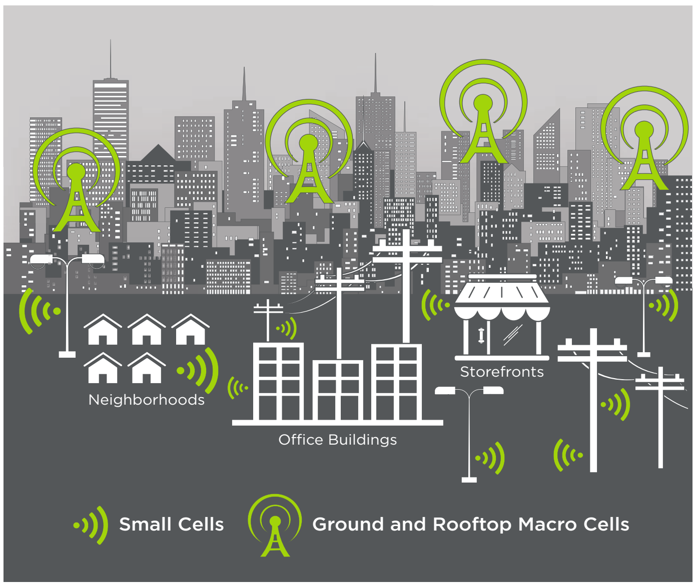
On the other hand, EPB in Chattanooga, Tennessee is a good example of a utility that did become a successful telecoms provider by building a fiber to the premises network across its territory. It also offered broadband services to end users and leveraged the fiber for smart grid applications. Fiber to the premises is a very expensive proposition, however, and 5G capabilities are expected to meet or exceed fiber in terms of bandwidth and latency.

Numerous spectrum bands will be leveraged for 5G networks, and sophisticated multiplexing technology will move the user or device across a wide range of spectrum bands (from as low as 400 MHz to as high as 80 GHz). To provide coverage at very high millimeter wave bands (between 30 GHz and 300 GHz), where data speeds will be extraordinarily fast, the network will require very small cell sites in a dense configuration. These will come in a variety of form factors, some as small as a softball or tablet. In dense environments, in a stadium for example, one of these tablet-sized cells might be

3. Navigant Research, Networking and Communications for Smart Grids and Smart Cities, 2016.
4. Navigant Research, Low Power Wide Area Networks for Power Utility Applications, 2017.

found under seats at 10 foot intervals. In less dense environments, the small cell might cover several miles. As noted in Section 1, small cells could be incorporated into smart grid infrastructure in order to extend the 5G network across a territory and create a revenue opportunity for utilities.

**Figure 3.1 Small Cells Densify Existing Cellular Networks**




(Source: Navigant Research)

A fiber backbone will be employed widely in 5G networks. Some utilities are already deploying fiber beyond their critical substations, which could position them well for future connectivity needs and new revenue opportunities. For example, Enel, Italy's largest utility covering 86% of meters in the country, is deploying a fiber network, investing more than $3 billion. The network will be used to connect a new generation of smart meters. Enel also plans to wholesale fiber capacity to other companies—which could include cellular carriers building 5G networks. By leveraging its network of poles, wires and existing rights of way, Enel's costs will be less that what another company might have to spend and its new fiber network will create new revenue stream opportunities.

5G networks will also enable augmented and virtual reality based applications. Augmented reality solutions that allow for training simulations in dangerous environments are expected to be developed for utilities. Examples might include team-based training in a substation or training for work at the top of live transmission towers. Eventually, augmented or virtual reality paired with robots could perform tasks that only a human can do today.

### 3.1.2 Sensing and Measurement Technologies

Ubiquitous connectivity makes the widespread deployment of sensing and measurement technologies an attractive—even vital—proposition. Communicating sensors can gather data on grid equipment health, feeding predictive maintenance analytics applications. They can improve transmission efficiency through dynamic line rating applications, monitor power quality, and facilitate DER integration, among many other applications.

#### 3.1.2.1 Sensing and Measurement Today: Smart Grid

Navigant Research anticipates the market for T&D sensing and measurement technologies will more than double between 2017 and 2025, from just more than $2 billion to nearly $5 billion.

However, these forecasts include largely standalone sensors that are used to retroactively make existing grid assets smart. Sensors are being added to substations to monitor all manner of equipment metrics, such as dissolved gas analysis for transformers, temperature, and more. A variety of feeder and pole-top sensors are also now affordable and many utilities are deploying them today. Combined with analytics solutions, this first generation of grid sensor technology is improving grid reliability and helping utilities with asset management, among other use cases.

In-depth analysis of the power grid sensing and measurement market can be found in the upcoming Navigant Research report *T&D Sensing and Measurement*.[5]

#### 3.1.2.2 Sensing and Measurement Tomorrow: Neural Grid

In the Neural Grid, smart infrastructure with embedded sensing and communicating capabilities will be the norm. Open standards for data types and structure will enable new applications to be created that leverage the depth and breadth of the data, and the data will be stored and managed in the cloud where it will inform AI and cloud robotics. This widespread visibility will fuel predictive maintenance applications, allowing utilities and other energy market participants to more efficiently manage infrastructure and maintenance efforts. Inventories can be reduced because managers will understand in advance exactly which devices in the network are at risk of failure. Truck rolls (or robot deployments) will be streamlined and minimized.

5. Navigant Research, T&D Sensing and Measurement, 2018.

**Figure 3.2 Asset Management Continuum**


(Source: Navigant Research)

### 3.1.3 Drones and Robotics

The utility industry has been slow to adopt robotics technologies, compared with verticals such as manufacturing. However, in recent years, a variety of new robots for grid applications has been developed. Drone technology is very well suited to line or very remote asset inspections. Relaxing US Federal Aviation Administration (FAA) regulations will help grow the demand for drones performing grid-related services in years ahead.

#### 3.1.3.1 Drones and Robotics Today: Smart Grid

Drones and line- and ground-based robotics are poised to disrupt traditional methods of grid asset inspection and management, replacing or supplementing workforces for tasks including line and substation inspection, storm damage assessment, and vegetation control. But while the range of potential drone and robotics applications for utility grid monitoring and management is vast, the market is merely in its infancy.

Drones and robotics can be used to inspect hard-to-reach infrastructure, replace personnel in high risk conditions, improve emergency response times, facilitate data collection and analysis, and enable aerial mapping and 3D modeling of grid assets. In addition to video cameras, drones can be mounted with a range of relatively lightweight inspection systems, including lidar, infrared, and hyperspectral imaging equipment, to enhance asset monitoring and management.

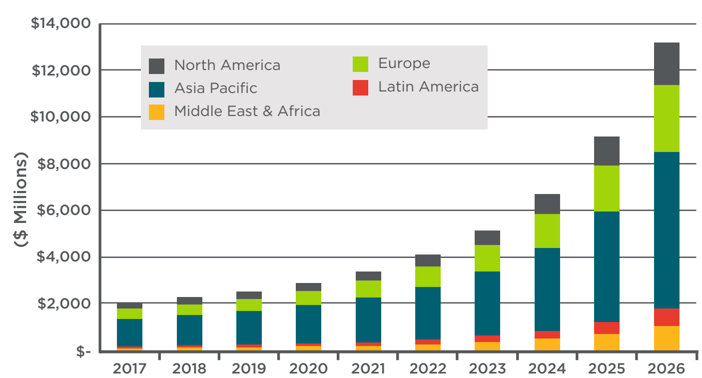
Deployed strategically, drones stand to improve awareness of grid conditions, increase reliability and efficiency of grid operations, reduce costs, and minimize risks to worker safety. The technology is advancing rapidly, and the business case is robust. For example, a single transmission tower manual inspection can cost up to $5,000 with current methods, while a drone piloted from the ground can do a better inspection for $200.

The primary barrier to more widespread deployment of drones for utility asset management in North America has been an immature regulatory scheme. In August 2016, new FAA regulations governing the commercial use of small unmanned aircraft systems (sUAS) took effect. Known as Part 107, the rule provides broad authority to operate sUAS weighing 55 lbs or less without applying for permission from the FAA. However, this authority comes with numerous restrictions, including uninterrupted visual line of sight. These and other requirements currently limit the ability of grid operators to deploy drones for tasks such as monitoring remote transmission lines beyond the visual line of sight (BVLOS).

Even so, the path to commercialization of drones for BVLOS missions is advancing. In February 2016, Xcel Energy became the first US utility to conduct an FAA-approved BVLOS mission to survey transmission lines for R&D purposes. More companies are seeking waivers under Part 107 to operate drones with fewer restrictions, and early demonstration flights conducted under waiver will help pave the way for more rapid commercialization of drones for grid monitoring.

As pilot programs drive regulatory change and emerging technologies advance, Navigant Research forecasts exponential growth in the hardware, software, and services segments of robotics and drones for T&D grid operations.

**Chart 3.1 Annual T&D Drones and Robotics Revenue by Region, World Markets: 2017-2026**




(Source: Navigant Research)

Complete analysis of the market outlook for robotics and drones for grid management applications can be found in the Navigant Research report *Drones and Robotics for Transmission and Distribution Operations.*[6]

6. Navigant Research, Drones and Robotics for Transmission and Distribution Operations, 2017.

### 3.1.3.2 Drones and Robotics Tomorrow: Neural Grid

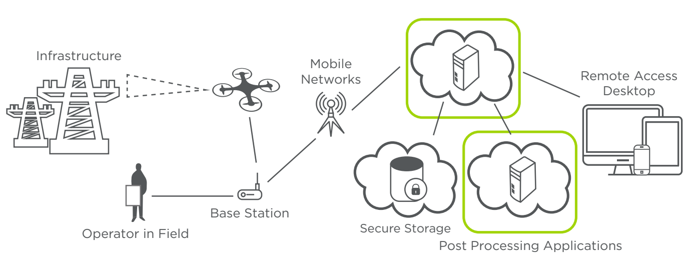
The accelerated growth in the market for utility drones and robotics shown in Chart 3.1 will continue in the years beyond the shown market forecast. In many cases, drones and robots will replace workers, particularly in less skilled and/or more dangerous positions.

As the Neural Grid develops, these devices will leverage vast stores of cloud data rather than relying on limited onboard memory or firewalled data in individual company data centers. AI and machine learning will greatly advance the capabilities of these robotics devices, moving them further up the skill spectrum within a grid maintenance organization. And like the sensing and measurement technologies described above, robotics and drones will have a significant impact on the way grid assets are managed.

With connected asset management, a robotics device is dispatched by an asset manager from a docking station and moves autonomously to a preprogrammed location to inspect, for example, an area of line recently affected by a storm. Sensors collect the applicable imagery, and the data is uploaded in real time to a central asset management platform. The integrity of the line is analyzed autonomously; if a risk is identified, the asset management platform is notified. Without manual intervention, the asset management suite identifies whether a crew has already been dispatched in that geographic region, and if so, notifies them of the damaged asset and provides them with the necessary information to conduct maintenance operations. If there is no crew in the field currently, the asset management suite dispatches one.

Figure 3.3 illustrates what a system employing the intelligent software analysis might look like. Highlighted in green are the asset management platform (top) and the intelligent analytics software system.

**Figure 3.3 Example Unmanned Aerial Vehicle Asset Management Workflow**




(Source: Aeryon Labs, Inc.)

Connected asset management systems are available today, but when cloud robotics leverage true AI, the systems and machines will learn and improve their response dynamically with each new available piece of data or situation outcome.

### 3.1.4 Analytics and AI

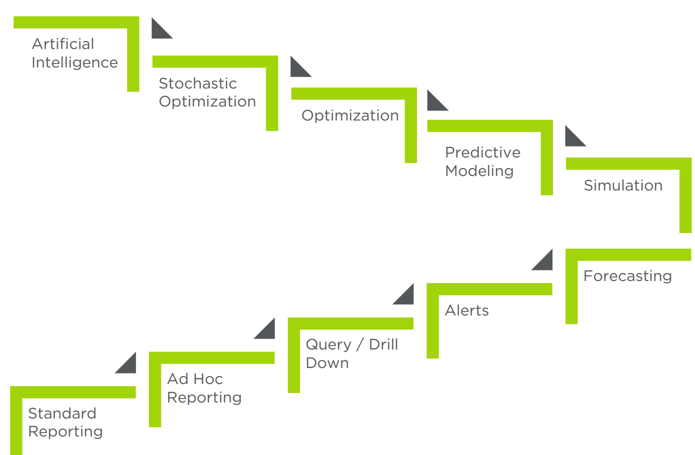
AI can be thought of as the top of the food chain in terms of analytics sophistication. Utilities have been developing relatively simple analytics applications in-house for years; more recently, many established and startup companies have offered a broad array of analytics solutions—many in the cloud.

### 3.1.4.1 Analytics Today: Smart Grid

Utilities today are increasingly seeking ways to manage, process, and act on the massive influx of data streaming in from meters, sensors, voltage monitors, and other devices deployed across the network. Going forward, the shift to a more decentralized power system with higher penetration of renewables means utilities will incorporate increasingly sophisticated time and weather patterns into their system forecasts, causing the volume of data to climb ever higher.

The need to manage and make optimal use of this data—to filter out the noise, analyze the value, and translate insight into automated decision-making and real-time problem solving—makes the integration of analytics into utility operations an almost foregone conclusion. While the level of sophistication of analytics solutions deployed today varies widely, it does not rise to the level of true AI.

**Figure 3.4 Analytics Sophistication Evolution**



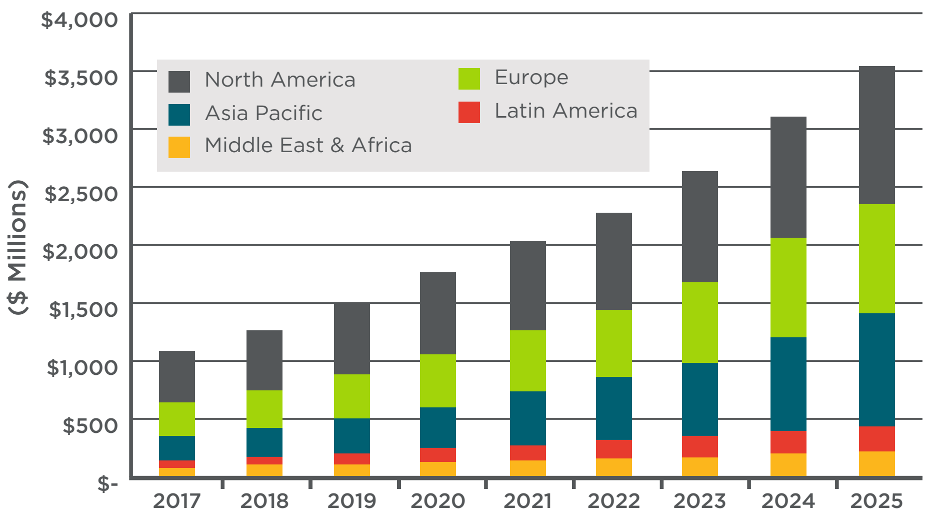

(Source: Honeywell)

Most analytics solutions in use in the energy industry today work within the bottom five steps in Figure 3.4. Many newer offerings rise to the level of predictive modeling and optimization, although these are not widely deployed as of today. More pervasive sensing and connectivity will lead to the volume and quality of data necessary to make these solutions powerful.

In one advanced analytics pilot, Swiss utility EBM tested Alpiq's GridSense technology in an 18-month trial at four single-family homes in Zurich. The GridSense solution used machine learning to anticipate user behavior and energy consumption, controlling appliances as well as onsite PV systems and EV charging stations. This solution integrates data on energy costs and weather forecasts to optimize energy efficiency and cost savings. The technology breaks load peaks in the power supply system, balances the loads, stabilizes the distribution grid, and ultimately saves electricity costs.

Navigant Research expects the market for utility analytics solutions to more than triple between 2017 and 2025, with asset analytics followed by customer operations analytics showing the highest growth rates. These are the very early stages of technology that will evolve into true AI in coming decades.

**Chart 3.2 Annual Utility Analytics Revenue by Region, World Markets: 2017-2026**




(Source: Navigant Research)

Complete analysis of the market outlook for utility analytics solutions can be found in the Navigant Research report, *Utility Analytics.*[7]

### 3.1.4.2 AI Tomorrow: Neural Grid

True AI will only become reality when the ubiquitous sensing and connectivity mentioned throughout this report are available. In the Neural Grid future, the volume and velocity of available data will be high and fast, versus the low and slow environment found today. Data will be widely shared in the cloud, and the analytics will be sophisticated enough to incorporate unstructured data, images, natural language processing, and more to iteratively learn and revise actions based on prior outcomes and new data.

AI powers autonomous operations, including the maintenance and asset management functions described in relation to sensors and robotics. Beyond operations, AI will inform all manner of tasks and prepare utilities to use their customer data, load data, DER integration data, etc. to develop new service offerings.

7. Navigant Research, Utility Analytics, 2016.

### 3.1.5 Cybersecurity

Cyber hacking is a growing problem globally—across all verticals. Utilities have begun to invest in protection of their customer data and grid infrastructure data and to prevent infiltration of control systems.

#### 3.1.5.1 Cybersecurity Today: Smart Grid

The communications and IT-based nature of smart grid solutions have already expanded the potential surface area for cyber attack at utilities. Cybersecurity threats pose a unique challenge for utilities due to their lack of predictability. Unlike outage events related to weather or aging assets, which can be predicted by utilizing historical data or advanced forecasting systems, utilities cannot foresee cyber attacks with any level of accuracy.

While large-scale attacks have been limited to date, the hack on the Ukrainian power grid in December 2015 and more recent ransomware attacks are motivating utilities to expand beyond traditional, compliance-based management practices and to begin actively addressing cybersecurity.

The potential effects of a well-coordinated cyber attack could be particularly devastating for the energy sector, due to cascading failures and the nature of IT and industrial control system networks. The smart grid cybersecurity landscape is constantly evolving, and staying up-to-date in terms of awareness, recognition, enterprise wide planning, and implementation is more important than ever in an environment beholden to reliability, efficiency, and customer experience.

Guidehouse projects robust growth for utility cybersecurity spending through 2025, with overall revenue of $1.8 billion in 2017 nearly doubling to $3.2 billion in 2026. These figures will increase many times over as the Neural Grid forms.

#### 3.1.5.2 Cybersecurity Tomorrow: Neural Grid

In the Neural Grid environment, utilities will be managing massively greater amounts and types of data, and large bodies of that data will be stored and analyzed in the cloud. Cybersecurity solutions and services will need to be deep, broad, and holistic, tying together protection for both hard (smart infrastructure) and soft assets. Cybersecurity solutions will also need to extend to integrated solar, wind, microgrid, and TE market assets and systems.

# 4. Conclusions and Recommendations

The Neural Grid platform and its ecosystem of new and enabling technologies and services represent the future of what today is known simply as the smart grid. But where the smart grid represents an enhanced and more automated version of the legacy electromechanical power grid, the Neural Grid represents a substantially expanded platform reliant less on dumb physical assets than on cloud-based intelligence and data that allow robotics and other smart infrastructure to work autonomously.

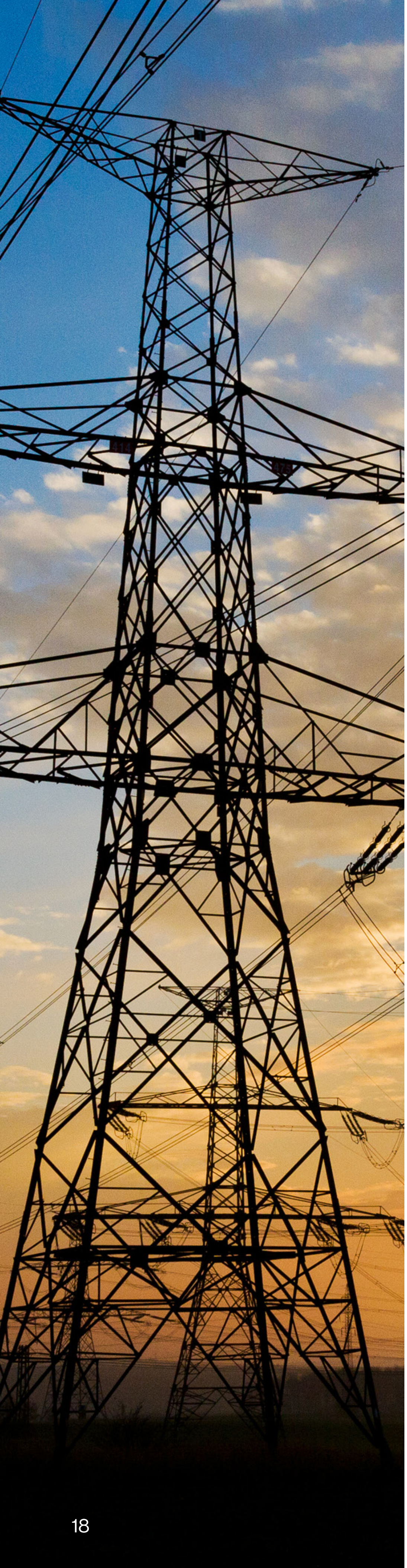
The four key elements of the Neural Grid ecosystem—infrastructure, end-user devices, enabling technologies, and apps and services—each exist in some form today. However, they will only power massive market expansion when they all work together seamlessly, providing more attractive products and services at a lower price than legacy systems. Once these disruptive technologies align, industry transformation could occur rapidly. In the mobile industry, it took less than a decade for a communications network business to morph into a robust multifunction platform for an enormous range of applications. In the electric utility industry, Navigant Research believes wholesale change will happen within 30 years—or less.

Significant new market value will be created in the Neural Grid (and Energy Cloud) environments, and utilities can either prepare today and grab their share—or cede dominance to new entrants from a variety of verticals. Telcos, tech giants (Google and Amazon will be in the mix), DER developers, service organizations, media companies, and retailers—any or all of these industries and others are actively looking for ways to get their piece of the pie. Utilities will face a very different business model in the decades ahead. They must proactively plan for obsolescence of the legacy energy transport business while simultaneously creating new offerings to tap the upside potential the Neural Grid promises to deliver.

## 4.1 Recommendations for Utilities

To remain relevant as the Neural Grid emerges, utilities should pursue innovation in two parallel tracks. The first track requires the utility to develop more efficient and cost-effective solutions to optimize the current business and revenue streams. This will ensure that the core business remains resilient while freeing up resources (human and financial) to invest in new opportunities. Many of the smart grid technologies and applications described in this white paper will aid in this effort. Simultaneously, utilities will need to form teams of progressive thinkers, probably with a strong millennial contingent, to create outside-the-box ideas for lucrative, high growth opportunities to be implemented within a 10- to 15-year time horizon.

Examples of new profit sources would include ownership of distributed resources, but should extend beyond such obvious measures to include partnerships with companies outside of the energy vertical, such as big tech names or telecoms providers. The right partner can not only help utilities bring interesting new offerings to market, but might also improve their reception. The names Google or Amazon, for example, instantly bring a cool factor that a 100-year-old utility name simply does not have on its own. Service offerings (applications) that leverage shared smart infrastructure, end-user devices, data, cloud-based intelligence, etc. should be designed to bring new value to end users in the form of services, including ones they never knew they needed.



Comprehensive in-home (or in-business) services that tie together energy and non-energy functions are another relatively straightforward way that utilities can partner outside of the energy space to improve customer stickiness. For a monthly subscription fee, the customer gets in-home support for heating and cooling, lighting, appliances, security, broadband, and tech support—and whatever else innovative partnerships might bring to the menu.

Opportunities may also be found in development of solutions that not only support internal operations, but can also be offered to other utilities. Field force training simulations based on augmented reality might be one example.

Ultimately, utilities will need multiple innovative offerings to weave a strong defense against the off-grid trend that the advent of affordable solar and storage, microgrid, and VPP solutions will eventually foster. The powerful technology underlying the Neural Grid platform will offer a number of ways to do so. But utilities must act now and rethink the fixed business model under which they have historically operated. If they do not, the Googles and Amazons of the world will move in.

## 4.2 Recommendations for Technology Vendors

Both legacy smart grid/infrastructure vendors and disruptive third parties from the tech and telecoms worlds are eager to exploit the disruption developing in the power utility industry. These actors should not overlook the very large and, for now, captive customer base that utilities own. Creative partnerships with utilities bring access to that base, via bills, call centers, online portals, social media, and more and may lend credibility to new offerings—even as the tech partner's name adds the cool factor.

Vendors and solution creators need to understand the long-term evolution occurring with regard to energy infrastructure and the changing role that utilities are likely to play. They must develop clear roadmaps that highlight for utility planners the future-proof nature of their offerings, and they must be able to articulate how their product or service will transition as data and systems move to the cloud.

Interoperability for app development across the Neural Grid platform (smart infrastructure, end-user devices, and cloud-based systems) will be key to the upward value spiral described in Section 2.3. Standards should be agreed upon across the vendor ecosystem to accelerate that transition.

Finally, cybersecurity cannot be a separate component from solution offerings. Security of the data in the Neural Grid will be paramount and excellent security should be a foundational element of any utility or energy product or solution in the marketplace today—not an afterthought that gets layered on top.

## 5. Acronym and Abbreviation List

3D....Three Dimensional
3G....Third Generation
4G....Fourth Generation
5G.... Fifth Generation
AI....Artificial Intelligence
B2G....Building-to-Grid
BVLOS....Beyond Visual Line of Sight
CEO....Chief Executive Officer
DER....Distributed Energy Resources
EV....Electric Vehicle
FAA....Federal Aviation Administration
FCC....Federal Communications Commission
GHz....Gigahertz
iDER....Integrated Distributed Energy Resources
IEA....International Energy Agency
IoE....Internet of Energy
IT....Information Technology
lbs....Pounds
lidar....Light Detection and Ranging
LPWA....Low Power Wide Area
LTE....Long-Term Evolution
MHz....Megahertz
PC....Personal Computer
PLC....Power Line Communications
POTS....Plain Old Telephone Service
R&D....Research and Development
SCADA....Supervisory Control and Data Acquisition
sUAS....Small Unmanned Aircraft Systems
T&D....Transmission and Distribution
T2G....Transportation-to-Grid
TE....Transactive Energy
US....United States
VPP....Virtual Power Plant

*Note: Editing of this report was closed on January 2, 2018.*

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